National Environmental Monitoring Standards

Data Processing

Processing of Environmental Time-series Data

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Change register

Version Number	Revision Date	Section	Topic	Revision Summary
1.0.0	Aug 2022			Initial release.
1.1.0	Mar 2023			
1.2.0	Jun 2024	The National Environmental Monitoring Standards		Updated to standardised text.
1.3.0	March 2026	Annex C	Open Channel Flow	Updated to include: • requirements for QRev to be used for the calculation of all ADCP and all ADV gaugings, with the uncertainty produced used for quality coding purposes. • requirement for the SUNY software to be used for all salt-dilution gauging method calculations. Clarification of the methodologies for calculating uncertainty for all discharge measurement methods.
1.3.1	September 2026	4.13	Repacking data	Material added relating to assignment of quality codes to repacked data.
		6.2.3	Quality codes	Additional guidance added related to differentiating between 'minor' and 'significant' modifications to the data.
		Annex A	Water Level	Corrections to numbering in Section 4
		Annex C	Open Channel Flow	Updated references to ISO documents to most recent versions.
		Annex C	Open Channel Flow	Inserted requirement for the OURSIN calculation to be used for measurement uncertainty

		Annex C	Open Channel Flow	Inserted requirements relating to QRevInt/QRevMS
		Annex C	Open Channel Flow	Inclusion of change to method code to identify the “Alpha” value utilised for surface velocity discharge measurements
		Annex D	Water Temperature	Substantive revision of entire Annex
		Annex H	Dissolved Oxygen	Substantive revision of entire Annex

Table of Contents

The National Environmental Monitoring Standards xxiv

About this Standard xxvii

The Standard – Data Processing xxx

1 Environmental Time Series Characteristics 1

1.1 Time-series data types 1
1.1.1 Instantaneous (continuous) 2
1.1.2 Discrete 2
1.1.3 Value in preceding interval 2
1.1.4 Value in succeeding interval 5
1.1.5 Censored data 6
1.1.6 Vector data 7
1.1.7 Multi-item data 7
1.2 Units of measurement 8
1.2.1 Formats for date and time units 8
1.2.2 Time zones 8

2 Data Capture 10

2.1 Electronic recording 10
2.2 Punched tape recording 10
2.3 Chart recording 11
2.4 Manual recordings 11
2.5 Verification data 12

3 Elements of a Data Processing System 13

3.1 Versions of data 14
3.1.1 Original data 14
3.2 Verification information 16
3.3 Data registers and tracking 17
3.4 Identification of records 18
3.5 Data provenance and status 18
3.6 Quality control 20
3.6.1 Methods 21
3.6.2 Data plots with time 22
3.6.3 Comparisons with time 23
3.6.4 Examples of deviation tests 25
3.6.5 Reporting 28
3.7 Non-stationarity 28
3.8 Control of editing 29
3.9 Evidence of modifications to data 29
3.9.1 Modifications to the time-series data 30
3.9.2 Modifications to verification information 30

4 Types of Operations 31

4.1 Interaction with quality code 31
4.2 Offset shift 31
4.2.1 Potential benefits 32
4.2.2 Possible risks 32
4.2.3 Effect on quality code 32
4.2.4 Guidance for use 32

4.2.5 Mathematics 33
4.2.6 Example 33
4.3 Time shift 34
4.3.1 Potential benefits 34
4.3.2 Possible risks 35
4.3.3 Effect on quality code 35
4.3.4 Guidance for use 35
4.3.5 Mathematics 35
4.3.6 Example 36
4.4 Linear drift adjustment 37
4.4.1 Potential benefits 37
4.4.2 Possible risks 37
4.4.3 Effect on quality code 38
4.4.4 Guidance for use 38
4.4.5 Mathematics 38
4.4.6 Example 39
4.5 Non-linear drift adjustment 39
4.5.1 Potential benefits 40
4.5.2 Possible risks 40
4.5.3 Effect on quality code 40
4.5.4 Guidance for use 40
4.5.5 Mathematics 40
4.5.6 Example 41
4.6 Time drift adjustment 42
4.6.1 Potential benefits 42
4.6.2 Possible risks 43
4.6.3 Effect on quality code 43
4.6.4 Guidance for use 43
4.6.5 Mathematics 43
4.6.6 Example 44
4.7 Linear transformation 44
4.7.1 Potential benefits 45
4.7.2 Possible risks 45
4.7.3 Effect on quality code 45
4.7.4 Guidance for use 46
4.7.5 Mathematics 46
4.7.6 Example 46
4.8 Change of data increment 47
4.8.1 Potential benefits 47
4.8.2 Possible risks 47
4.8.3 Effect on quality code 47
4.8.4 Guidance for use 47
4.8.5 Mathematics 47
4.8.6 Example 48
4.9 Non-linear or multi-variable transformation 48
4.9.1 Potential benefits 48
4.9.2 Possible risks 49
4.9.3 Effect on quality code 49
4.9.4 Guidance for use 49
4.9.5 Mathematics 50
4.9.6 Example 50
4.10 Transitioning between transformations 50

4.10.1 Potential benefits 51
4.10.2 Possible risks 51
4.10.3 Effect on quality code 51
4.10.4 Guidance for use 51
4.10.5 Mathematics 52
4.10.6 Example 52
4.11 Spike removal 53
4.11.1 Potential benefits 53
4.11.2 Possible risks 53
4.11.3 Effect on quality code 54
4.11.4 Guidance for use 54
4.11.5 Example 55
4.12 Filtering or resampling noise 55
4.12.1 Potential benefits 55
4.12.2 Possible risks 56
4.12.3 Effect on quality code 56
4.12.4 Guidance for use 56
4.12.5 Mathematics 57
4.12.6 Example 58
4.12.7 Noise induced by data collection method 58
4.13 Repacking data 59
4.13.1 Potential benefits 59
4.13.2 Possible risks 59
4.13.3 Effect on quality code – data repacked to a shorter timestep 59
4.13.4 Effect on quality code – data repacked to a longer timestep 60
4.13.5 Guidance for use 60
4.13.6 Example 61
4.14 Changing the data type 61
4.14.1 Potential benefits 62
4.14.2 Possible risks 62
4.14.3 Effect on quality code 62
4.14.4 Guidance for use 62
4.15 Compressing data 63
4.15.1 Potential benefits 63
4.15.2 Possible risks 63
4.15.3 Effect on quality code 64
4.15.4 Guidance for use 64
4.15.5 Example 65
4.16 Marking gaps 66
4.17 Closing gaps and interpolation 67
4.17.1 Potential benefits 67
4.17.2 Possible risks 67
4.17.3 Effect on quality code 68
4.17.4 Guidance for use 68
4.17.5 Mathematics 68
4.17.6 Example 68
4.18 Infilling a gap with observations 69
4.18.1 Potential benefits 69
4.18.2 Possible risks 69
4.18.3 Effect on quality code 69
4.18.4 Guidance for use 69
4.19 Infilling a gap with a curve 69

4.19.1 Potential benefits 70
4.19.2 Possible risks 70
4.19.3 Effect on quality code 70
4.19.4 Guidance for use 70
4.19.5 Example 71
4.20 Infilling a gap with synthetic data 71
4.20.1 The process 71
4.20.2 Potential benefits 72
4.20.3 Possible risks 72
4.20.4 Effect on quality code 72
4.20.5 Guidance for use 72

5 Applying Adjustments to Data 73

5.1 Principles 73
5.1.1 Modifications to data 73
5.1.2 Traceability and data integrity 74
5.1.3 Modifications explained 74
5.2 Processing steps 75
5.3 Order in which to apply adjustments 76
5.4 Missing data 76
5.5 Infilling gaps 76
5.5.1 Choice of methods for infilling 77
5.5.2 Infilling with synthetic data 77
5.5.3 Describing accuracy of the infilled period 78

6 Metadata 79

6.1 Site metadata 79
6.2 Time-series metadata 80
6.2.1 Records of data acquisition 80
6.2.2 Records of data processing 81
6.2.3 Quality codes 81
6.2.4 Comments 82

7 Quality Assurance 89

7.1 Requirements 89
7.2 Quality review 89
7.2.1 New data 90
7.2.2 Editing applied 90
7.2.3 Metadata 90
7.2.4 Tests for quality and accuracy 91
7.3 Audit 92
7.3.1 Benefits of audit 92
7.3.2 Audit cycle 92
7.3.3 Minimum audit requirements 93
7.3.4 Other requirements 95

8 Preservation of Record 96

8.1 Archiving policies, procedures and systems 96
8.2 Records required to be archived 96
8.2.1 Original data 96
8.2.2 Archiving non verified data 97
8.3 Housekeeping 98
8.4 Storage of physical records 98

References 99
Appendix 1 - Interpreting Control Charts 100
Appendix 2 - Using Regression Analysis to Synthesise Record 102
Appendix 3 - Significant Figures and Decimal Places 104
Annex A Water Level Data Processing 106
1 General Overview 106
1.1 Normative references 106
2 Quality Control 106
2.1 Additional metadata required 106
3 Potential Errors and Recommended Editing 110
4 Metadata 129
5 Quality Assurance 137
6 Preservation of Record 137
7 References 137
Appendix A.1 Methods for Infilling Gaps 138
1 Information Requirements 138
2 Recommended Methods 138
2.1 Infilling with observations 139
2.2 Infilling by manual entry 140
2.3 Infilling a recession 140
2.4 Infilling by regression analysis 140
2.5 Infilling flow by routing upstream flows 141
2.6 Infilling flow using equivalent quantiles from flow duration curves 141
2.7 Infilling flow records by ratio of areas (specific discharge) 142
2.8 Infilling flow record using a water budget 142
2.9 Infilling flow record using rainfall–runoff models 142
3 Selecting a Suitable Donor Site 143
4 Other Considerations 144
4.1 Time resolution of infill data 144
4.2 Seasonality of relationships 144
4.3 Non-linear relationships 144
4.4 Using multiple donor sites 144
5 References 144
Annex B Rainfall Data Processing 146
1 General Overview 146
2 Quality Control 147
2.1 Rainfall Data Quality Matrix 147
2.2 Additional metadata required 148
2.3 Plots and comparisons 149
2.3.1 Fixed interval totals 149
2.3.4 Between-station comparisons 151

2.4 Gauge verification and validation 151
2.4.1 Tipping bucket (intensity) gauge 151
2.4.2 Primary reference gauge 153
2.4.3 Test tips 153
2.4.4 Status checks 153
2.5 Deviation tests 154
3 Potential Errors and Recommended Editing 156
3.1 Sources of errors 156
3.1.1 Systematic error 156
3.2 False intensities 157
3.2.1 Rainfall rate 157
3.2.2 Interference 158
3.2.3 Fouling 159
3.2.4 Restricted bucket movement 161
3.2.5 Loss of calibration 161
3.2.6 Range limits 162
3.3 Catch discrepancies 163
3.3.1 Site and environment factors 163
3.3.2 Intensity gauge and recording faults 164
3.3.3 Primary reference gauge catch loss and measurement errors 165
3.4 Time faults 167
3.5 Missing data 171
3.5.1 Closing gaps in incremental data 172
3.5.2 Methods for infilling gaps 173
4 Adjusting Data to Primary Reference 174
4.1 Snow 174
5 Metadata 174
5.1 Quality coding 174
5.1.1 The Rainfall Site Matrix 175
5.1.2 The Rainfall Data Quality Matrix 175
5.1.3 Data processing actions and adjustments 175
5.2 Example rainfall comments 176
5.2.1 Site/Initial Comments 176
5.2.2 Equipment Comment examples 176
5.2.3 Operational Comment examples 177
5.2.4 Data Comment examples 178
5.2.5 Data Processing Comment examples 179
5.2.6 Transformation Comment examples 180
5.2.7 Stationarity Comment examples 181
6 Preservation of Record 181
7 References 182
Appendix B.1 Methods for Infilling Gaps 183
1 Information Requirements 183
2 Recommended Methods 183
2.1 Infilling using primary reference gauge totals 184
2.2 Assessing the primary reference gauge total 184
2.3 Estimating the primary reference gauge total 185

2.4 Infilling periods of no rain 186
2.5 Selecting a suitable donor site 187
2.6 Infilling by regression analysis 187
2.7 Infilling from rainfall–runoff models 188
3 Other Considerations 188
3.1 Seasonality of relationships 188
3.2 Using multiple donor sites 189
4 References 189
Appendix B.2 Changes to Event Rainfall 190
1 Fixed Interval Recording 190
1.1 Punch-tape recorders 190
1.2 Aquitel telemetry 190
1.3 Data type 190
1.4 Data compression 191
2 Tip Recording 192
2.1 Zero values 192
2.2 Data type 192
2.2.1 Discrete totals 192
2.2.2 Total in preceding interval 192
2.3 Data compression 193
3 Combining Records of Different Type 193
Annex C Processing of Gauging Results 195
1 General Overview 195
1.1 Normative references 195
1.2 Documenting the data processing system for gaugings 195
1.2.1 Gauging register 196
1.2.2 Original records 197
2 Quality Control 198
2.1 Additional metadata required 198
2.2 Deployment tests and checks 199
2.3 Stage height for the gauging 200
2.4 Calculation of uncertainty 200
2.4.1 Rotating-element current-meter measurements 201
2.4.2 ADV instruments 201
2.4.3 ADCP profilers with velocity-area stationary method 201
2.4.4 ADCP profilers with velocity-area moving boat method 201
2.4.5 POEM instruments 202
2.4.6 Float-based surface velocity measurements 202
2.4.7 Image velocimetry methods 202
2.4.8 Salt dilution methods 202
2.4.9 Volumetric methods 203
2.4.10 Weirs and flumes for discharge measurement 203
2.4.11 Indirect methods 203
2.5 Review of results 203
2.5.1 ADCP moving boat method measurement review 205
2.5.2 ADCP stationary method measurement review 206

2.6 QRevInt/QRevMS 207
2.7 Derived and related data 208
2.7.1 Cross-sections 208
2.7.2 Hydraulic variables 208
3 Potential Errors and Recommended Editing 209
3.1 Sources of errors 209
3.1.1 Random error 209
3.1.2 Systematic error 209
3.1.3 Spurious error 210
3.2 Editing gauging data 210
3.3 Deleting gauging data 211
4 Metadata 212
4.1 Quality coding 212
4.2 Example gauging results comments 213
4.2.1 Site/Initial Comments 213
4.2.2 Equipment Comment examples 215
4.2.3 Operational Comment examples 215
4.2.4 Data Comment examples 216
4.2.5 Data Processing Comment examples 217
4.2.6 Stationarity Comment examples 217
5 Audit 217
6 Preservation of Record 218
7 References 218
Appendix C.1 Computation of Mean Gauge Height for a Gauging 220
Appendix C.2 Decision Tree for Non-wadeable Gauging 221
Appendix C.3 Gauging Results – Items and Codes 222
1 Minimum Requirements 222
2 10-item Gauging Results (historic) 222
3 15-item Gauging Results (legacy & Hilltop) 223
4 18-item Gauging Results (legacy NIWA) 224
5 Missing Items 224
6 Gauging Method Codes 224
7 Gauging Agency Codes 224
Annex D Water Temperature Data Processing 225
1 General Overview 225
1.1 Normative references 225
1.2 Water temperature as a supplementary variable 225
2 Quality Control 226
2.1 Additional metadata required 226
2.2 Plots and comparisons 227
2.2.1 Comparisons 228
2.2.2 Between-station comparisons 228

2.3 Reliability of reference values 229
2.3.1 Calibration of reference sensors 230
2.3.2 Validation of in-situ sensors 230
2.4 Deviation tests 230

3 Potential Errors and Recommended Editing 231

3.1 Sources of errors 231
3.2 Unintended offset or incorrect change of offset 232
3.3 Steps in the data 234
3.3.1 Instrument replacement 234
3.3.2 Interference or disturbance 234
3.3.3 Sensor clearance or cleaning 235
3.4 Drift 237
3.4.1 Calibration drift 237
3.5 Spikes 238
3.6 Noisy data 239
3.7 Over-ranging 240
3.8 Sensor exposure 242
3.9 Incorrect scaling 242
3.10 Time faults 244
3.11 Missing data 245
3.11.1 Methods for infilling gaps 245

4 Metadata 246

4.1 Quality coding 246
4.2 The Quality Coding Matrix 246
4.2.1 Data editing actions and adjustments 247
4.3 Example water temperature comments 247
4.3.1 Site/Initial Comments 248
4.3.2 Equipment Comment examples 250
4.3.3 Operational Comment examples 251
4.3.4 Data Comment examples 251
4.3.5 Data Processing Comment examples 252
4.3.6 Transformation Comment examples 253
4.3.7 Stationarity Comment examples 254

5 Preservation of Record 255

6 References 255

Appendix D.1 Methods for Infilling Gaps 256

1 Information Requirements 256

2 Recommended Methods 256

2.1 Infilling with backup water temperature data 257
2.2 Infilling with observations 257
2.3 Infilling by manual entry 257
2.4 Infilling the curve between adjacent peaks and troughs 257
2.5 Infilling by regression analysis 258
2.5.1 Selecting suitable donor sites 258
2.5.2 Time resolution of the synthetic record 258
2.5.3 Seasonality of relationships 259

3 References 259

Annex E Turbidity Data Processing 260
1 General Overview 260
1.1 Normative References 260
2 Quality Control 261
2.1 Additional metadata required 261
2.2 Plots and comparisons 261
2.2.1 Comparisons 262
2.2.2 Between-station comparisons 262
2.3 Reliability of reference values 262
2.3.1 Validation of field instruments 263
2.3.2 Laboratory results 264
2.4 Deviation tests 264
3 Potential Errors and Recommended Editing 267
3.1 Sources of errors 267
3.2 Unintended offset or incorrect change of offset 267
3.3 Steps in the data 269
3.3.1 Instrument replacement 269
3.3.2 Interference and macro-fouling 269
3.3.3 Sensor clearance or cleaning 270
3.4 Drift 271
3.4.1 Baseline drift 272
3.4.2 Calibration drift 273
3.5 Spikes 275
3.6 Noisy data 276
3.7 Over-ranging and sensor saturation 277
3.8 Sensor exposure 278
3.9 Incorrect scaling 279
3.10 Time faults 281
3.11 Missing data 282
3.11.1 Methods for infilling gaps 283
4 Post-processing Data Manipulation 284
4.1 Combining two concurrent at-site records 284
4.2 Transformations 284
5 Metadata 284
5.1 Quality Coding 284
5.2 Example turbidity comments 284
5.2.1 Site/Initial Comments 285
5.3 Equipment Comment examples 286
5.4 Operational Comment examples 286
5.5 Data Comment examples 287
5.6 Data Processing Comment examples 288
5.7 Transformation Comment examples 290
5.8 Stationarity Comment examples 290
6 Preservation of Record 290
7 References 291
Appendix E.1 Methods for Infilling Gaps 292

1 Information Requirements 292
2 Recommended Methods 292
2.1 Infilling with backup turbidity data 293
2.2 Infilling using secondary turbidity data 293
2.3 Infilling using water samples collected for this purpose 294
2.4 Infilling with ad-hoc and manual observations 294
2.5 Infilling by manual entry 294
2.6 Infilling a recession or baseline 294
2.7 Infilling by regression analysis 295
2.8 Infilling using relationships with discharge 295
2.8.1 Characteristics of turbidity–discharge relationships 295
2.8.2 Developing and applying turbidity-discharge functions 297
2.8.3 Infilling truncated events 297
Annex F Water Meter Data Processing 299
1 General Overview 299
1.1 Normative references 299
1.2 Scope of this annex 299
1.3 Effect of data type 300
2 Quality Control 301
2.1 Additional metadata required 301
2.2 Plots and comparisons 304
2.2.1 Fixed interval totals 304
2.2.2 Cumulative totals 305
2.2.3 Comparisons 305
2.2.4 Between-station comparisons 307
2.2.5 Portable pumps 307
2.3 Verification 308
2.3.1 Verification of installation 308
2.3.2 Verification of data collection 309
2.3.3 Pulse output tests 310
2.3.4 Status checks 311
2.4 Deviation tests 311
2.4.1 Interpretation of installation verification results 312
3 Potential Errors and Recommended Editing 313
3.1 Sources of errors 313
3.1.1 Systematic error 314
3.2 False calculated rate of take 314
3.3 Spikes 315
3.4 Noisy data 316
3.5 Loss of calibration 318
3.6 Incorrect scaling 319
3.7 Time faults 319
3.7.1 Supervisory Control and Data Acquisition (SCADA) systems 320
3.8 Missing data 322
3.8.1 Seasonal recording 323
3.8.2 Closing gaps in incremental interpolating data 323
3.8.3 Methods for infilling gaps 324
3.9 Data transfer 324

4 Adjusting Data to Verification Results 325
5 Metadata 325
5.1 Quality coding 325
5.2 Data processing actions and adjustments 325
5.3 Example water meter data comments 326
5.3.1 Site/Initial Comments 326
5.3.2 Equipment Comment examples 326
5.3.3 Operational Comment examples 327
5.3.4 Data Comment examples 328
5.3.5 Data Processing Comment examples 329
5.3.6 Transformation Comment examples 330
5.3.7 Stationarity Comment examples 330
6 Preservation of Record 331
7 References 331
Appendix F.1 Methods for Infilling Gaps 332
1 Information Requirements 332
2 Recommended Methods 332
2.1 Using a pulse tally or totaliser readings to infill a gap 333
2.2 Assessing a totaliser reading to infill a gap 333
2.3 Estimating a totaliser reading to infill a gap 334
2.4 Infilling periods of no water take 334
2.5 Calculating infill record from other meters 335
2.6 Infilling by regression analysis 335
2.7 Infilling from models 336
3 Other Considerations 337
Annex G Soil Moisture Data Processing 338
1 General Overview 338
1.1 Normative references 338
1.2 Scope of this annex 338
1.3 Units of measurement 338
1.4 Supplementary variables 339
1.5 Complementary measurements 340
2 Quality Control 340
2.1 Additional metadata required 340
2.2 Plots and comparisons 342
2.2.1 Comparisons 342
2.2.2 Between-station comparisons 343
2.3 Calibration, validation, and verification 344
2.3.1 Field calibration and verification of in-situ dielectric sensors 344
2.3.2 Calibration and validation of reference neutron probes 345
2.3.3 Reliability of reference values 346
2.3.4 Laboratory results 347
2.4 Deviation tests 348
3 Potential Errors and Recommended Editing 348
3.1 Sources of errors 348

3.2 Steps in the data 349
3.2.1 Instrument replacement and disturbance 350
3.2.2 Offset errors 350
3.3 Drift 352
3.4 Spikes 352
3.5 Noisy data 353
3.6 Over-ranging 354
3.7 Saturation bias 355
3.8 Sensor exposure 356
3.9 Incorrect scaling 356
3.9.1 Wrong measurement units 356
3.9.2 Wrong instrument configuration 357
3.10 Time faults 358
3.11 Missing data 359

4 Field Calibration 360

4.1 Field calibration data 360
4.2 Deriving the field calibration relation 361
4.2.1 Example 362
4.3 Field calibration metadata 364
4.4 Applying the field calibration 364
4.5 Uncertainty of the field calibration relation 365

5 Metadata 365

5.1 Quality coding 365
5.1.1 The Quality Coding Matrix 366
5.1.2 Blanket provisions 366
5.1.3 Data editing actions and adjustments 367
5.2 Example soil moisture comments 367
5.2.1 Site/Initial Comments 368
5.2.2 Equipment Comment examples 368
5.2.3 Operational Comment examples 369
5.2.4 Data Comment examples 370
5.2.5 Data Processing Comment examples 371
5.2.6 Transformation Comment examples 372
5.2.7 Stationarity Comment examples 374

6 Preservation of Record 374

7 References 375

Annex H Dissolved Oxygen Data Processing 376

1 General Overview 376

1.1 Normative references 376
1.2 Measurement 376
1.3 Supplementary variables 377
1.4 Complementary measurements 378

2 Quality Control 379

2.1 Additional metadata required 379
2.2 Plots and comparisons 380
2.2.1 Comparisons 380
2.2.2 Between-station comparisons 381

2.3 Reliability of reference values 381
2.3.1 Calibration and validation of reference sensors 383
2.3.2 Calibration and validation of in-situ sensors 383
2.4 Deviation tests 384
3 Potential Errors and Recommended Editing 385
3.1 Sources of errors 385
3.2 Data offset 386
3.3 Steps in the data 387
3.3.1 Instrument servicing and replacements 388
3.3.2 Interference or disturbance 389
3.3.3 Sensor clearance or cleaning 389
3.4 Drift 391
3.4.1 Baseline drift 391
3.4.2 Amplitude drift 391
3.4.3 Loss of linearity 392
3.5 Spikes 393
3.6 Noisy data 394
3.6.1 Real noise 394
3.6.2 Erroneous noise 395
3.7 Over-ranging 395
3.8 Sensor exposure 398
3.9 Incorrect scaling 398
3.9.1 Wrong measurement units 399
3.9.2 Wrong instrument configuration 399
3.10 Time faults 400
3.11 Missing data 401
3.11.1 Methods for infilling gaps 402
4 Metadata 403
4.1 Quality coding 403
4.1.1 The Quality Coding Matrix 403
4.1.2 Blanket provisions 404
4.1.3 Interaction with quality of supplementary measurements 405
4.1.4 Data editing actions and adjustments 406
4.2 Example DO comments 406
4.2.1 Site/Initial Comments 406
4.2.2 Equipment Comment examples 408
4.2.3 Operational Comment examples 409
4.2.4 Data Comment examples 409
4.2.5 Data Processing Comment examples 411
4.2.6 Transformation Comment examples 412
4.2.7 Stationarity Comment examples 413
5 Preservation of Record 414
6 References 414
Appendix H.1 Methods for Infilling Gaps 416
1 Information Requirements 416
2 Recommended Methods 416
2.1 Infilling with backup dissolved oxygen data 417
2.2 Infilling with observations 417

2.3 Infilling by manual entry 418
2.4 Infilling the curve between adjacent peaks and troughs 418
2.5 Reinstating a clipped peak 418
2.6 Infilling by regression analysis 418
2.6.1 Selecting suitable donor sites 419
2.6.2 Time resolution of the synthetic record 419
2.6.3 Seasonality of relationships 419

3 References 419

Annex I Discrete Water Quality Data Processing 420

1 General Overview 420

1.1 Normative references 420
1.2 Scope of this annex 420
1.3 Variable names and nomenclature 421
1.4 Units of measurement 421
1.5 Effect of data type 422
1.5.1 Discrete data (non-interpolating) 422
1.5.2 Data storage architecture 422
1.6 Supplementary variables 422
1.7 Complementary observations and measurements 423
1.8 Documenting the data management system 425
1.8.1 Field and Office Manual 425
1.8.2 Monitoring objectives and sample design elements 425
1.8.3 Site History Record 425
1.8.4 Forms 426
1.8.5 Identifier conventions 426
1.8.6 Tracking the status of samples 427
1.8.7 Method detection limits 428
1.8.8 Quality control and quality assurance processes 428
1.8.9 Original records 428

2 Quality Control 430

2.1 Quality coding matrices 430
2.2 Additional metadata required 430
2.2.1 Monitoring programmes 430
2.2.2 Sampling runs 430
2.2.3 Sites 430
2.2.4 Visits 431
2.2.5 Instruments 431
2.2.6 Laboratories 431
2.2.7 Samples 432
2.2.8 Bottles 432
2.2.9 Measurements 432
2.3 Plots and comparisons 433
2.3.1 Scatter plots 433
2.3.2 Mapping services 434
2.3.3 Comparisons 434
2.3.4 Between-variable comparisons 434
2.3.5 Between-site comparisons 435
2.4 Reliability of measurements 435
2.4.1 Calibration and validation of field meters 435
2.4.2 Laboratory results 436

2.4.3 Standardisation and compensation 439
2.4.4 Uncertainty of measurement 440
2.4.5 Non-standard methods and method change 440
2.4.6 Review of results 441
2.4.7 Stationarity 442
2.5 Deviation tests 443
2.5.1 Deviation over time 443
2.5.2 Departure from expected values 444
2.5.3 Automation 446

3 Potential Errors and Recommended Editing 446

3.1 Sources of errors 446
3.1.1 Systematic error 446
3.1.2 Field measurement errors 446
3.1.3 Sampling error 447
Sampling location (horizontal position and depth) 447
3.1.4 Manual data entry 447
3.1.5 Data import 447
3.2 Data offset 448
3.3 Steps in the data 449
3.3.1 Instrument servicing and replacements 449
3.3.2 Method change 450
3.4 Drift 451
3.5 Spikes 452
3.6 Over-ranging and non-detects 454
3.6.1 High-end calibration 454
3.6.2 Method detection limit 455
3.7 Incorrect scaling 455
3.7.1 Wrong measurement units 456
3.7.2 Wrong instrument configuration 456
3.8 Time faults 457
3.8.1 File time of measurements 457
3.8.2 Correction of sample time 458
3.9 Missing data 459
3.9.1 Deleting data 459

4 Post-processing 460

4.1 Transformations 460
4.1.1 Surrogates 460
4.1.2 Method change 'alignment' 461
4.2 Generating a time series 461
4.3 Data transfer 461

5 Metadata 462

5.1 Description 462
5.2 Quality coding 463
5.2.1 Quality coding matrices 463
5.2.2 Blanket provisions 464
5.2.3 Data editing actions and adjustments 465
5.3 Example (time-series) comments 466
5.3.1 Site/Initial Comments 467
5.3.2 Equipment Comment examples 471
5.3.3 Operational Comment examples 472

5.3.4 Data Comment examples 473
5.3.5 Data Processing Comment examples 474
5.3.6 Transformation Comment examples 475
5.3.7 Stationarity Comment examples 475

6 Quality Assurance 476

6.1 Peer review of data processing 476
6.2 Other reviews 477
6.2.1 Site metadata 477
6.2.2 Visual clarity equipment 477
6.2.3 Light penetration (PAR) 477
6.2.4 Maintenance of instruments and calibration standards 477
6.2.5 Frequency of censored values 478
6.2.6 Quality coding matrix assessments 478
6.3 Quality assurance (test) samples 478
6.4 Inter-agency field practice audit 479
6.5 Laboratory quality checks 479
6.6 Data audit 480

7 Preservation of Record 480

7.1 Original data 480
7.1.1 Field Record forms 480
7.1.2 Laboratory reports 481
7.1.3 Laboratory data transfer 481
7.1.4 Storing multiple versions of the same result 482
7.1.5 Supplementary data 482
7.2 Final records 482
7.2.1 Time series and time-series comments 482
7.2.2 Average of duplicate measurement results 483
7.2.3 Raw (with UoM) vs. rounded or censored measurement 483
7.2.4 Data verification and editing 483
7.2.5 Results of repeat tests on retained samples 483
7.2.6 Supplementary data 484
7.2.7 Complementary data 484
7.3 Metadata 484
7.3.1 Quality assurance records 484
7.3.2 Records of instruments 484
7.3.3 Checks of automated quality control and quality assurance 485
7.3.4 Records of audits 485
7.3.5 Measurement results from quality assurance samples 485
7.4 Documents 485
7.4.1 Electronic document stores 486
7.5 Data migration and integration 486

8 References 487

Annex J Continuous Air Quality Particulate Matter (PM10 and PM2.5) Data Processing 488

1 General Overview 488

1.1 Normative references 488
1.2 Scope of this annex 489
1.2.1 Exclusions 489
1.3 Variable names and nomenclature 489

1.3.1 PM_x STP data 489
1.3.2 PM_x Equivalent data 490
1.4 Units of measurement 490
1.5 Effect of data type 490
1.5.1 Data storage architecture 490
1.5.2 Data averaging 491
1.5.3 Running or moving statistics 491
1.5.4 Gap handling 492
1.6 Supplementary data 492
1.7 Complementary data 494
1.8 Documenting the data management system 495
1.8.1 Monitoring objectives and design 495
1.8.2 Site History Record 496
1.8.3 Forms 496
1.8.4 Method detection limits 497
1.8.5 Equivalency testing 497
1.8.6 Original records 497

2 Quality Control 498

2.1 Quality coding matrix 499
2.2 Additional metadata required 500
2.3 Plots and comparisons 501
2.3.1 Screening checks 501
2.3.2 Comparisons 501
2.3.3 Between-station comparisons 502
2.4 Reliability of measurements 502
2.4.1 Calibration and validation 503
2.4.2 Reference values 504
2.4.3 Uncertainty 504
2.5 Deviation tests 504
2.5.1 Deviation over time 504
2.5.2 Departure from expected values 504
2.5.3 Automation 505

3 Potential Errors and Recommended Editing 505

3.1 Sources of errors 505
3.2 Unintended offset or incorrect change of offset 506
3.3 Steps in the data 508
3.3.1 Instrument replacement and configuration 508
3.3.2 Interference, obstruction, and disturbance 509
3.3.3 Instrument cleaning 509
3.3.4 Application of equivalency relations 509
3.4 Drift 510
3.4.1 Baseline drift 510
3.4.2 Amplitude (span) drift 511
3.4.3 Calibration drift 512
3.5 Spikes and noise 514
3.5.1 Housing environment 514
3.5.2 Negative values 515
3.6 Incorrect scaling 516
3.6.1 Analogue instruments 516
3.6.2 TEOM instrument measurement bias 516
3.7 Time faults 517

3.8 Missing data 518
3.8.1 Invalidating data 519
3.8.2 Infilling missing record 521
4 Equivalency Testing and Co-location 521
4.1 Definitions 522
4.1.1 Equivalency testing 522
4.1.2 Co-location study 522
4.2 Test or study data 522
4.3 Deriving the relation 523
4.3.1 Uncertainty of the relation 523
4.4 Metadata 524
4.5 Applying the results 525
5 Post-processing 526
5.1 Transformations 526
5.1.1 PM_x STP data 526
5.1.2 PM_x Equivalent data 526
5.1.3 Averaging 526
5.1.4 Co-location 527
6 Laboratory Processes 528
6.1 Tracking the status of samples 528
6.1.1 Chain of custody form 528
6.1.2 Sample identification 529
6.2 Laboratory results 529
6.2.1 Quality assurance 529
6.2.2 Reporting and archiving results 530
6.2.3 Results review 531
7 Metadata 532
7.1 Description 532
7.1.1 Site metadata 532
7.1.2 Time-series metadata 532
7.2 Quality coding 533
7.2.1 The Quality Coding Matrix 533
7.2.2 Child codes 533
7.2.3 Blanket provisions 534
7.2.4 Data editing actions and adjustments 534
7.3 Example PM10 and PM2.5 comments 535
7.3.1 Site/Initial Comments 535
7.3.2 Equipment Comment examples 536
7.3.3 Operational Comment examples 537
7.3.4 Data Comment examples 538
7.3.5 Data Processing Comment examples 540
7.3.6 Transformation Comment examples 541
7.3.7 Stationarity Comment examples 542
8 Quality Assurance 543
8.1 Peer review of data processing 543
8.2 Data audit 543
9 Preservation of Record 544

9.1 Original data 544
9.1.1 Forms 544
9.1.2 Supplementary data 545
9.1.3 Complementary data 545
9.2 Final records 545
9.2.1 Time series and time-series comments 545
9.2.2 Multiple data series 545
9.2.3 Records of data processing 546
9.2.4 Supplementary data 546
9.2.5 Complementary data 546
9.2.6 Metadata 547
9.3 Quality assurance records 547
9.3.1 Records of instruments 547
9.3.2 Checks of automated quality control and quality assurance 548
9.3.3 Records of audits 548
9.3.4 Records of equivalency testing 548
9.4 Documents 548
9.4.1 Electronic document stores 549
10 Data exchange 549
10.1 Data acquisition 549
10.2 Data supply and publication 550
10.3 Data migration and integration 550
11 References 550
Appendix J.1 Adjusting Concentrations to Standard Temperature and Pressure 552
Barometric pressure and altitude 553
Appendix J.2 Effect of Data Type on Data Averaging 554

The National Environmental Monitoring Standards

The National Environmental Monitoring Standards (NEMS), and associated codes of practice, Glossary, and Nat ional Quality Code Schema can be found at www.nems.org.nz.

Development

The strategy that led to the development of these Standards and associated documents was established by Jeff Watson (Chair) and Rob Christie (Project Director) of the initial NEMS Steering Group, in 2014.

The NEMS initiative is supported by the Environmental Data Special Interest Group (ED SIG) (formerly the Local Authority Environmental Monitoring Group (LAEMG)), who contribute members to the NEMS Steering Group.

Implementation of the strategy is overseen by the NEMS Steering Group, which currently comprises Glenn Ellery (Chair), Jeff Watson (Technical Advisor), Phillip Downes, Rachel Herbert, Jon Marks, Charles Pearson, Jochen Schmidt, Clare Barton, Abi Loughnan, Sonja Miller, and Raelene Mercer (Project Manager).

The NEMS Steering Group directs preparation of NEMS documents on authority from the Chief Executives of the regional and unitary councils and the Ministry for the Environment (MfE).

The development of these documents involves consultation with regional and unitary councils across New Zealand, major electricity generation industry representatives, research institutes, and organisations providing supporting services such as laboratory processing. These agencies together are responsible for the majority of environmental monitoring in New Zealand.

Implementation

Stationarity

NEMS Standards are intended for long-term monitoring programmes. Stationarity of record, whereby changes to methods and instruments do not introduce bias over the lifetime of the record, is an essential property (see also NEMS Glossary), without which a record cannot be confidently analysed for temporal trends.

Because the methods of collecting and processing environmental data do change over time, the Standards include provisions for identifying and mitigating potential loss of stationarity.

Data fit for purpose

To facilitate data sharing, the NEMS Steering Group recommend that NEMS Standards are adopted throughout New Zealand and all data collected be processed and quality coded in accordance with the methodologies described in the Standards.

The quality code is determined from the Standard adopted and applied at the time of data acquisition. The degree of rigour with which requirements of the Standards are applied may depend on the quality of data sought. The highest quality code (QC 600) may be assigned to data that meet the stated requirements for good data.

Data of lesser quality are accommodated but are assigned a lower quality code (i.e. less than QC 600). They may be fit for the current intended monitoring purpose but restricted in their use for a range of other current and future purposes.

Measured data coded as QC 500 (fair), or QC 400 (compromised) may be the best practicably achievable due to site limitations and/or transient lapses in data quality.

Health and safety

When implementing the Standards, current legislation relating to health and safety in New Zealand and subsequent amendments shall be complied with.

NEMS Codes of Practice (COP) provide additional guidance on health and safety issues and structural design. Use only the most recent published version of any NEMS COP.

Limitations

It is assumed that, as a minimum, the reader of these documents has an understanding of environmental monitoring and data processing techniques, and some competency in their application.

The documents do not relieve the user (or a person on whose behalf they are used) of any obligation or duty that might arise under any legislation, and any regulations and rules under those Acts, covering the activities to which these documents have been or are to be applied.

Instructions for manufacturer-specific instrumentation and methodologies are not included in NEMS documents.

The information contained in NEMS documents relies upon material and data derived from a number of third-party sources. It is provided voluntarily and for information purposes only.

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A full list of those who have contributed funding and time to the NEMS project is available at www.nems.org.

Review

This document will be assessed for review within one year of its initial release and thereafter will be assessed for review approximately once every two years. Document status and proposed review dates can be found at www.nems.org.nz.

Feedback

If you wish to provide feedback regarding this version of the document, please provide it to https://www.nems.org.nz/feedback/.

About this Standard

Introduction

Time-series data are collected from field measurements and instrumentation in order to quantify temporal and spatial variations in environmental phenomena. Following recording on some medium, whether on paper and/or an electronic digital device, time-series data are converted to a form suitable for archiving and retrieval. In addition, data undergo a range of checks to determine their accuracy and reliability, and may be corrected, edited or adjusted to improve their useability. Data processing in environmental monitoring refers to the quality control procedures that time-series data are subjected to before they can be stored and made available for analysis. Data processing is therefore a significant intermediate task between data collection and delivery of verified data for use.

This document sets out an overall process that includes the types of data and issues that may be encountered, the necessary and recommended quality control actions, and the types of operations that might need to be applied to the data. However, the various time-series management systems in use in New Zealand differ in their structure, implementation, available tools, and application and operation of those tools; therefore, for data processing to be efficient and effective at an organisational level, data producers must know how their system is configured, how it works, and how to use it.

A number of annexes are included, identified alphabetically, each specific to a variable measured.

When reference is made to an appendix, section, figure, or table in the main document, only the appendix, section, figure, or table number is used in the reference.

When reference is made to a section within an annex its number is prefixed by the Annex letter, although section numbering within the annex does not carry the letter. Appendices to, and figures and tables within the annexes carry the annex letter.

This Standard was prepared by Marianne Watson (Hydronet Ltd). Development of the initial draft was overseen by Jon Marks (NEMS Steering Group representative) building from earlier work by John Fenwick and working group members Mike Gordon, Brent Watson, Peter Stevenson, and Nicholas Holwerda. Grateful thanks are extended to Mike Ede for his review comments and to Jochen Schmidt, David Brown, Murray Hicks, Paul Peters, Johanna Rodgers, Cindy Lowe, Glenn Ellery, and Juliet Milne for their contributions to development of Annexes D to I inclusive. The input of working group members Asaeli Tulagi, Angela Perks, Stacey Binsted, Luke Fullard and Lizzie Ingham for Annex I *(Discrete Water Quality)* and Teresa Aberkane, Emma Reeves, Vanitha Pradeep, Nathan Cross, and Sarah Harrison for Annex J *(Air Quality Particulate Matter)* is also gratefully acknowledged.

Objective

The objective of this Standard is to ensure that environmental time-series data, and their associated metadata, are processed and stored in a consistent way to facilitate regional and national analyses. This document is made up of two parts. The first part describes the generic requirements and methods for processing environmental time-series data. The second part is a series of Annexes (which will be added to over time) describing procedures specific to particular variables.

Scope

This Standard applies to the processing of environmental time-series data before they are permanently stored in, and made available for analysis from, a recognised time-series management system (TSM). It includes common data types, methods of quality control, data editing techniques, and requirements for associated metadata.

The environmental time series covered by this Standard include at-point numeric time series, vector data for wind, and 'less than' or 'greater than' censored time-series data.

This Standard recognises that data may be used in near real-time with minimal and/or some automated processing, and that automated quality control and editing of data intended for permanent archiving is desired and becoming more prevalent.

Exclusions

For the purposes of this document, data processing does not include analyses of the data, except where analysis is required for quality control.

Two and three-dimensional time series (e.g. time series of cross-sections or lake profiles), and non-numeric time series other than censored (*< or >*) data and metadata, are not covered by this Standard.

Requirements for site and station metadata, including preservation of these records and ensuring their availability as and when required for data processing, are the domain of the relevant normative reference for each variable and are not repeated in this Standard.

A time series may be calculated by transforming the time series of a surrogate variable. An example is a flow series, which is most often obtained from a water level series by applying stage–discharge relationships that are derived from discrete open-channel flow measurements. This document does not cover developing the relationships between surrogate and target variables, or the process of transformation of surrogates, which is usually automatic as the data are accessed. These processes may be covered by other NEMS, for example in the case of flow, NEMS *Rating Curves*.

This Standard is designed for application to environmental data, and it does not address industrial applications (although many of the principles may apply).

Terms, Definitions and Symbols

Relevant definitions and descriptions of symbols used in this Standard are contained within the NEMS *Glossary*, available at www.nems.org.nz.

Normative References

This Standard shall be read in conjunction with the following references:

- NEMS Glossary – *Terms, Definitions and Symbols*
- NEMS *National Quality Code Schema*

and any additional normative references specific to the measured variable as listed in the Annex for that variable.

The Standard – Data Processing

Requirements for all data

The following table summarises the application of this Standard for environmental time-series data processing, and includes requirements for:

- appropriate storage of data
- documenting and managing data processing procedures
- verifying data collected, including assessing its quality and reliability
- improving usability of the data, as required
- ensuring modifications are necessary, appropriate, and traceable, and
- preserving required forms of the data and its associated metadata.

Note: Modifying data to improve its usability may reduce its quality code because the quality coding schema incorporates data provenance.

Reference in the table, and elsewhere in this Standard, to 'an (or the) organisation' means one or more of the agencies responsible for the recording, collection, verification, processing, and/or archiving of a time series of environmental data.

Table 1 – Requirements for all data.

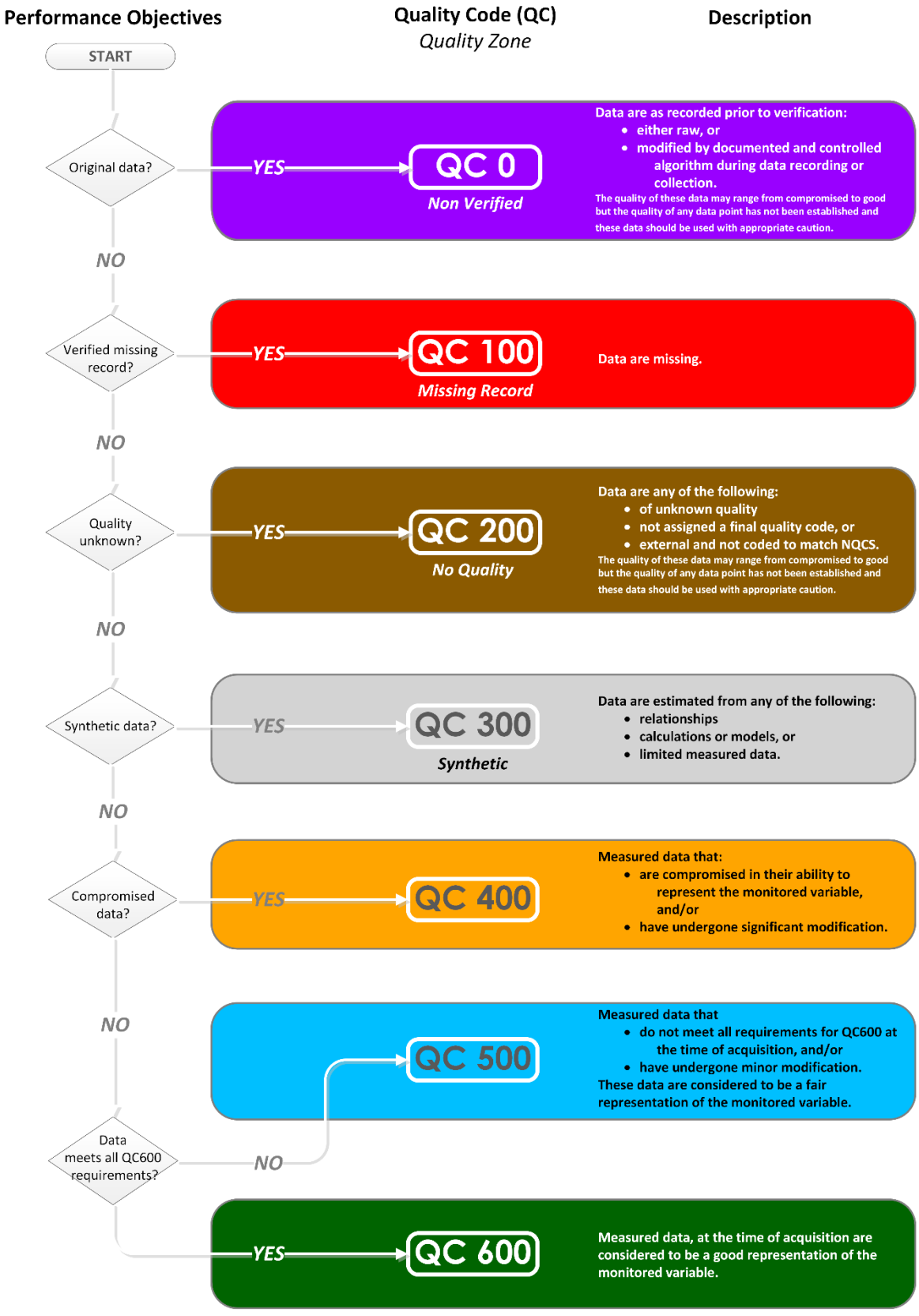
Data Types	The data type used to store data shall ensure correct representation, interpretation, analysis, and reporting of the measured values. If storing data as censored, an organisation must develop, document, and implement their own protocols if not available elsewhere in NEMS.	Section 1.1
Units of Measurement	Units must conform to requirements of the relevant NEMS normative references. Dates and times shall be fully specified in DMY order to 1-second resolution of a 24-hour clock in Standard Time for New Zealand or the Chatham Islands.	Section 1.2
Management of Data and Processing Systems	An organisation shall establish and implement procedures to achieve the following: All data records shall be clearly identified with at least the site name/identifier and date and time of the record. Multiple data streams and/or versions of data for the same variable and period must be uniquely identified, tracked, and managed to ensure integrity is preserved and all data stored are traceable to source.	Section 2 and Section 3

Management of Data and Processing Systems (cont.)	All verification information must be securely stored, permanently retained, retrievable, and referred to during processing of the time series. Define and formally document what constitutes the original data for each time-series record, and the source of data to be processed, and the pathways to data publication and final archiving. Identify periods of data at the various stages of processing, and identify the provenance and status of data, and track timeliness of data processing. Maintain backups of data in its original (as defined) and subsequent forms.	
Quality Control	Quality control must be applied to all data collected using, but not limited to, the relevant procedures described in this Standard. Records of all quality control inspection and testing must be compiled and retained. Anomalies identified in data must be investigated to establish cause, edited appropriately, and recurrence prevented where possible. Data known to be faulty shall not be archived, other than in an original record. Machine algorithms used for quality control must be documented, changes to them controlled and tracked, and be regularly reviewed with outcomes documented and retained.	Section 3.6 and Annexes
Control of Editing	An organisation shall control the amount and type of editing that can be performed and the authorisation to do so. Editing and adjustments applied must adhere to the principles, procedures and operations described in this Standard. Evidence of modifications to, or discarding of, time-series data or verification information, and justification of these actions, must be recorded and retained, including those performed in the field or automatically by a data acquisition system.	Sections 3.8 and 3.9 Section 4, Section 5, and Annexes Section 6.2
Missing Data	Gaps in continuous time series shall be avoided whenever practicable. Gaps shall be closed, marked, or infilled using the most preferred method(s) possible selected from this Standard, as is appropriate for the variable, the duration of the period missing, and the availability of supporting information. Infill with synthetic record is permitted, with some cautions and exclusions, but each period must be identified to data users via a Data Comment and quality code of QC 300.	Section 5.4 and Annexes

Stationarity	All information contributing to assessment of stationarity must be securely stored, permanently retained, and summarised for data users. Stationarity shall be preserved as much as is reasonably practicable. Processing methods and editing actions shall not unduly disturb stationarity already achieved. Any known or suspected changes in stationarity shall be recorded in the metadata.	Section 3.7
Metadata	All required metadata, comprising site and instrument information (site metadata) and time-series metadata, must be created, collected, and/or collated, then verified and permanently archived. Site metadata and data acquisition records relevant to the time series must be readily available when the data are processed. A quality code shall be assigned to all data according to: • the national quality coding schema, and • the normative NEMS for that variable, and • the guidance in this Standard, and • the extent of modifications to the data. Timestamped and time-bound comments, conforming to the minimum requirements of this Standard, shall be filed to identify the data, and to inform a data user so they may determine the data's fitness for purpose. An organisation shall develop and implement policy to distribute relevant quality codes and comments with the time-series data.	Section 6
Quality Review and Audit	All agencies shall implement standard methodologies for quality review and for periodic more formal audit of archived data. All editing, and metadata compiled during processing, shall be routinely peer reviewed prior to archiving using, but not limited to, procedures described in this Standard. Periodic audit of archived data is recommended. A minimum of biennial audit of machine-processed data is required if they were not reviewed by a suitably trained and experienced person prior to archiving. An audit must address, but is not limited to, the minimum requirements set out in this Standard. Information about reliability, accuracy, and utility of the data resulting from an audit shall be collated into a formal report. Further alteration of data that have passed an audit shall be formally controlled.	Section 7

Preservation of Record	An organisation shall develop, maintain, and implement policies, procedures, and systems for the permanent archiving of records, including those needed for traceability of the data, and the assessment of stationarity and fitness for purpose. The following shall be stored, retained indefinitely, and (if electronic) backed up regularly: • original data as defined • final data as verified • supplementary data • all required metadata • additional time series and/or metadata as specified by an Annex. Physical records that must be retained indefinitely should be stored in conditions suitable for their preservation and efficient retrieval.	Section 8 and Annexes

Quality coding of data



Application

All data produced and archived under NEMS Standards shall be filed with all required metadata, including a quality code assigned in accordance with NEMS *National Quality Code Schema*. The schema permits valid comparisons within and across multiple data series.

The quality coding flowchart as shown shall be used as the framework to assign quality codes to data.

Quality coding matrices are being introduced to all monitoring NEMS to decide an initial quality code of QC 400, QC 500, or QC 600 for measured data within this framework. This initial quality code is the maximum achievable for the data; the final quality code may be lower.

Measured data can be assigned a final quality code of QC 600 (good) if the outcome of the quality coding matrices is QC 600, and the data have not been modified (i.e. edited, adjusted, or transformed during data processing).

Data that have undergone minor modification are eligible for a final quality code of QC 500 provided their initial quality code from the matrices is at least QC 500. An initial quality code of QC 500 from the matrices can be retained as the final quality code unless the data are subsequently significantly modified.

Regardless of initial quality code obtained from the quality coding matrices, final quality code cannot be higher than QC 400 if the data have undergone significant modification.

Quality coding matrices may identify data as not meeting QC 400 and needing remedial action. Data processing will then determine the final quality code to be applied. In the interim, affected data may be assigned QC 200 (not assigned a final quality code) or retain QC 0 (as recorded). Guidance on selecting and applying suitable quality codes during data processing is included in this Standard.

Quality codes are determined from the Standard(s) applied at the time data are acquired. As Standards are updated there is no requirement to review and possibly revise the quality codes of data already archived. The Standard(s) and version(s) applied must therefore also be tracked in the metadata by way of a Stationarity Comment when a new Standard and/or version is adopted.

1 Environmental Time Series Characteristics

In the context of this Standard, the time-ordered observations forming the time series are of environmental variables such as water level, water temperature, and most of the other variables that make up the suite of National Environmental Monitoring Standards (NEMS).

1.1 Time-series data types

There are several types (kinds) of time-series data. The purpose of these different types is to ensure stored values are correctly interpreted. The types differ by how the data are interpolated (or not interpolated) in the time intervals between stored values, and by what the stored values represent and therefore how the data are to be treated. In other words, the same series of numbers can be stored as any one of a range of data types, but which type determines the information derived from those numbers.

A time series may be one of the following types (OGC, 2016):

- instantaneous (continuous)
- discrete (discontinuous)
- instantaneous (discrete) total
- value in preceding interval, where the value may be:
  - a statistic summarising samples in the interval (usually an average, maximum or minimum), or
  - a constant (e.g. a pump rate), or
  - a total (that is continuous, i.e. interpolating)
- value in succeeding interval, where the value may be:
  - a statistic summarising samples in the interval (usually an average, maximum or minimum), or
  - a constant (a form of 'event' or 'status' data, e.g. a gate setting), or
  - a total (that is continuous, i.e. interpolating).

There are other data types available in many time-series management systems. Most are variations on the above, for example:

- 'quasi-continuous', which plots data as if it were an instantaneous continuous (and therefore interpolating) data type but analyses the data as discrete values
- cumulative totals
- other statistical methods of representing the measured values and/or controlling interpolating between the stored values. These are not discussed further unless relevant within a specific annex to this Standard.

Time-series management software may specify interpolation method separately from data type. This provides more options for data storage but usually, although not exclusively, an individual time series remains restricted to one combination of type and interpolation method that is set when the time series is defined and does not change during the record.

The data type used to store data must be consistent with how the values in the time series were obtained, what they were intended to represent, and the validity of any interpolation permitted between the stored values.

For example, logged values that are the average of more frequent sampling in the recording interval up to each timestamp, should be stored as type 'average in preceding interval'. These data will then be aggregated as averages and not totals and interpolating at any time between adjacent timestamps will return a value equal to the value stored at the end of the interval, being the average for that interval.

Data may be converted from one data type to another (see Section 4.14).

1.1.1 Instantaneous (continuous)

Instantaneous data are the most common type in environmental monitoring and originate from recorders that take observations at instants (usually regular intervals) of time, e.g. water level measurements at a recording site. The values are intended to represent a continuous signal, i.e. the data are assumed connected and it is valid to interpolate linearly with time between them. Therefore, for the data to be representative of the variable, values need to be collected sufficiently frequently to adequately follow the rate of change in the phenomenon being measured.

1.1.2 Discrete

Discrete data are values that are known, suspected, or assumed to be discontinuous. Interpolation between the stored values is not valid, i.e. no assumptions are made about how the variable behaved between samples. Examples are spot values of water quality variables and measurements of open channel flow (i.e. gaugings).

If the data type is discrete totals, values can be accumulated. An example is rain gauge tip counts where each tipping bucket is assumed to have filled instantly and therefore interpolation between tips is not valid and not supported, but total rainfall in a period can be calculated from the sum of the tips recorded in the period.

1.1.3 Value in preceding interval

If the value stored is an average of more frequent samples in the interval it is important to consider what the average represents and assign the appropriate data type.

- If intended as a point sample at the time the value is recorded it should be stored as instantaneous data (see Section 1.1.1).

- If it represents the average value of the variable in the interval it should be stored as value in preceding interval, also known as histogram data.

The value may also be a constant, such as a rate per unit time (e.g. of a pump), or a total (e.g. rainfall).

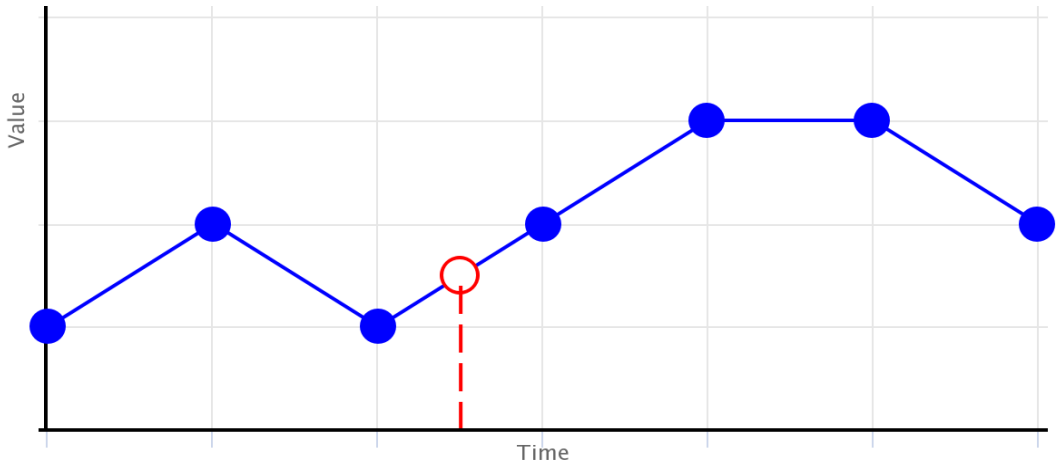


Figure 1 – A depiction of instantaneous time-series data. A value at any time (e.g. the red circle) can be interpolated linearly with time from adjacent recorded values (blue dots).

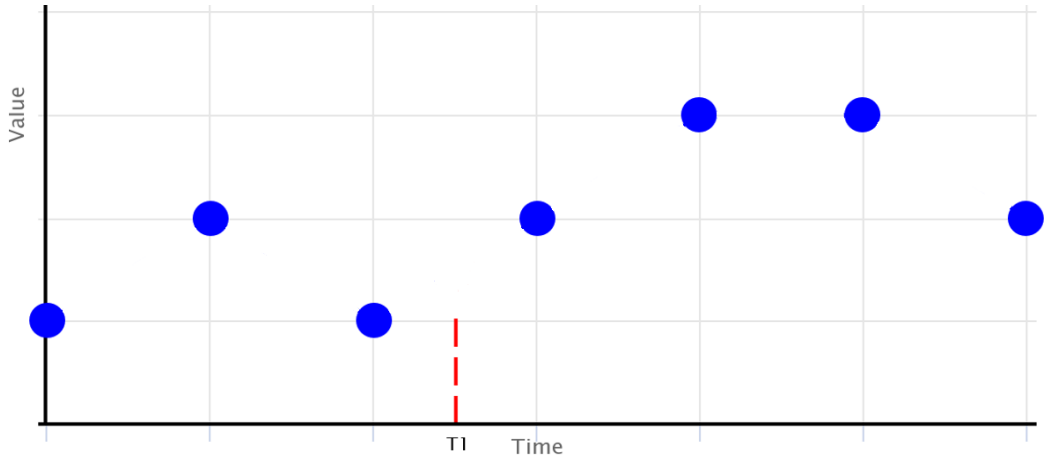


Figure 2 - A depiction of discrete time-series data. Interpolation between values is not valid. Values at times other than those stored (e.g. at T1) cannot be inferred.

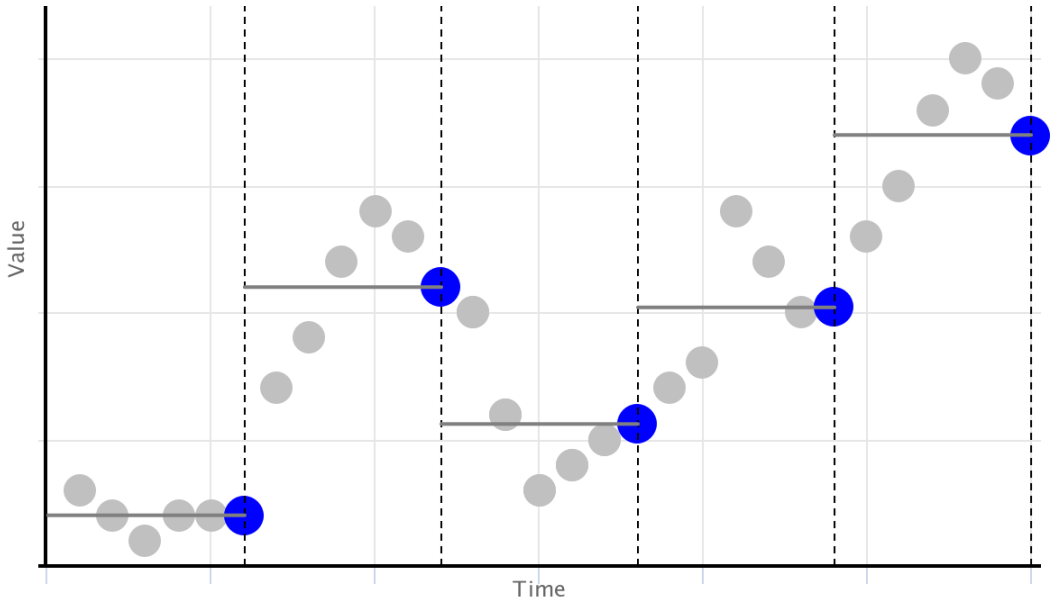


Figure 3 – A depiction of average in preceding interval (histogram) time-series data (blue dots) that are the average of samples (grey dots) within each preceding time interval.

1.1.3.1 Incremental data

Incremental data are values intended to be totalled over any specified period of time. Totals are aggregated for periods spanning multiple recording intervals. Incremental series can be presented using a bar chart (with totals at regular or irregular intervals) or as a cumulative trace.

In New Zealand, data that are incremental refers more specifically to values representing a total in the preceding interval where the interpolation method is continuous and linear. Rainfall data have traditionally been stored this way, whether the rain gauge bucket tips are recorded as they occur or are counted into set (fixed) intervals. Use of a discrete (non-interpolating) incremental data type is rare but should be considered.

The continuous linear interpolation method assumes each stored total has accumulated at a constant rate within the interval, as shown by the dashed lines in Figure 4. Because the data type refers to an interval and the data are intended to be continuous, the end of one interval also sets the start of the next, i.e. the previous timestamp is essential to interpretation of the current value. Any values of zero incorporated into the time series are interpreted as periods of no rain in the preceding interval.

To interpolate values at intermediate times (e.g. the red value in Figure 4), the average rate of accumulation (represented by the dashed line) is used to calculate the portion of the stored total assumed to have accumulated in the new (shorter) interval.

Incremental totals that are continuous and interpolating can be aggregated into multiples of the recording interval (e.g. hourly or daily totals from 15-minute data), or apportioned, by way of the average rate of accumulation, into smaller or different intervals (e.g. from daily totals at midnight to daily totals at 9 a.m.). A total for any period of time is obtained from a combination of aggregation and apportioning.

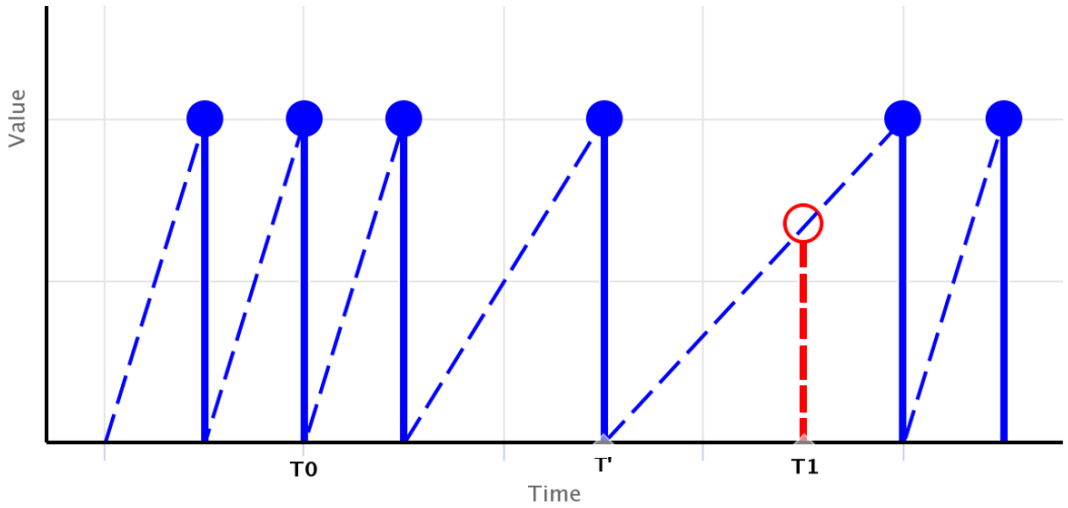


Figure 4 – A depiction of 'total in preceding interval' incremental time-series data (blue dots). Dashed lines show the average rate of accumulation in each interval. Total for the period T0 to T1 is the sum of the value after T0 and the value at T' plus the value interpolated at T1 (red circle).

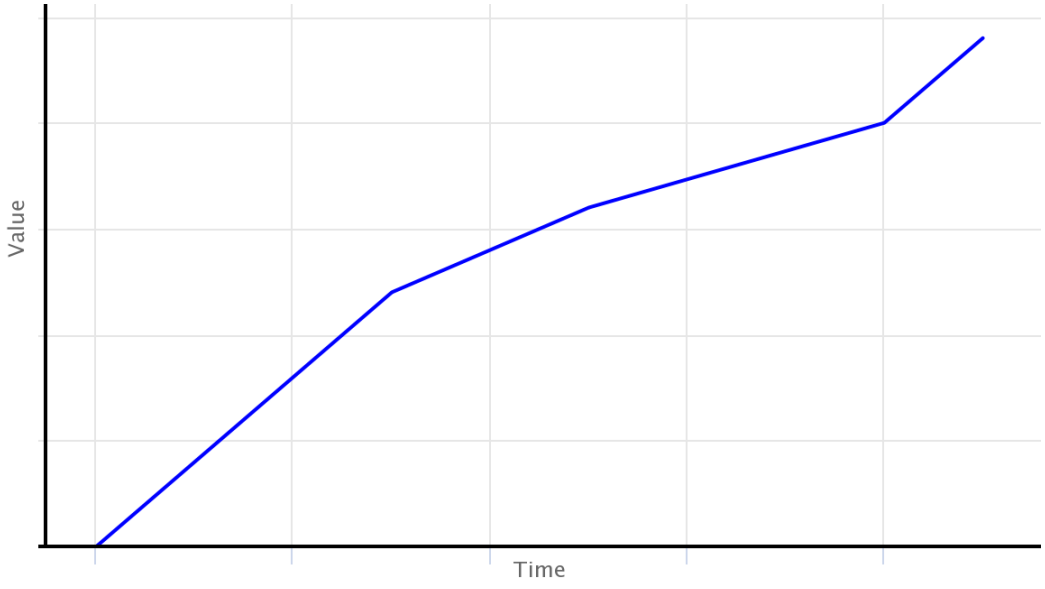


Figure 5 – A depiction of incremental time-series data plotted as a cumulative trace (using the same data as in Figure 4). Slope of the line is the average rate of accumulation in each interval.

1.1.4 Value in succeeding interval

This data type is used when values that represent measurement(s) over intervals of time are stored at the beginning of the interval, rather than at the end.

In some time-series managers the values may be any of the forms available for 'preceding interval' data type (i.e. an average, maximum, total etc.), including choice of interpolation method, but others are more restrictive. Some systems support transformation between the two, either in the database or when reporting from it.

1.1.4.1 Event (step) data

If the value is a constant in the succeeding interval, it may be known as event or step data (not to be confused with event rainfall data; see Appendix B.2).

Event data are only captured at a change of state, and that state expressly remains the same until another change of state is recorded. This means that each event is represented by a single value at the start of each period. Thus, for this type of event data there is no apportioning between data points, as there is for incremental data, nor linear interpolation with time as there is for instantaneous (continuous) data. An example of event data is the changing settings of a hydraulic gate.

Special cases of event data are 'switch status', where the values are restricted to 0 ('off') and 1 ('on'), and the Hilltop implementation of quality coding.

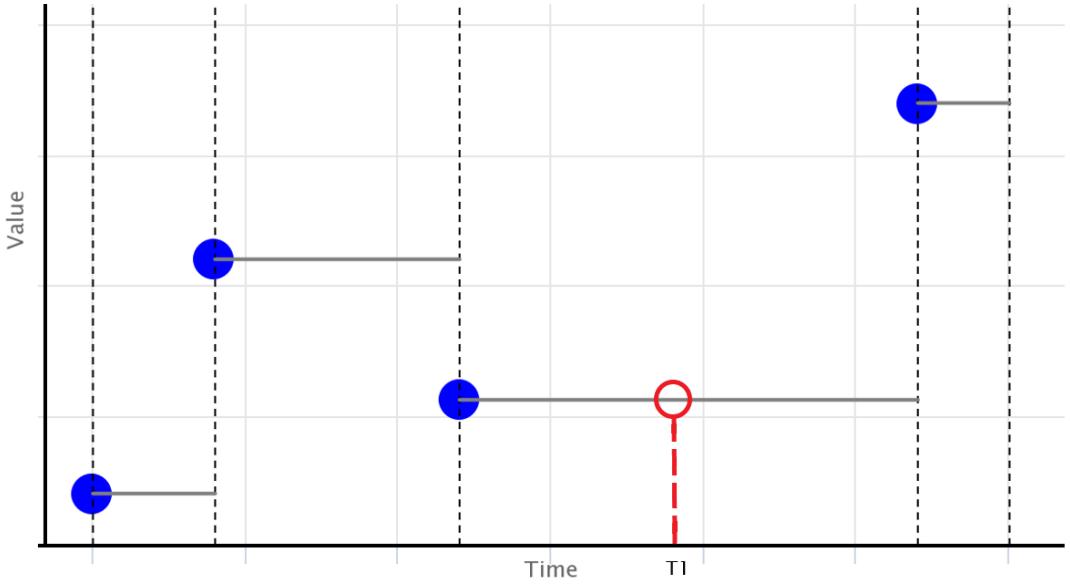


Figure 6 – A depiction of event time-series data. Each event is represented by a single value at the start of the relevant period. The value interpolated at time T1 is the same as is stored at the beginning of the interval.

1.1.5 Censored data

Censored values are those that are only partially known and are recorded as being greater than (>) or less than (*<*) a limit or threshold, or within a range.

Censored values are often found in discrete water quality data, either as greater than the maximum value of the calibrated range of the meter or test, or less than its method detection limit (MDL). These censoring thresholds may change over time.

A laboratory's official result may be a validated but censored value. Laboratories may also be asked to supply an 'uncensored' (i.e. raw unrounded) measurement result and the associated uncertainty of measurement (UoM), in accordance with either the relevant NEMS normative reference or JCGM (2008).

Continuous sensors may return values outside their calibrated range, in which case a decision must be made whether to trim, censor, reduce quality code, comment, or some combination of these actions.

Censoring real time publication of data may be an initial temporary step prior to verification and decision on the final form of the data to be archived.

If policy for a specific variable's censored data is not provided within the relevant NEMS normative reference an organisation must develop, document, and implement their own protocols, giving due consideration to the purpose of the data collection and maintaining consistency of treatment within and across datasets.

As a minimum, an organisation's data processing system shall include the following:

- the ability to differentiate censored data from uncensored data
- methods for storing, editing, and reporting censored data to ensure correct interpretation of the values
- methods for storing, editing, and reporting the associated uncertainty of uncensored data that would otherwise be reported as censored, and
- protocols for treatment of values that are out of calibration range, if not included in the relevant NEMS normative reference for that variable.

1.1.6 Vector data

Vector data within the scope of this NEMS are restricted to wind direction, which will usually be measured in conjunction with wind speed.

The purpose of the specific data type is so that graphing and analysis tools take account of the values ranging between 0 and 360 degrees with 0 and 360 being the same 'north' direction, and therefore present wind roses rather than plots that 'run off the edge' as direction goes through north.

1.1.7 Multi-item data

The most common time series of multi-item data is gauging results (see Appendix C.1); however, not all time-series managers store gauging results as a time series. Some store gauging data in relational database tables with the results queried as needed for quality control, reporting, and ratings work.

Although multi-item data as a time series is supported in some systems their use is discouraged. The main disadvantage is that all items must be populated, which leads to use of default or substitute values in the instance of an item being missing. An example is the historic use of a value of -1 to indicate an item was 'not measured' (or not calculated from the measurements).

1.2 Units of measurement

Measurement units of all variables must conform to requirements of the NEMS normative reference for each variable. Generally, units are metric in accordance with the SI system of measurement.

1.2.1 Formats for date and time units

Date and time format requirements are:

- a fully specified (i.e. 4-digit) year
- DMY or YMD (i.e. not American-format dates)
- 24-hour clock
- time resolution of 1 second, and
- conventional DD-mon-YYYY (with dashes or spaces) or DD-MM-YYYY and hh:mm:ss (with or without colons) in filed comments (see also Section 6.2.4.1).

Conformance with ISO 8601 (ISO, 2004) is desirable to facilitate data exchange, but may be achieved either directly or by facility for conversion of date and time format(s).

1.2.2 Time zones

Coordinated Universal Time (UTC) is based on the time at Greenwich, England. New Zealand Standard Time (NZST) is UTC + 12 hours, and New Zealand Daylight Time (NZDT) is UTC + 13 hours.

In New Zealand, data shall be archived in NZST, except for in the Chatham Islands (CHAST), which is 45 minutes ahead of NZST.

1.2.2.1 Daylight saving

NZDT (and CHADT) is in common use in the summer months but, for reasons of continuity and standardisation, time-series databases shall use NZST (or CHAST). Data collection should record in NZST (or CHAST) unless there are overwhelming reasons to use NZDT (or CHADT).

To avoid confusion, it is normal that field notes record both standard time and daylight time when applicable, and that the time references are stated when data are provided.

Policy on daylight saving periods has changed over time since it was first introduced in 1927. For historic NZDT (and CHADT) periods in New Zealand refer to https://www.govt.nz/browse/recreation-and-the-environment/daylight-saving/history-of-daylight-saving-in-nz/

Daylight saving periods since the mid-1940s are as follows:

from:	1946	NZST established, with no daylight saving
	1974/75	first Sunday in November to last Sunday in February
	1975/76	last Sunday in October to first Sunday in March
	1989/90	second Sunday in October to third Sunday in March
	1990/91	first Sunday in October to third Sunday in March
	2007/08	last Sunday in September to first Sunday in April (i.e. current)

2 Data Capture

The term 'data capture' refers to the processes of recording data in written, graphic, punched media, analogue or digital electronic forms and converting, if necessary, to a medium whereby it can be further processed, stored, and analysed.

2.1 Electronic recording

Electronic recording is by far the most common method of capturing time-series data. Electronic data loggers began to be used to store values from sensors in the 1970s and their use expanded significantly in the 1980s. Ongoing developments in technology now provide a diverse range of options for data capture and collection, including:

- data logging at site, either on-board the sensor or to a separate, often multi-purpose data logger from which the captured data are then either periodically manually downloaded and/or polled by a telemetry or SCADA system
- transmission of measurements via hard-wire or wireless communications from a sensor or intermediate electronic device to a central collection point such as a data logger servicing a network of nearby sensors, or a cloud server, or a mobile device
- transmission of measurements via hard-wire and/or wireless communications from a sensor or intermediate electronic device to a dedicated centralised data acquisition system, such as a telemetry or SCADA base, or client-server portal.

Capture to electronic form is inherent to electronic recording so this step of data processing has become simpler. At the same time, the technology has made it easier for errors to be more serious and widespread, so that quality control needs to be rigorous and quality assurance (in terms of error prevention) is more important.

Transmission of measurements can be prone to timing and intermittent communication issues causing data loss that is difficult to detect. For this reason, a data logger at site is recommended, and is required for some variables, e.g. rainfall (see Section 3.6 of NEMS Rainfall v2.1). Two records are therefore possible from the same sensor that must be carefully identified, tracked, and managed (see Section 3), then possibly combined, while preserving traceability of the contributing data.

2.2 Punched tape recording

A significant amount of historical water level and rainfall record was produced by punched-tape analogue-to-digital recorders. These electro-mechanical instruments were widely used from the 1960s to the 1980s and were the first commonly used machine-readable recorders. They usually punched binary-coded decimal (BCD) measurement values at each time interval or the time of an event as lines of holes in a

roll of paper tape and could be read relatively rapidly by an optical tape reader and translated to computer files.

Data processing operations were similar to those used for the later solid-state data logger, and verification processes developed for them are the basis of those used today for electronic data.

2.3 Chart recording

Analogue (chart) records of variables such as water level and rainfall were commonly collected in the past, and in a few places this technology may still endure due to its advantage of rapid interpretation by lay people and/or for historical reasons. On occasions, chart data may need to be reprocessed to improve a historical record.

Capture to digital form can be done by manual reading and key entry, which normally involves a person reading the series of values at an appropriate time interval and writing these to a form from which the values are later keyed into a computer file (see Section 2.4).

More commonly, digitising is carried out from either a digitising tablet or a scanner. Tablet or flat-bed digitising is the most common method and relies to some extent on the skill of the operator to not introduce errors of precision or interpretation into the record. The use of a scanner with software to interpret the trace is a more recent development, particularly for 'data rescue', and while this process can also have errors of precision, or of interpretation if the trace is obscured in some way, it can be an improvement over methods used in the past.

2.4 Manual recordings

Examples of data that may be recorded manually include:

- verification data (see Section 2.5)
- discrete water quality data obtained by field measurement and observation, and/or laboratory analysis of samples
- ad hoc at-site observations, such as
  - current meter streamflow measurements (gaugings)
  - climate observations that are not logged
  - battery voltage
  - surveyed levels, e.g. datum checks
- 'citizen science' observations
- regular 'self-monitoring' observations by consent holders or their agents, e.g. daily water meter or staff gauge readings
- river or lake cross-sections
- values read by eye from a chart or punched tape.

Manual recordings may be captured directly to an electronic file or manually typed (keyed) in after capture to paper via a form, chart, level book or field station logbook.

2.5 Verification data

When visiting a recording station or measurement site, for servicing or any other reason, it is standard practice to record:

- manual observations of the relevant variables:
  - readings of a primary reference gauge
  - water quality observations using a handheld device
  - intermediate observations, i.e. at times between logged values
  - values read by eye from a logger display
  - weather conditions, e.g. presence of snow at a rainfall site
  - flood levels
- the date and time of the observations, recorded unambiguously (in particular, using NZST and noting NZDT), and
- any other information that may assist in the verification and interpretation of the data (see Section 3.2 and the relevant NEMS normative references).

Verification data may also include results for samples collected at site but analysed off-site in a laboratory, for example for water quality variables, suspended sediment, or soils.

These records must be permanently retained, and available and referred to during processing of the time series for the purposes of verification and/or adjustment of the data (see Sections 3 and 5), compiling of metadata (see Section 6), and for quality assurance (see Section 7).

Electronic secure storage of these records is recommended. This can be achieved by implementing electronic field sheets or by scanning and indexing paper records as they arrive in the office, then maintaining regular backups.

3 Elements of a Data Processing System

This section focuses on the components and procedures that need to be included in a data processing system in order for data integrity and processing traceability to be assured.

Time series and related data are valuable in that they are relatively expensive to collect, are usually irreplaceable, and have the potential to have very high use value. To realise and maintain their value, there must exist a means of verifying their integrity and accuracy and giving assurance that errors are largely absent. The data must be traceable in a readily followed form.

Data processing is best done as soon as practical following data capture, otherwise some opportunities for verification may be lost.

A data processing system shall include provisions to:

- store multiple versions of the data (see Section 3.1)
- keep backups of the data in its original and subsequent forms (see Section 3.1)
- file all field observations, results, and other information used to verify the data, track activities at site, and monitor conditions that are affecting or may in future affect reliability and/or stationarity of the data (see Section 3.2)
- identify periods of data at the various stages of processing (see Sections 3.3 and 3.4)
- identify the provenance and status of data (see Section 3.5)
- track the timeliness of data processing (see Sections 3.3 and 3.5)
- present the data in a number of ways for checking and reviewing (see Section 3.6)
- identify anomalies in data and provide a means of identifying issues that need correcting in order to prevent recurrence (see Sections 3.6 and 3.7)
- control the amount and type of editing that can be performed and the authorisation to do this (see Section 3.8)
- present and store evidence of any modifications to the data (see Section 3.9)
- assign quality codes, in accordance with the NEMS normative references for the variable, and having regard to any editing and transformations that have been applied (see Section 4 and the respective Annexes to this document).

The following sections enlarge on the above requirements.

3.1 Versions of data

It is common to have multiple versions of a time series and/or copies of the same data. For example, there may be:

- one or more raw versions (see Section 2.1) as captured and not modified on-site and/or during data collection (see Section 3.1.1)
- an original version as defined by the data collection agency (see Section 3.1.1)
- possibly one or more versions with quality tags and/or flags and/or automatic editing or adjustments applied as sent to a user or website, in real or near-real time, or as a first step to verification and processing of the data for archiving
- possibly one or more versions at various stages of editing (which may include cleaning the data to remove recording errors and/or adjusting the data, with or without verification control, to eliminate bias)
- possibly one or more versions at various stages of review, if pre-processed and/or partially or fully verified and processed by machine
- the final processed, verified data (cross-checked with independent readings, edited if necessary, and metadata attached)
- an audited and possibly 'certified' version, and
- backup and/or shared copies of any of the above.

Different time-series managers have different architecture and different degrees of management of multiple versions and copies of data. Versioning and copies may be provided by way of multiple files, multiple time series within a file, multiple time series and/or versions within a central database, or as a series of transactions on a file or database.

Good housekeeping of all versions and copies is essential to maintain integrity of the data. If the time-series manager does not provide sufficient housekeeping services, they must be achieved by way of office procedure (see Section 8).

3.1.1 Original data

An organisation shall define and formally document:

- what is regarded as the original data taken into their data verification and editing processes (see Section 8.2.1)
- where the data to be processed for final archiving are drawn from, and
- how data travel through their system(s) from data logger to the various forms of publication, including near real-time web services and final archive.

For publication of original data see Section 3.5, 'Data provenance and status'.

For archiving of original data (as an original or final record) see Section 8, 'Preservation of Record'.

The following conditions apply to telemetered data:

- the data shall be quality coded as QC 0 (as recorded, non verified) while in their original form as defined, and before verification, processing, and/or quality review by a suitably trained and experienced person (see Section 7.2)
- the data shall be quality coded as QC 200 (not assigned a final quality code) if they are published partially verified and edited such that they are no longer the original data
- data recorded without acquiring verification data (e.g. supplementary) but otherwise quality reviewed by a suitably trained and experienced person (see Section 7.2) may be quality coded as QC 200 (unknown quality) for publication or archiving as a final record (see Section 8.2.2)

  Note: The data cannot be fully verified without reference readings or test results so cannot attain a higher quality code than QC 200.

- implemented automatic functions that modify the data captured and/or collected must be described, and changes to those functions controlled, tracked in the station history, and summarised in the metadata (see Section 5)
- performance of the automatic functions shall be regularly checked and the outcome of those checks documented (see Sections 5 and 7)
- ad hoc changes applied at, or initiated from, the telemetry base, e.g. rescaling a sensor or changing a sampling method, must be controlled and documented in a manner equivalent to making the change on site.

The 'first write' to the time-series management system intended to process and store the data may be regarded as the original version in the context of data processing (see Section 8.2.1), but if measured values arriving at the data logger have been censored, aggregated and/or altered in some way on the logger or by the data collection system (e.g. auto-filtering by a telemetry system) this 'first write' is not unmodified (raw) data.

If all operations on the data are not fully traceable throughout the process (i.e. from raw measured values before <u>any</u> modification, to the final archiving of the data) the data archived as a final record cannot be assigned a quality code higher than QC 300.

Fully traceable means that either:

- the measured values are able to be obtained, retained, referred to during data verification, and retrieved at any time in the future, or

- all modifications that have been made to the measured values during data capture and collection are known, documented, able to be confirmed as valid during data verification, and able to be reversed if necessary.

3.2 Verification information

All information that enables tracking and verification of the data and activities at site must be stored securely, permanently retained, and be readily retrievable. Typically, this information will include:

- calibration certificates
- results of instrument validations (pre-deployment and at-site)
- verification data, such as reference readings or laboratory test results
- supplementary data, if any
- backup or adjacent site data, if any
- field station logbooks, electronic field sheets, or equivalent, recording:
  - site and variable name(s)
  - date and time of visit
  - date, time, and result of inspections
  - conditions at the time of inspections
  - instrument serial numbers
  - equipment installation/removal records
  - details of software and/or configuration changes to instrument and/or data logger
  - manual observations and measurements
  - status of power supply and communications
  - notes of maintenance carried out
  - comment on issues and possible interferences
  - name of the person making the logbook entry
- completed checklists and forms (e.g. level checks, annual site survey)
- photographs, and possibly video.

All information contributing to assessment of stationarity must be stored securely, permanently retained, and be summarised for users of the data. This information will include information from field visits but may also include other related records, such as imagery over time and results of trend analyses of conditions at site and/or deviations in the data.

If the measured data are used as a surrogate for another variable, data collected to calibrate the relationship between the variables become part of the verification

information, for example, the discharge measurements and observations of control conditions when water level is being measured to derive flow.

3.3 Data registers and tracking

Periods of data between two or more physical on-site observations, whether time-series, point or sample data, need to be tracked and their processing managed.

- Earlier data records in chart, tape, or paper form are tangible, unique, and permanent so they are easily identified, tracked, secured, and able to show evidence of what has been done to them.
- Datapaks (now obsolete) and storage cards are also tangible, but not unique or permanent if reused. Data may be inadvertently overwritten before they are permanently stored if not suitably tracked and managed.
- Electronic data with no tangible presence must be tracked and managed to ensure the same traceability and security as is provided by physical records. If multiple versions of raw data are collected, e.g. primary and backup, or telemetered and manually downloaded, procedures must also ensure the integrity of each version and allow the source of data subsequently published and/or processed and archived to be traced.

Agencies shall establish data processing procedures aimed at:

- achieving traceability of data files and data verification status, and
- efficient processing of the data while preserving and verifying its integrity.

In one or more registers designed for the purpose:

- track data as it arrives in the office
- update the register as further periods of data arrive
- identify any missing periods
- include the start and finish times of the period of data being processed
- update the register(s) as data progresses through the various steps, confirming that the editing, checking, quality coding, and updating to archive as final verified data, has been done
- sign off each step with at least the staff member's initials and date, or a more formal approval system may be used.

Note: Sign-off encourages staff to take responsibility for and gain 'ownership' of their work and its progress.

Registers may be paper-based, spreadsheet-based and/or part of a database or automated data collection system.

If more than one register is used there must be continuity in traceability of data between them. The register(s) will thus contain a complete chronological record of the passage of data from logged to verified archived forms.

3.4 Identification of records

All data records shall be clearly identified and must at least include the site name/identifier and the date and time of the record.

3.5 Data provenance and status

Organisations must document the provenance of datasets, encompassing their origin, subsequent modification, and changes in status. Their current status (e.g. whether they have been verified as fit for use) also needs to be readily known.

The NEMS quality codes provide information about status, degree of modification, and reliability of data. Filed comments further identify dataset origin, details of any modifications, and alert to other relevant factors such as legal constraints on dissemination, limitations of the data and cautions about use. These are designed and intended primarily for users of the data.

Some time-series software packages also include approval facilities to convey status of any period of data and help manage dissemination of data. These facilities are designed and intended primarily to assist data producers. If a more manual approach is necessary, the organisation's data processing procedures must provide for adequate tracking of the progress of any period of data through the process and should define the conditions for release of data from the various steps within the process.

For example, the following may be defined:

- raw data (as captured) published automatically direct to a website:
  - quality coded QC 0 (original non verified, raw)
  - available to the public but with disclaimers as to accuracy, and advice on how it should and should not be used
  - data subject/likely to change.
- original data that may have had initial automated checks applied (i.e. pre-processed) but are not verified by field check(s) and detailed inspection:
  - quality coded QC 0 (original non-verified)
  - if available for release will have disclaimers
  - data subject to change.
- data that cannot be fully verified (e.g. no reference instrument) but have undergone quality review in all other respects (see Section 7.2):
  - quality coded QC 200 (not assigned a final quality code)

    - if available for release will have disclaimers, and applicable metadata including explanation of quality codes
    - data unlikely to change.
- data that have been checked by a field visit, but for which some editing is not yet completed:
    - available for release with quality code of QC 200 (provisional, not assigned a final quality code), and applicable metadata including explanation of quality codes, and disclaimer
    - data likely to change.
- data that were collected, verified, processed, and archived prior to adoption of NEMS and not subsequently reviewed and/or quality coded according to NEMS
    - available for release with quality code of QC 200 (of unknown quality), and applicable metadata including explanation of quality codes, and disclaimer
    - data unlikely to change but may be subject to confirmation.
- data that have been checked by a field visit, edited, and marked as verified, but not yet passed a quality (peer) review (see Section 7.2):
    - quality coded as QC 400 or QC 500 (verified and graded) as applicable
    - available for release with quality code changed to QC 200 (provisional, not assigned a final quality code), and applicable metadata including explanation of quality codes, and disclaimer
    - data subject to confirmation.
- data that have been checked by a field visit and marked as final and verified but not yet passed an audit review (see Section 7.3):
    - quality coded as QC 400, QC 500, or QC 600 (verified and graded) as applicable
    - available for release with applicable metadata, including explanation of quality codes
    - data might be modified in future.
- verified final data that have passed the organisation's audit review process (see Section 7.3):
    - quality coded as applicable
    - available for release with applicable metadata, including explanation of quality codes
    - possibly 'certified' or 'locked', i.e. a formal process of approval must be followed to change the data in future.

3.6 Quality control

Quality control comprises inspection and testing of the data and is the purpose of the data verification process. A number of routine checks must be applied to all data collected.

Some checks may be applied as part of near real-time data publication (see Section 3.1), and some may be repeated more than once throughout the full process, including during quality review after processing is completed (see Section 7).

For data that are laboratory results, rigorous quality control is carried out by the laboratory, and data processing need only be concerned with spurious errors, usually of human origin, and ensuring correct identification, transcription, documentation, and storage of results.

For other time-series data, rigorous quality control is an essential part of data processing that must be able to also identify anomalies within the data that arise from measurement and/or recording errors, and measurement and/or recording system faults and failures. Necessary capability includes:

- comparing recorded values with field checks and verification data, and assessing tolerance within the context of conditions at site during the visit (e.g. the greater uncertainty of a staff gauge reading during a flood)
- detecting possible anomalies (such as steps, spikes, gaps, poor resolution, out of range values, noisy periods, or unusually flat or straight segments) that may occur, and possibly resolve, between site visits
- identifying missing timesteps in fixed interval data that may indicate a system fault or reset and possible data corruption or loss
- comparing the data to one or more other datasets that would be expected to show some correlation (e.g. backup or supplementary data, associated variables, adjacent or nearby station(s), adjacent catchment(s), modelled data for the same variable and period)
- access to all relevant site and time-series metadata (see Section 6 and the relevant Annex as applicable), and
- ability to review the chronological history of the above four points to identify persistent faults or failures, and bias or trend in deviations from reference values that may not necessarily be outside verification tolerances (see Appendix 1).

Problems identified must be investigated to establish plausible cause then a suitable remedy formulated and applied. Feedback must be provided where necessary to prevent recurrence (see Section 3.6.5). Editing of data must be controlled (see Section 3.8).

3.6.1 Methods

Inspection and testing for quality control may be:

- manual, carried out by skilled personnel using data plots, quality charts and/or tables, and statistical tests, or
- pre-set and/or automated, or
- implemented using some combination of manual, pre-set and/or automated functions.

Method selection should be commensurate with the:

- nature and inherent variability of the data
- frequency of site inspections
- range, frequency, and reliability of reference measurements
- availability of other reliable datasets for comparison
- available resources and skills, and
- scope and reliability of available and/or possible automation.

There is a trade-off between:

- the skills required to manually inspect and verify a record
- sufficient prior data collection and/or knowledge to establish pre-set thresholds, and
- sufficient redundancy of data collection to provide reliable comparators for automated inspection and test.

For example: simultaneous measurements from a second instrument at the same site, or of a closely correlated variable at the same site, or of the same variable at a closely correlated nearby site.

Comparisons can be made using:

- allowable percentage deviation
- range and uncertainty bounds, and
- allowable deviation for the relevant quality codes.

Inspection for anomalies, whether automated or manual, should evaluate the data giving consideration to:

- the characteristic behaviour of the variable
- the instruments and installation, when performing well and poorly
- the nature of the location, site, and measurement environment, and
- events known or suspected to have occurred.

Machine algorithms may be used:

- to identify anomalies, and
- to generate alerts for later manual review and processing, or

- as a first step to auto-processing of the data (see Section 5).

Machine algorithms must be:

- described in the organisation's data processing procedures,
- detailed in the site file and/or station history for each site, as applicable,
- controlled and tracked, with respect to changes of function and/or application, and
- subjected to regular review with outcomes documented and retained (see Section 7).

Records of all quality control inspection and testing must be permanently retained as part of the site and/or time-series metadata (see Section 6).

For illustration purposes, examples in this Standard are graphical as would be used for manual inspection and test. This does not imply that automated methods cannot be used.

Further examples and guidance specific to each measured variable may be found in the relevant Annex.

3.6.2 Data plots with time

To be effective for verification purposes, plots of data with time must display at a resolution sufficient to see all the features of the data as collected.

- Use a 1-month time scale for all initial plots, including comparison plots. Anomalies noticeable at this scale will tend to be those requiring further attention.
- Zoom and pan sufficiently to check range and continuity of shorter-term features and cycles such as peaks, recessions, drawdown and recovery, daily sine curves and tide cycles.
- Zoom to the time of each site visit to check for anomalies introduced by inspection, sampling, cleaning, sensor replacement, and other maintenance activities.
- Plot the full period of processing at full range to check for outliers and time faults, trends that may indicate drift, and changes in pattern that may be due to poor and/or declining sensor performance.
- For incremental data use bar and cumulative plots. Cumulative plots are the most useful for comparisons. Use bar plots at resolutions of:
  - the maximum recording interval, e.g. 5 minutes, to check for spurious or invalid data, unmarked gaps, and unusually erratic or similar rates, and
  - intervals consistent with expected norms and thresholds, e.g. hourly, daily, weekly, to check data range and timing of events, and trends that may be due to calibration drift.

- For comparison plots of the same variable, use:
  - a common axis to check for data range anomalies, and
  - separate axes with auto-scaling to assess patterns and detail without range of the data confusing or clouding perspective.

Note: Some graphical tools (mainly those intended for publication graphics) compress and/or resample data and may not display all features such as steps and spikes. These are not suitable displays for quality control.

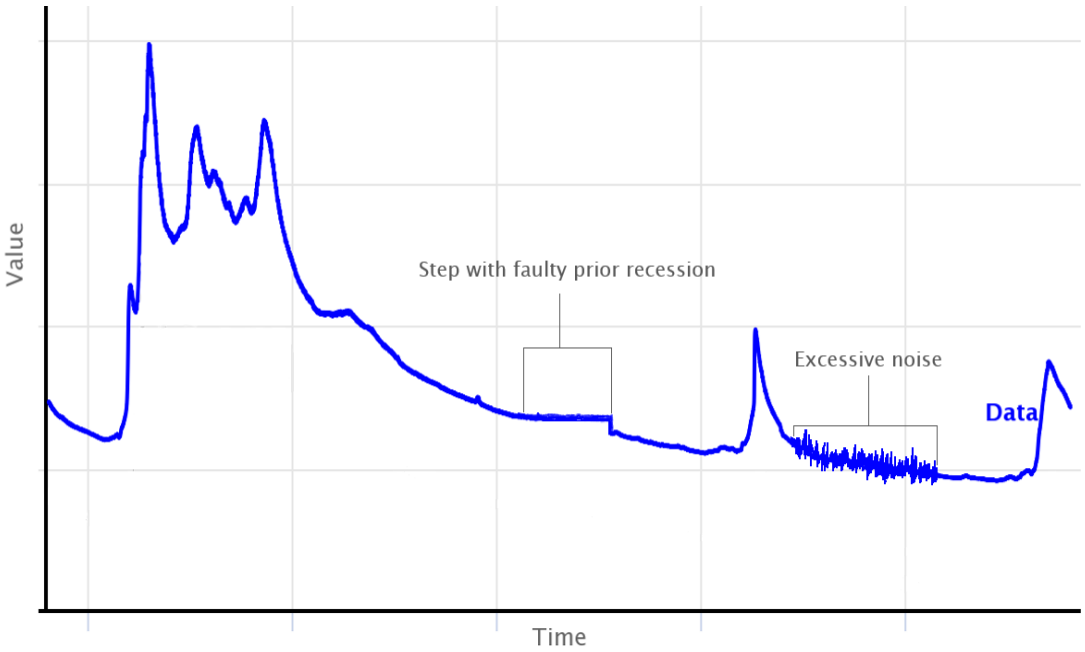


Figure 7 – A plot of stream water level showing anomalies in the data.

3.6.3 Comparisons with time

Comparisons with time are useful to identify anomalies, but they are equally useful to confirm data are reliable if there is some doubt. They are especially useful when the data collected do not conform to a typical pattern for some reason, e.g. a record of water levels below a hydro-electricity generator or downstream of a control gate.

Time of travel and attenuation must be accounted for when comparing record from stations some distance apart on the same river network.

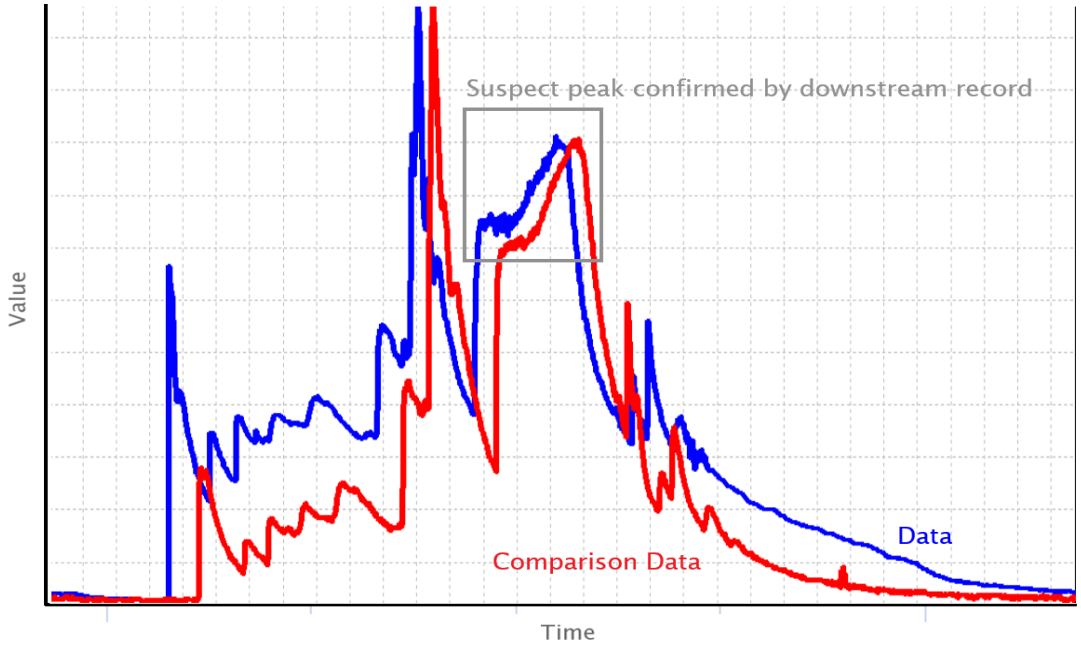


Figure 8 - A comparison with time of water levels from stations on the same river confirming that a peak suspected to be faulty record has been captured correctly.

3.6.3.1 Use of models

Output from calibrated models running in near-real time for the same site or an adjacent or a nearby site, possibly for prediction purposes, can be compared with incoming actual data for rapid quality control.

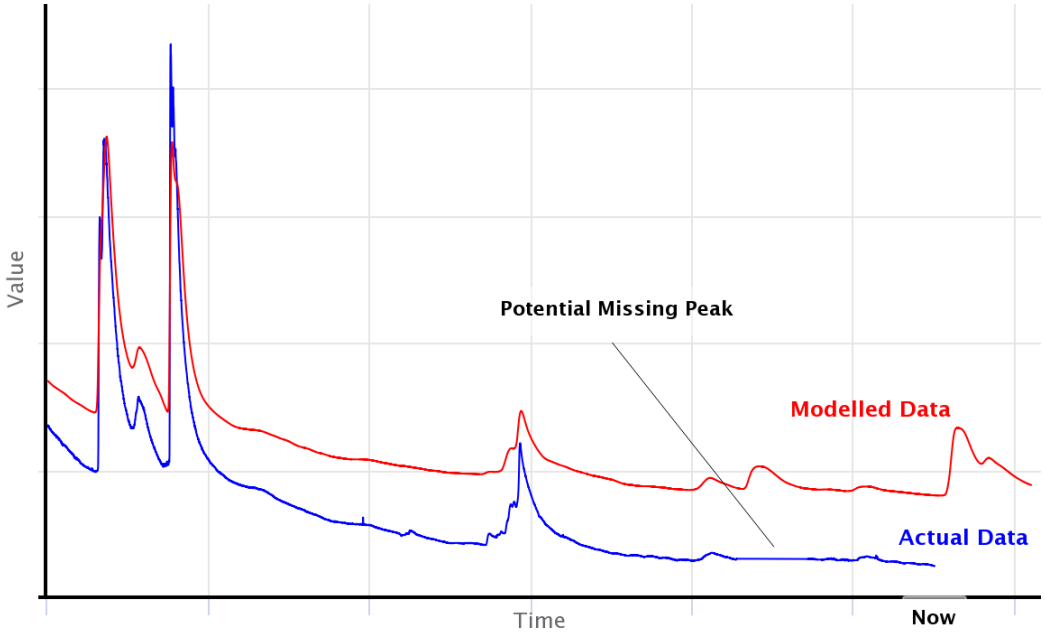


Figure 9 – Comparison plot of modelled and actual flow, for quality control purposes.

3.6.4 Examples of deviation tests

Tests of deviation of logged values from corresponding verification data include:

- direct comparison of simultaneous values (e.g. a scatter or x-y plot)
- monitoring a simplified chronological sequence of deviations (e.g. control charts, run charts, or equivalent tabulations)
- assessing deviation with time and value, to diagnose time- and range-dependent drift, respectively.

Other tests that may be useful are:

- tracking cumulative departures (e.g. cusum charts)
- mass and/or double mass analysis (more useful for investigating longer-term issues, such as stationarity, than day-to-day quality control).

Uncertainties can be incorporated if known.

Deviation tests may also usefully be compiled using the logged data from two sites.

Quality plots in the following sub-sections illustrate some of the more common tests.

3.6.4.1 Scatter plot (X–Y plot)

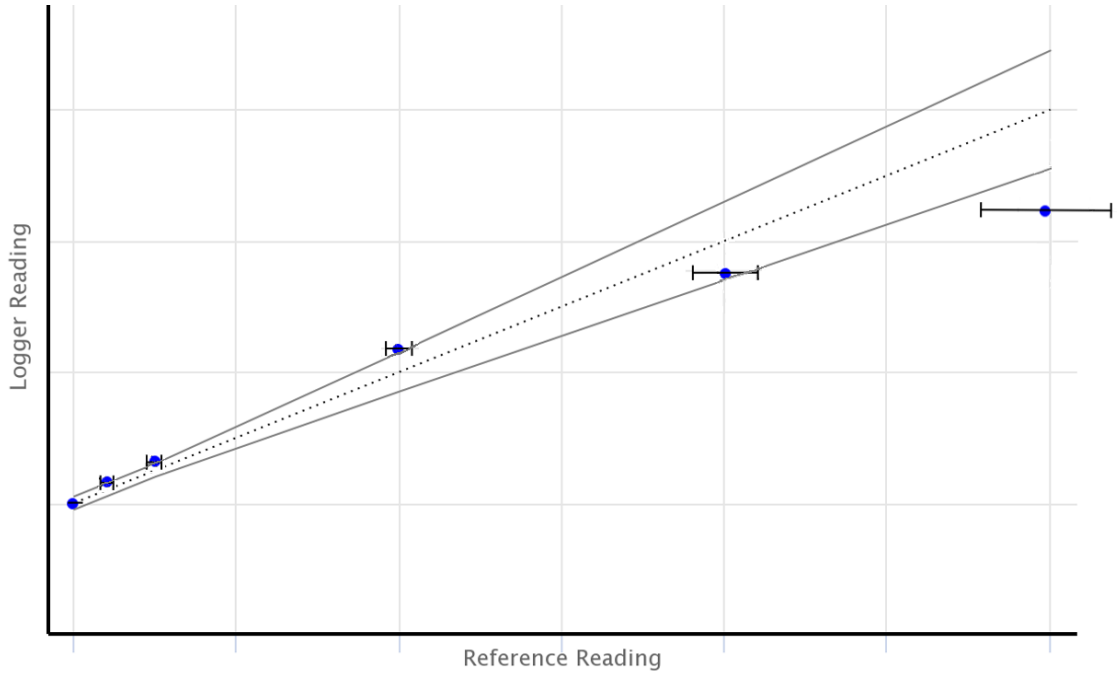


Figure 10 – Scatter plot of manual reference observations (with their uncertainty bounds) vs. logged values. The allowable tolerance envelope is shown by the solid grey lines and agreement is shown by the dotted line.

3.6.4.2 Control chart

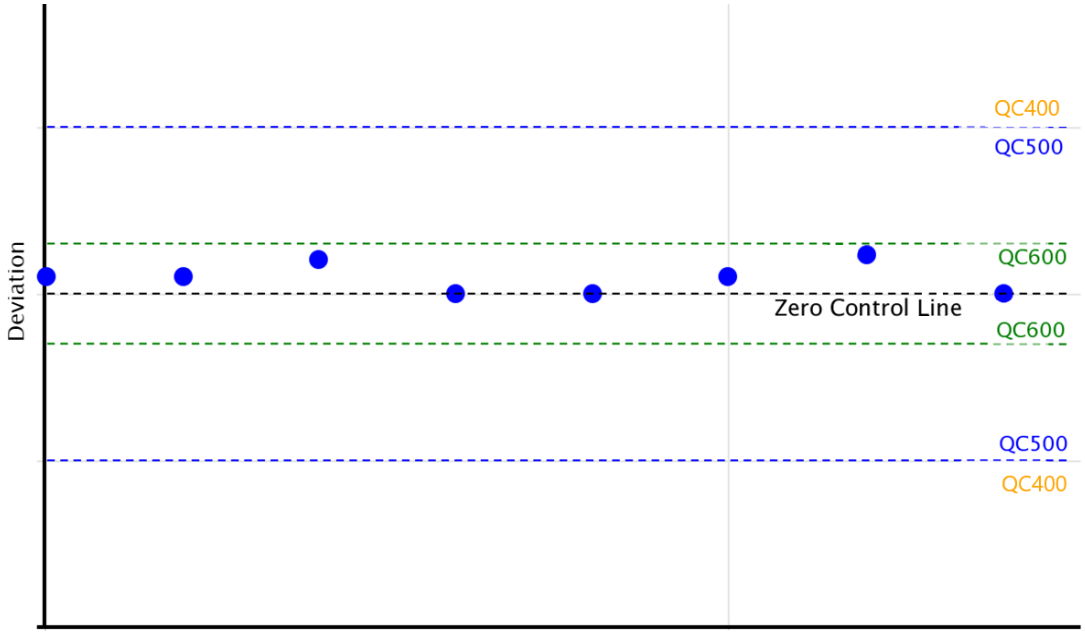


Figure 11 – A control chart for assessing the deviation of logged values from simultaneous manual reference observations. The dotted lines represent the tolerance thresholds for the various quality codes.

Control charts are a simplified form of deviation with time presentation, used to monitor a process and alert when the process may be out of control; in the case of collecting environmental time-series data that is when the variable measurement system does not return logged values that are within defined agreement of corresponding reference values.

A control chart is chronological but does not have a true time x-axis.

Indications of a process out of control are deviations outside limits and any trends, cycles, or bias whether within or outside limits. Limits may be set by Standards or by statistical thresholds such as standard deviation.

A control chart can indicate offset and drift problems but cannot inform whether drift is linear or non-linear because the chart does not use a true time axis.

For guidance on how to interpret a control chart see Appendix 1.

3.6.4.3 Run chart

A run chart is a simpler form of control chart. It does not have threshold lines and may only display the sign of the deviation, thus providing for non-parametric assessment of variation (e.g. the greater the number of changes of sign in a sequence of differences the less bias is present in the data).

Run charts may be presented as tabulations or print-plots.

3.6.4.4 Deviation with time

These can be a simple plot of differences with time or a modified control chart where the x-axis is true time.

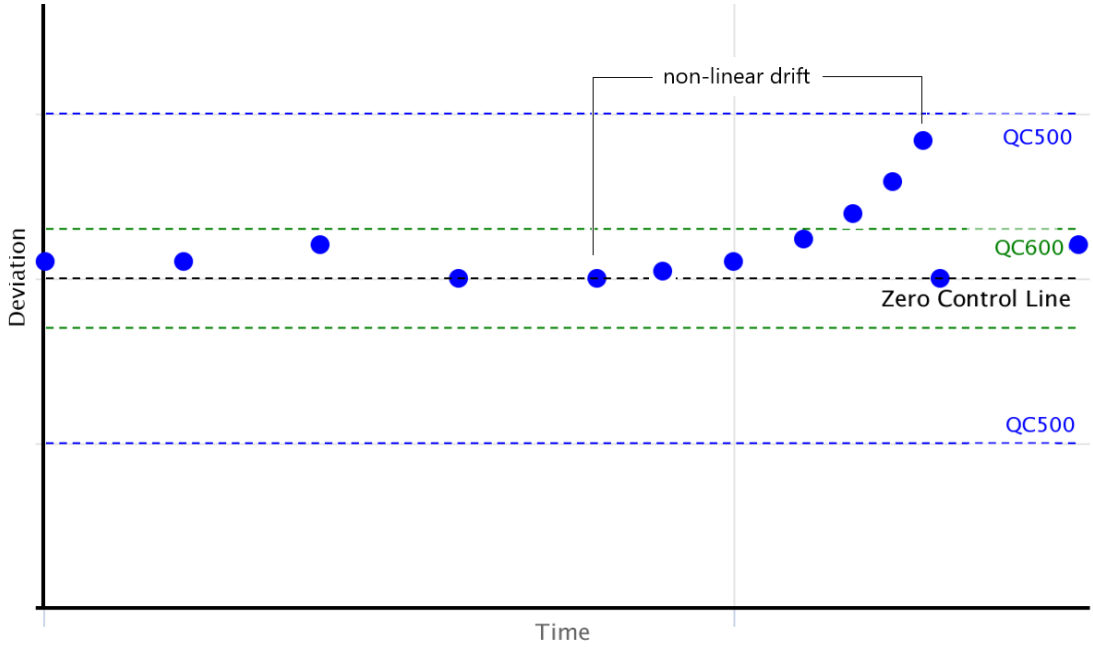


Figure 12 – Deviation with time adapted from a control chart and showing a period of non-linear drift, able to be ascertained because the x-axis is true time.

3.6.4.5 Deviation with range

This test detects range-dependent bias or drift. Deviation is calculated as sample minus reference and the sign of the difference indicates the direction of the deviation.

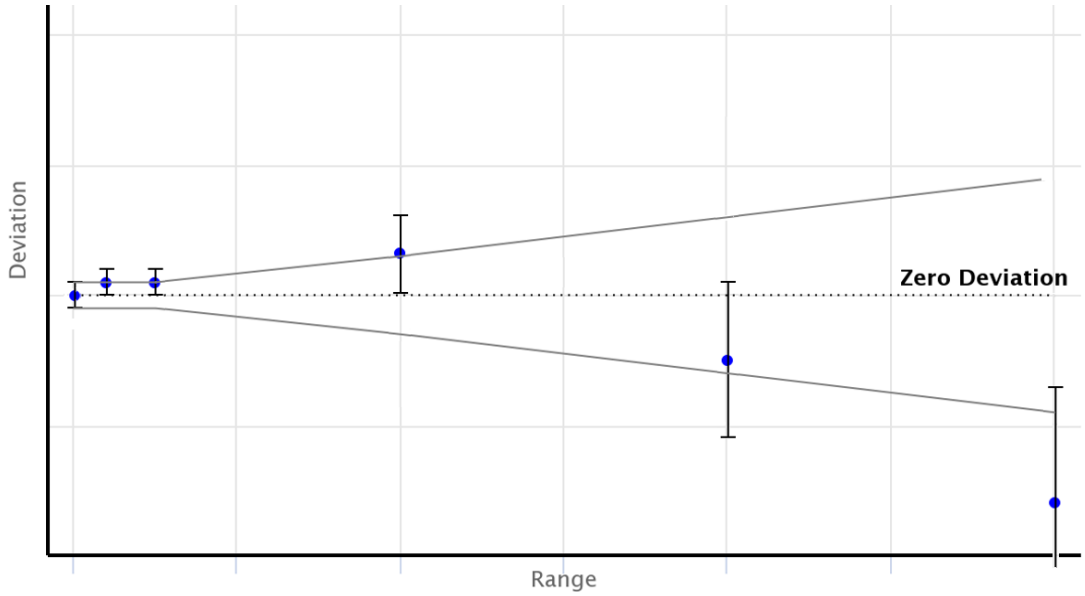


Figure 13 – Deviation of logged values from corresponding reference values (with uncertainty bars) versus the range of values. The allowable tolerance envelope is shown by the solid grey lines and agreement is shown by the dotted zero deviation line.

3.6.5 Reporting

To prevent problems recurring, feedback to the field operation must follow discovery of significant or persistent issues during data processing that have not already been identified.

Feedback may be achieved by:

- having the same staff member responsible for both site operation and processing the data collected from it, or
- team meetings, and/or
- adopting a more formal quality assurance non-conformance reporting framework.

Feedback may include:

- requests for additional checks and information (e.g. validating an instrument) before current data processing can be completed
- recommended changes at site
- recommended changes to field procedure for future data collection.

If errors are discovered in verification (field inspection) data (e.g. a wrong inspection date, survey origin, etc.) refer to Section 3.9.2.

3.7 Non-stationarity

Non-stationarity may cause discontinuities that compromise a long-term record but are difficult to quantify. Avoidance is preferred. Stationarity is formally evaluated during data audit (see Section 7.3) but should be monitored and managed during data processing.

Data collection and processing practices must record all known influences and events that may affect stationarity.

Editing actions must not disturb or disrupt stationarity already achieved. For example, undesirable practices are:

- routine adjusting of data to reference readings (see Section 5)
- unduly varying method(s) of deriving synthetic data (see Section 5.5)
- applying different methods to the same problem for different periods within the same time series (e.g. swapping between stage adjustments and rating change(s) to compensate for weed growth).

When non-stationarity is detected, the issue and its likely effects on the data must be described in a Stationarity Comment (see Section 6.2.4.9). Response to identified non-stationarity might also include:

- field actions to resolve the issue (e.g. removing obstructions or reversing instrument changes)
- transforming data to compensate for, or minimise, the effect.

If an above action has been taken, cross-reference the Stationarity Comment from the relevant Operational (see Section 6.2.4.5) and/or Transformation Comments (see Section 6.2.4.8).

3.8 Control of editing

The amount and type of editing that can be performed, and the authorisation to do this, shall be controlled within an organisation. Editing and adjustments applied to data must adhere to the principles, procedures, and operations described in Sections 4 and 5 and the relevant Annex.

The organisation's procedures shall make personnel aware that:

- a conservative approach is required, including deciding when and how much to edit data
- editing of data is controlled
- data editing needs to be done
  - in a conservative fashion
  - according to principles and requirements of this Standard, and
  - following the organisation's procedures.
- the procedures may limit an individual's authority as to what editing they may carry out without explicit approval, and
- significant changes to data must be peer reviewed.

An organisation's data processing procedures will likely change over time. Some aspects of data provenance may be related to the version of the procedures and NEMS documents being used at the time of processing. Therefore, version control of such procedures should be maintained, and which version of procedures and Standards applied at the time of processing the data should be tracked in the time-series metadata (see Section 6.2).

3.9 Evidence of modifications to data

Evidence of, and justifications for, any modifications to measured values shall be recorded in the metadata so that the entire process from raw to final verified data can be tracked and justified.

3.9.1 Modifications to the time-series data

The organisation's processes shall include, as a minimum, the following steps and records:

- a record of any modifications and transformations applied within the data logger program and, if applicable, the telemetry data software
- a record of diagnosis and description of any errors found in the data, any assumptions made when editing that data, and a description of the editing process
- timestamped comments filed as part of the metadata attached to the time series, which summarise issue(s) identified with the data and resolution of them in a standardised format and vocabulary so that meanings are clear, and
- the filed comments about data editing must include the period to which the comment applies in addition to its timestamp, the reason for making the change to the data, a summary of the evidence that confirms the validity of the change, the identity of the person carrying this out, and the date that this was done (see Section 6.2.4).

3.9.2 Modifications to verification information

It is possible for verification information to contain errors. If verification information is suspect, altered, or disregarded:

- seek confirmation of the information whenever practicable (e.g. by repeating a survey or validating an instrument)
- ensure assumptions are defensible
- record the decision in the processed time-series metadata, and with the original verification information
- ensure changes to the verification information are:
  - noted on, or included in, the original record, but not in a way that obscures or deletes the original information, and
  - annotated with date of the change and name of the person responsible for making the change
- record and store full explanation with the verification information in question, and summarise the explanation in the time-series metadata
- consider downgrading the time-series quality code for the period that would otherwise be verified by the information.

4 Types of Operations

In this section, the usual types of data manipulations performed after data collection and before final archiving, their potential benefits, and the possible risks in applying them are described. For further details specific to a particular variable, refer to its relevant Annex.

4.1 Interaction with quality code

Manipulating the data has the intended purpose of improving its reliability and usability; however, within the NEMS quality coding framework, doing so may require a reduction of quality code if the recorded data have been altered on the basis of assumptions that cannot be fully verified.

Data may be corrected for a known and fully traceable recording fault. In this case quality code is usually unaffected.

Data may be adjusted to minimise the effect of a detected recording fault, wherein assumptions are made about cause of the fault and/or what the values would have been had the fault not occurred. Minor adjustments reduce quality code to a maximum of QC 500; significant adjustments to a maximum of QC 400. Refer to Section 6.2.3 for explanation of 'minor' and 'significant'.

Operations may change the way data are stored and/or represented to better suit system limitations or desired use of the data. If value or time resolution of data is reduced, its quality code may be affected, depending on the requirements of the Standard for each variable.

4.2 Offset shift

An offset shift adds a constant positive or negative value arithmetically to every data value in a specified period.

It can be regarded as a correction if applied in response to:

- a wrongly configured instrument where all necessary parameters of the incorrect and correct configuration can be established, the incorrect configuration reversed, and the measurements recovered without doubt. In this case it is often also associated with a scaling error that must be corrected at the same time, or
- an intended, persistent, and traceable change of datum and/or recording zero.

It is an adjustment when applied to compensate for a deduced constant difference between recorded and expected values, usually associated with a spontaneous shift of physical instrument position, or a spontaneous reset to, or change of, instrument zero.

4.2.1 Potential benefits

Potential benefits of applying an offset shift are:

- eliminating an introduced error, for example, by having the sensor or logger set to the wrong recording zero, or perhaps a more convenient zero for field operations
- making the data more meaningful for a user; for example, changing stage above assumed datum to Mean Sea Level
- minimising suspected constant bias in a period, revealed by verification of the data.

4.2.2 Possible risks

Possible risks of applying an offset shift are:

- the offset applied is inaccurate because:
  - it is inferred rather than directly and independently measured
  - associated scaling error is not properly resolved
  - verification data are uncertain, unreliable, or incomplete
  - assumptions about the cause, extent, duration and/or effect of the fault are wrong
- an offset shift is inappropriate because the observed bias is not a result of a step change in the relationship between instrument and primary reference zero.

4.2.3 Effect on quality code

A correction has no effect on the quality code for most variables. An adjustment, if minor, reduces quality code to no higher than QC 500, and if significant to no higher than QC 400.

Refer to Section 6.2.3 for explanation of 'minor' and 'significant', and the individual annexes for further guidance on code selection.

4.2.4 Guidance for use

- Use when a constant bias between recorded and expected values is detected or assumed to exist. Residual variation may persist, but it should be random and within expected tolerance.
- The basis for correction should be at least as accurate as the data itself.
- Review, and revise if necessary, the quality code of the period altered.
- File a comment explaining the change and reason(s) for it.

4.2.5 Mathematics

Function: $Y' = Y + C$

Where Y' is the corrected data, Y is the original value and C is the constant (positive or negative) to be added.

4.2.6 Example

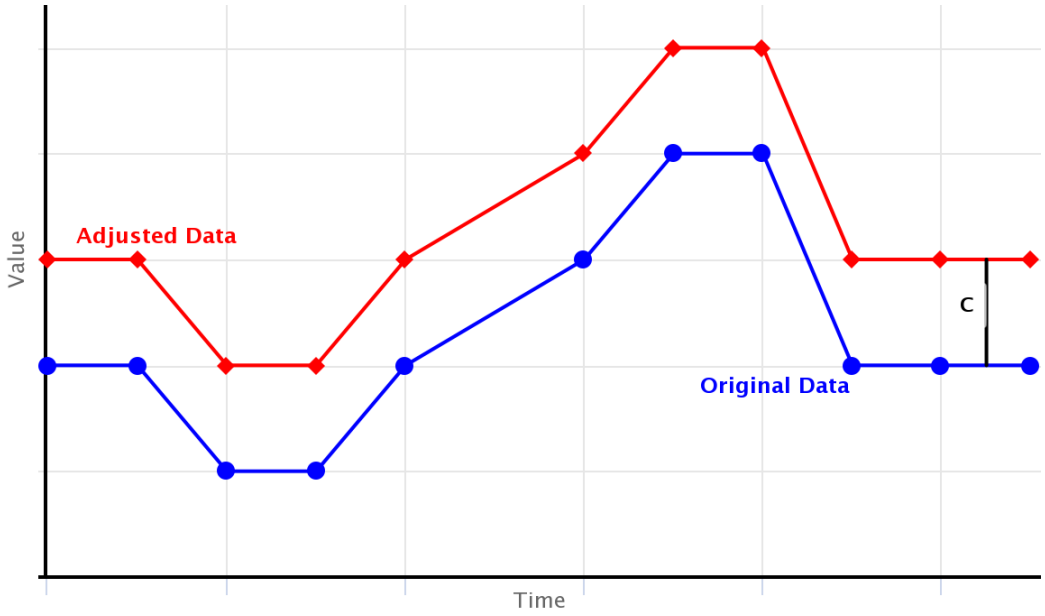


Figure 14 – Example of offset shift, where an offset, C, has been added to an entire dataset.

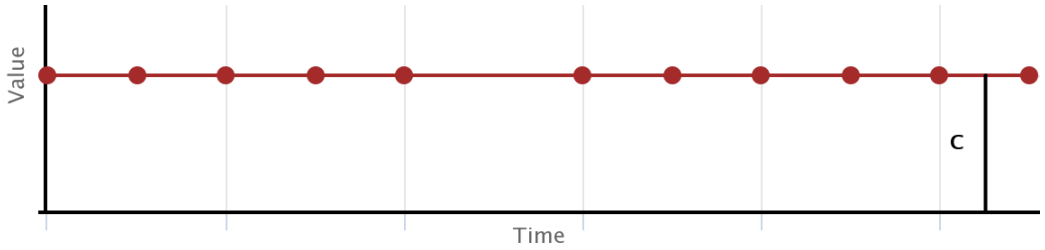


Figure 15 – Graph showing the value of the offset, C, for the shift applied in Figure 14.

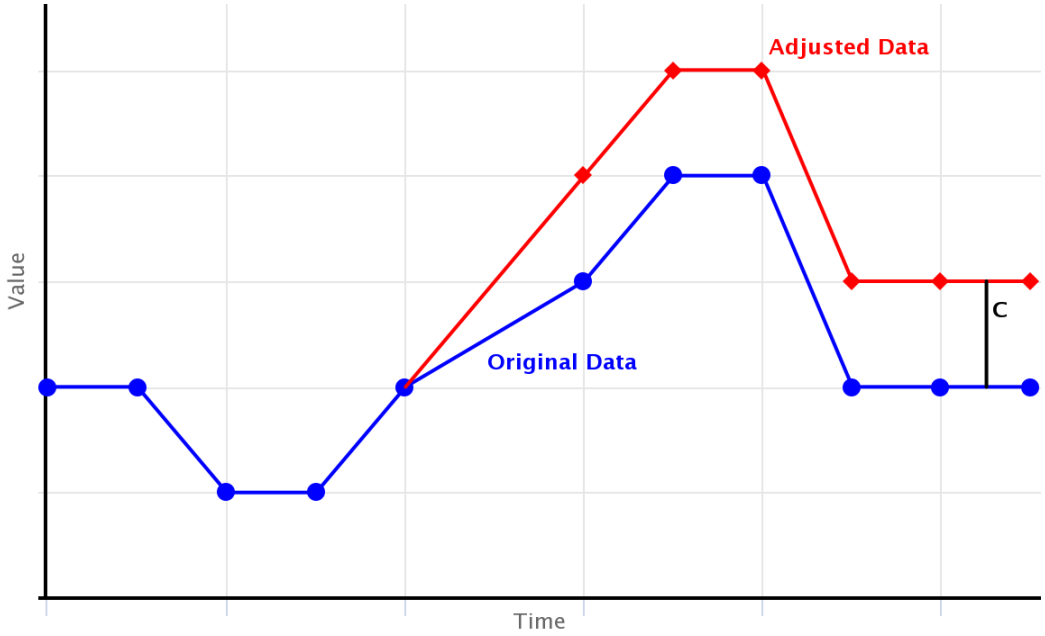


Figure 16 – Example of offset shift, where an offset, C, has been added to part of a dataset.

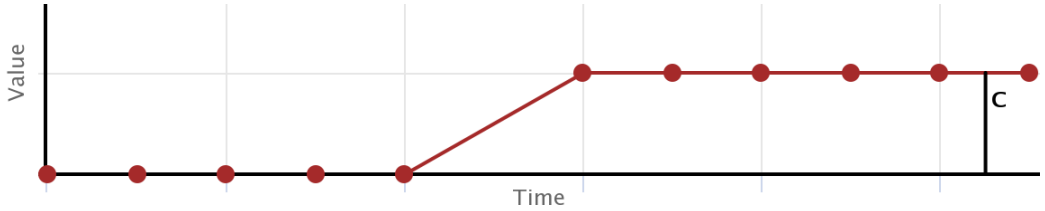


Figure 17 – Graph showing the value of the offset, C, for the shift applied in Figure 16.

4.3 Time shift

A time shift moves a period of data backward or forward in time without disturbing the duration of the data or the timesteps between the stored values.

The shift may be necessary because of:

- a change of time zone
- an incorrectly set logger start date and/or time, or
- a logger reverting to a default 'initial' date and time.

Shifts between daylight saving time and standard time are a special case because of the hour 'lost' when clocks move forward and the hour 'repeated' when clocks move back. The consequent overwriting of the hour of data recorded prior to the move back at the end of a period of daylight saving is one of the main reasons for recording all continuous time-series data in Standard Time.

4.3.1 Potential benefits

Potential benefits of applying a time shift are:

- assigning values their correct sampling dates and times
- making the data more meaningful for a user, for example, shifting from UTC to NZST.

4.3.2 Possible risks

Possible risks of applying a time shift are:

- inadvertently stretching or contracting time by, for example, not accounting properly for leap years or transitions into and/or out of daylight-saving periods
- inadvertently overwriting other data.

4.3.3 Effect on quality code

A time shift has no effect on quality code.

4.3.4 Guidance for use

- Data collected with the wrong time period assigned must be shifted to its correct time period.
- The amount of shift required must be determined from evidence that should be unequivocal.
- File a comment explaining the change and reason(s) for it.
- Suitably identify the relevant original and/or raw data as possessing wrong times (in case it is required again in the future).
- If the times needed correcting prior to import, record in the metadata that the raw data were changed prior to import, the time shift that was applied, and the reason(s) for it.

4.3.5 Mathematics

Function: $T_n = T_x + C$

Where T_n is the new timestamp, T_x is the original timestamp at time x, and C is the constant amount of time to be added (or subtracted).

4.3.6 Example

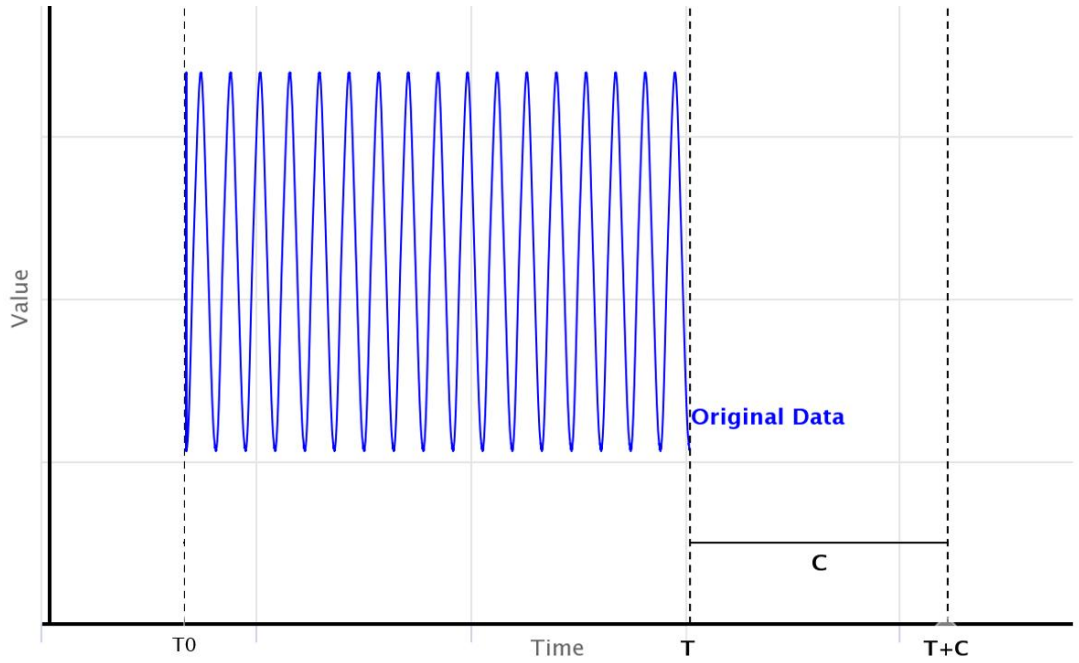


Figure 18 – Example of a time shift where the entire dataset is to be moved forward by an amount of time, C.

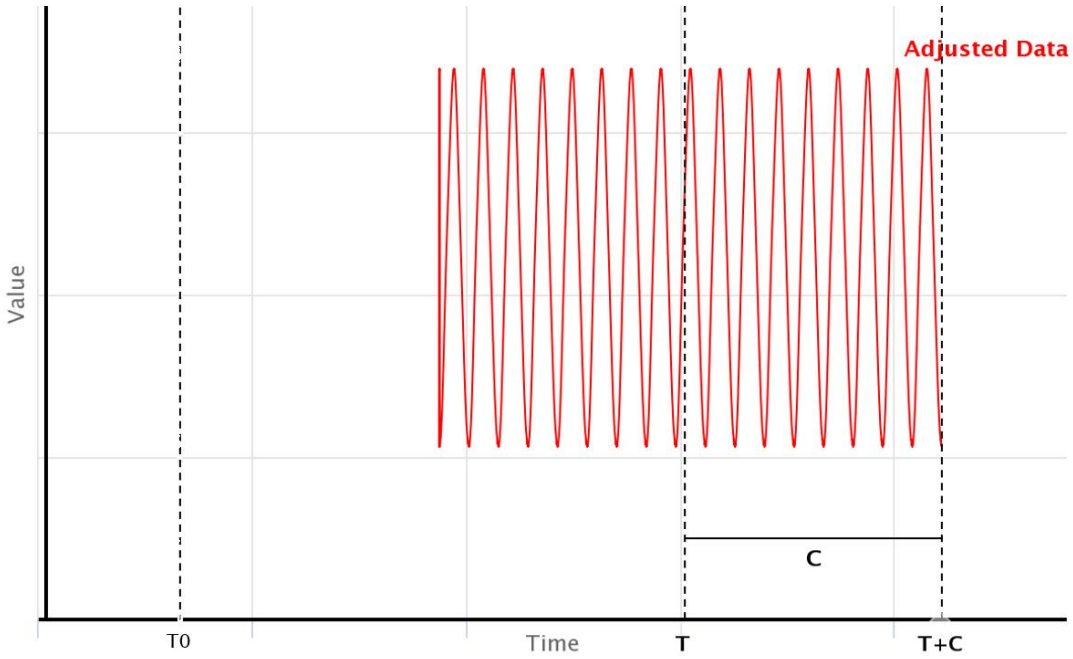


Figure 19 – Example of the result of a time shift where the entire dataset shown in Figure 18 has been moved forward by the time period, C, with all timesteps preserved.

4.4 Linear drift adjustment

A linear drift adjustment applies a progressive offset shift, where the amount of shift varies linearly with time over the period of the adjustment. The adjustment may be one- or two-tailed. A one-tailed adjustment begins or ends with zero change. The difference between original and adjusted values may increase or decrease through the adjustment period.

4.4.1 Potential benefits

Potential benefits of applying a linear drift adjustment are:

- minimising gradual apparent errors related to sensor performance, such as:
  - calibration drift
  - biofouling
  - silting
  - gradual change of base level, for example, due to deterioration of an optical sensor's lens
- compensating for periods of gradual interference, for example, weed growth affecting a flow site's control.

4.4.2 Possible risks

Possible risks associated with applying a linear drift adjustment are:

- the amount of offset applied to any value may be inaccurate because:
  - it is inferred rather than directly and independently measured
  - verification data are infrequent, uncertain, unreliable, or incomplete
  - assumptions about the cause, extent, duration and/or effect of the fault are wrong, for example, the drift is actually non-linear or the period assumed affected is wrongly identified
- while the method is used to distribute 'corrections' over a time period, it can also be considered as distributing errors
- successive adjustments to reference may distort the data due to the influence of:
  - the random uncertainty in the reference values, or
  - a large uncertainty in a single reference value due to measurement conditions, e.g. a high stage staff gauge reading.

4.4.3 Effect on quality code

If the adjustment is minor, maximum quality code is QC 500 over the period of adjustment. If the adjustment is significant, maximum quality code is QC 400 over the period of adjustment.

Refer to Section 6.2.3 for explanation of 'minor' and 'significant', and the individual annexes for further guidance on code selection.

4.4.4 Guidance for use

- Drift adjustments should be used with caution.
- Adjustment of data within tolerance should only be necessary if a step of some significance is created when the cause of the drift is resolved. For data used as a surrogate, significance is determined by the effect on the subsequent variable.
- Linear drift can be compensated for using rating curves, but only one method (rating curves or linear drift adjustment) should be used in a record, with the decision a balancing of efficiency and effectiveness.
- Review, and revise if necessary, the quality code of the period altered.
- File a comment explaining the change and reason(s) for it.

4.4.5 Mathematics

Function: $Y' = Y + C_0 + (C_1 - C_0)\left(\frac{T_n - T_0}{T_1 - T_0}\right)$

Where Y' is the adjusted value, Y is the original value, C_0 and C_1 are the offsets to be added at the start and finish times, respectively, T_0 is the start time of the adjustment, T_1 is the finish time and T_n is elapsed time since T_0.

4.4.6 Example

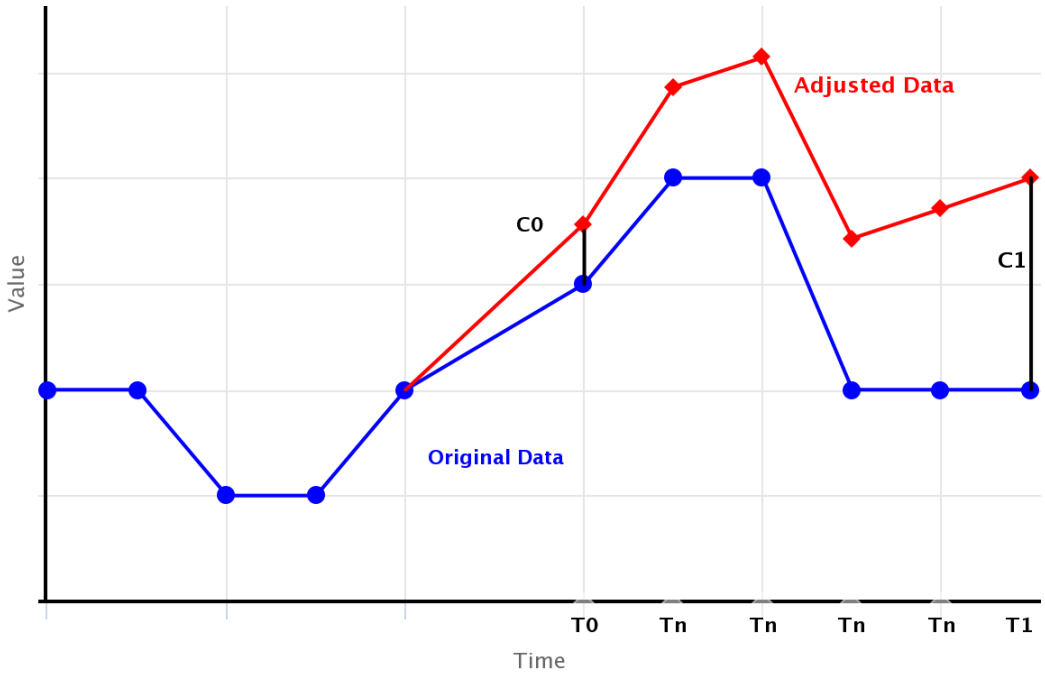


Figure 20 – Example of a two-tailed linear drift adjustment of C_0 to C_1 applied over the time period T_0 to T_1.

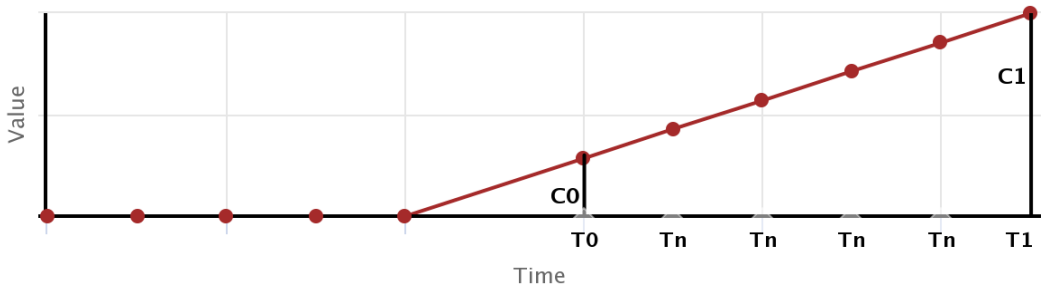


Figure 21 – Graph showing the gradually changing offset applied by the linear drift adjustment in Figure 20.

4.5 Non-linear drift adjustment

Non-linear drift with time may take many forms depending on cause and the tools available to adjust for non-linear drift differ between the time-series software used in New Zealand.

A simple but effective form of non-linear drift adjustment can be achieved by applying a progressive shift where the amount of shift is a linearly increasing or decreasing percentage of each value in the period of the adjustment (a 'percent linear' adjustment). The adjustment may be one- or two-tailed. A one-tailed adjustment begins or ends with zero change. The difference between original and adjusted values changes through the adjustment period in proportion with elapsed time and each original value, so the scale of the data is also changed.

4.5.1 Potential benefits

A non-linear drift adjustment may be more suitable for issues with some water quality sensors, and forms of biofouling or interference caused by growth of vegetation, than a linear drift adjustment.

4.5.2 Possible risks

The possible risks associated with a non-linear drift adjustment are essentially the same as for a linear drift adjustment (see Section 4.4.2).

4.5.3 Effect on quality code

If the adjustment is minor, maximum quality code is QC 500 over the period of adjustment. If the adjustment is significant, maximum quality code is QC 400 over the period of adjustment.

Refer to Section 6.2.3 for explanation of 'minor' and 'significant', and the individual annexes for further guidance on code selection.

4.5.4 Guidance for use

- Drift adjustments should be used with caution.
- Adjustment of data within tolerance should only be necessary if a step of some significance is created when the cause of the drift is resolved. For data used as a surrogate, significance is determined by the effect on the subsequent variable.
- While rating curves can apply non-linear relations, transition between ratings is linear with time so they are not a recommended alternative.
- Review, and revise if necessary, the quality code of the period altered.
- File a comment explaining the change and reason(s) for it.

4.5.5 Mathematics

Function: $Y' = Y + (C_0/100)Y + ((C_1 - C_0)/100)\left(\frac{T_n - T_0}{T_1 - T_0}\right)Y$

Where the function is the 'percent linear' example, Y' is the adjusted value, Y is the original value, C_0 and C_1 are the percentages of Y to be added at the start and finish times, respectively, T_0 is the start time of the adjustment, T_1 is the finish time and T_n is elapsed time since T_0.

4.5.6 Example

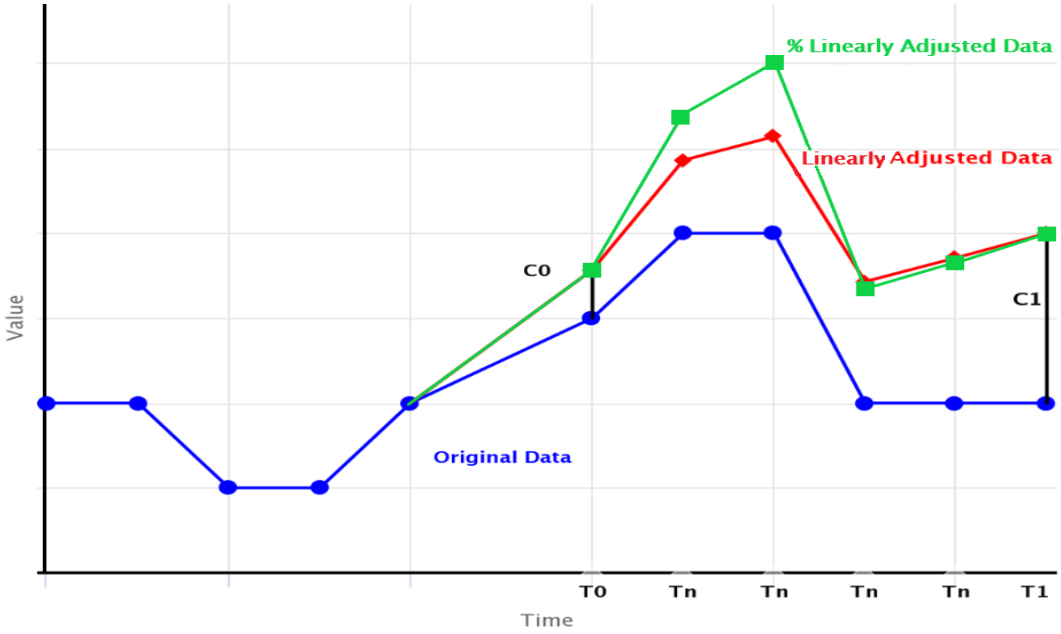


Figure 22 – Comparison of examples of two-tailed linear drift (red trace) and % linear drift (green trace) adjustments of C_0 to C_1 applied over the time period T_0 to T_1. For linear drift C_0 and C_1 are constants. For % linear drift they are percentages of the original value.

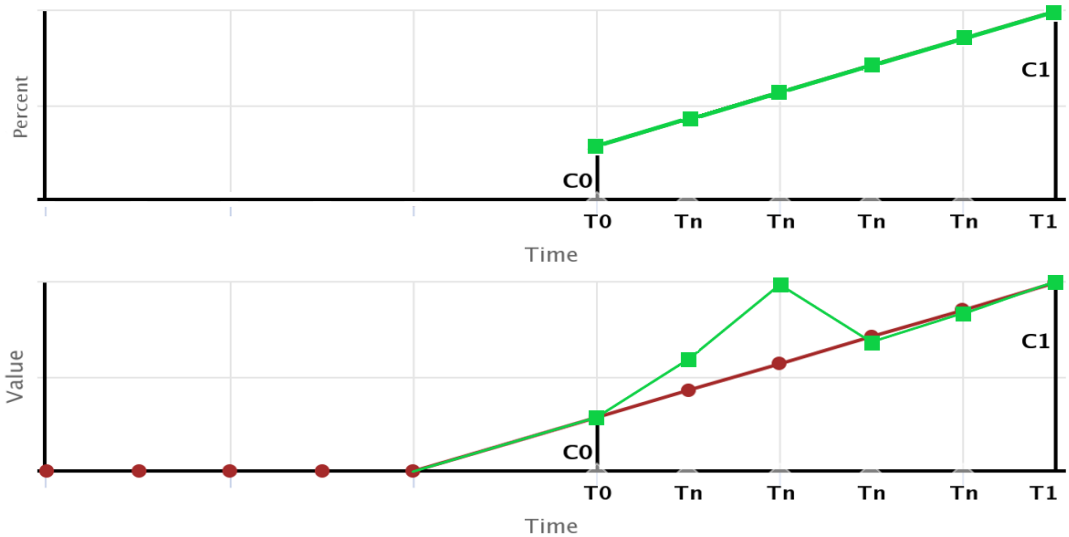


Figure 23 – Graphs showing the linear change in percentage (top) of the % linear adjustment (green trace), and its effect in terms of offset added (bottom) compared with the linearly increasing offset of the linear drift adjustment from Figure 202 (red trace).

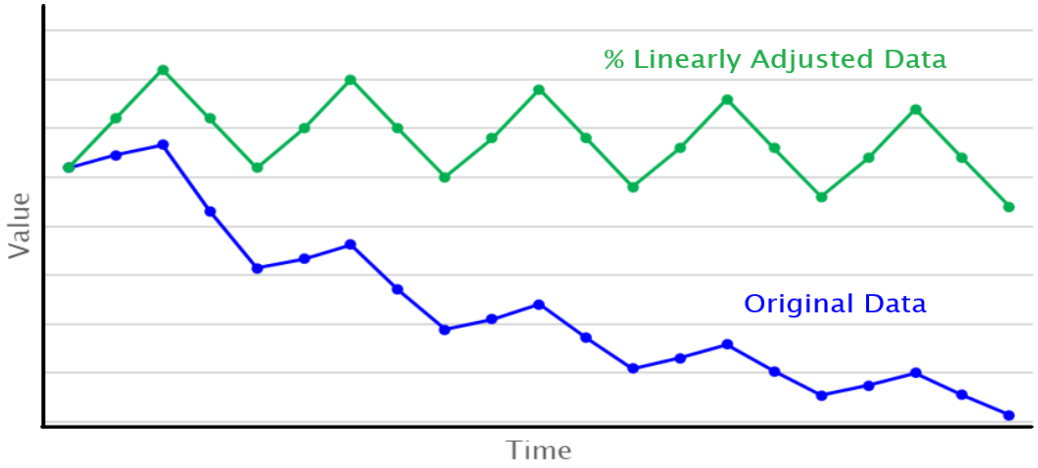


Figure 24 – Example of a one-tailed % linear drift adjustment of 0 to 200% applied over the entire dataset and showing the recovered range of the cycle.

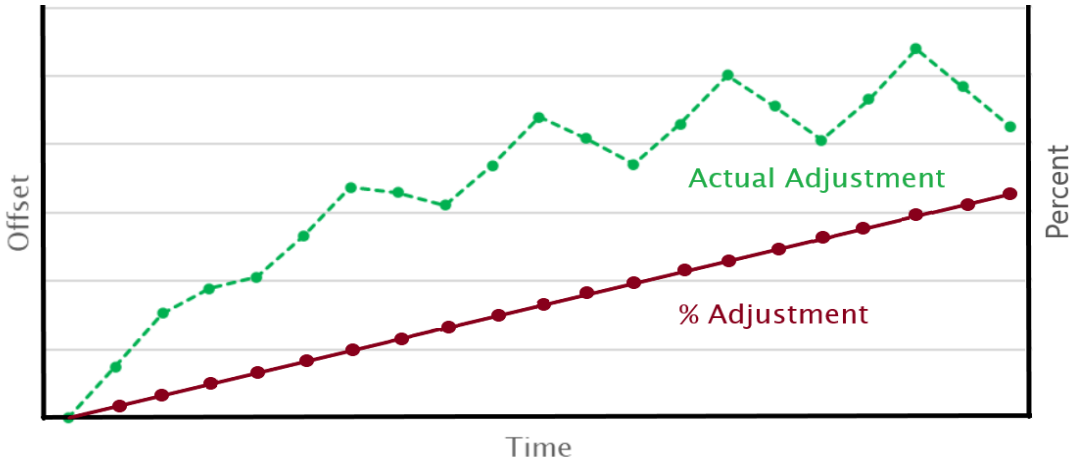


Figure 25 – Graph showing the proportional increase in the amount of actual offset applied to the original data in Figure 24 by the 0 to 200% non-linear drift adjustment.

4.6 Time drift adjustment

The time range of a dataset may be stretched or contracted. Time is altered progressively through the affected period, i.e. the amount each timestep within the period is stretched or contracted is prorated in proportion with its elapsed time since the start of the adjustment.

4.6.1 Potential benefits

'Elastic' time adjustment minimises error resulting from an instrument clock having lost time (run slow) or gained time (run fast) over the period.

4.6.2 Possible risks

Possible risks associated with time drift adjustment are:

- clock drift is rare with modern devices; it is more likely for a solid-state clock to have stopped or reset
- the method assumes the rate of drift is constant when it may not be
- if the evidence (including accuracy of reference observations) is in any way uncertain, errors may be introduced of the same order as, or greater than, the adjustment.

4.6.3 Effect on quality code

If the adjustment is minor, maximum quality code is QC 500 over the period of resulting actual time. If the adjustment is significant, maximum quality code is QC 400 over the period of resulting actual time.

Refer to Section 6.2.3 for explanation of 'minor' and 'significant', and the individual annexes for further guidance on code selection.

4.6.4 Guidance for use

- Time adjustments should be applied with caution.

  Note: NEMS requirements for accuracy of timing of measurements varies with the variable and environment. However, practically, adjusting fixed interval data for a period of clock drift that has accumulated to a discrepancy of less than one recording interval is rarely justifiable. Consequently, the need for time adjustments is effectively governed by the frequency of clock resets if a clock's timekeeping is relatively poor.

- Confirm, by comparison with another suitable record:
  - that the clock has drifted, and not stopped or reset, and
  - the period to be adjusted is correctly identified.
- Review, and revise, if necessary, the quality code of the period altered.
- File a comment explaining the change and reason(s) for it.

4.6.5 Mathematics

Function: $T_n = T_x + C * \left(\frac{T_x - T_0}{T_1 - T_0}\right) \quad T_0 \leq T_x \leq T_1$

Where T_n is the new timestamp, T_x is the original timestamp at time x, T_0 is the start time of the period to be adjusted, and T_1 is the original finish time. C is the amount of time correction required between the actual and original finish times.

Note: In the Figure 26 example, the value of C is negative, thus the original finish time is brought back by the value C to the actual finish time.

4.6.6 Example

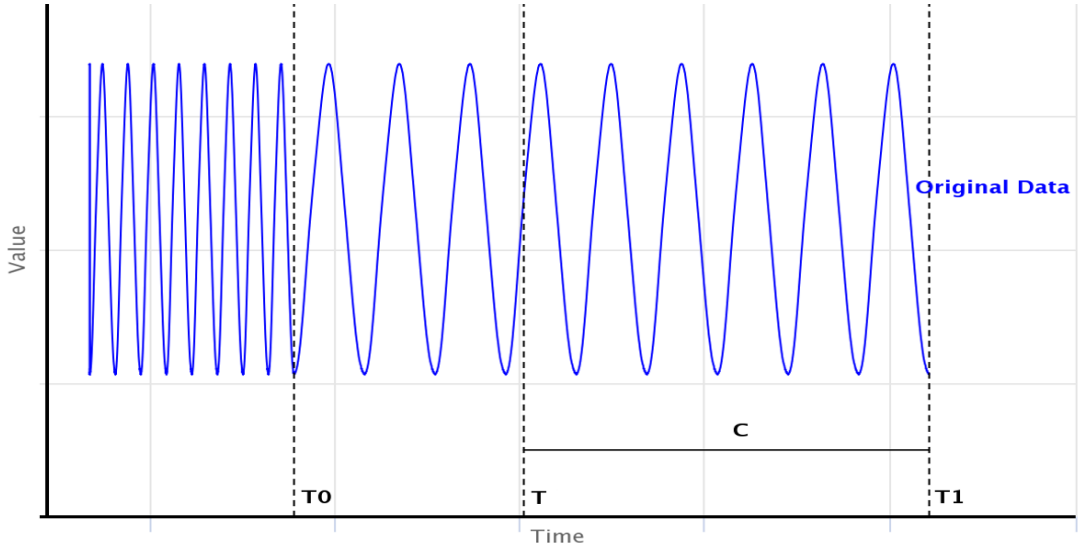


Figure 26 – Example of time drift where a clock has run fast between T0 and T so the apparent end time is T1, or when part of a dataset has been erroneously stretched. The period T0 to T1 needs to be contracted by the overall amount of time C.

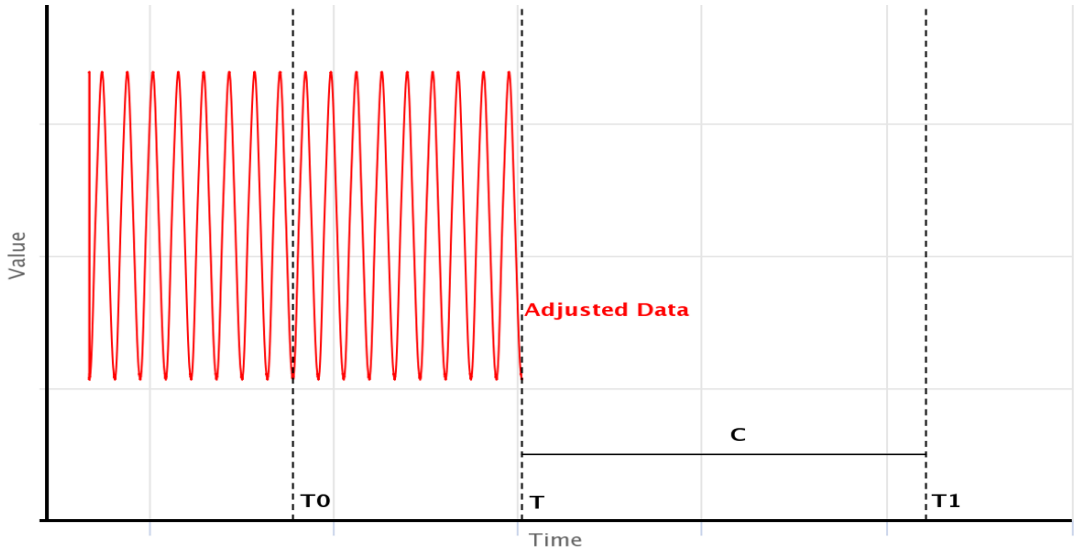


Figure 27 – Example of a time drift adjustment where the stretched data in Figure 26 have been contracted by the overall amount of time C.

4.7 Linear transformation

Linear transformation alters each value in a specified period according to a linear relationship that is applied to every value in the series.

It can be regarded as a correction if applied:

- in response to a wrongly configured instrument where all necessary parameters of the incorrect and correct configuration can be established, the incorrect configuration reversed, and the measurements recovered without doubt. In this case it is often also associated with an offset error that must be corrected at the same time, or
- to convert between units or variables where there is a direct physical relationship that is not subject to assumptions and/or approximations.

4.7.1 Potential benefits

Potential benefits of and situations for applying a linear transformation are:

- rescaling data, such as to recover data collected from an incorrectly configured sensor
- converting data units, e.g. from imperial to metric
- reducing errors introduced by a shift in a sensor's calibration that has not also resulted in a loss of its linear response
- converting from a surrogate variable to the variable of interest, e.g. water pressure to water level, or resistance to conductivity.

  Note: this conversion may be done within an 'intelligent' logger or sensor.

4.7.2 Possible risks

A linear transformation may introduce error if:

- the relationship applied is in any way approximate
- the underlying relationship is actually non-linear, and/or
- the relationship is transferred as rating curve point-pairs between different time-series management systems (see Section 5.2.2, 'Exchanging a Rating between Software' in NEMS Rating Curves).

  Note: To be transferable between different systems without risk, relationships must be explicitly defined and applied using equations.

4.7.3 Effect on quality code

- A correction has no effect on the quality code for most variables.
- An adjustment, if minor, reduces quality code to no higher than QC 500, and if significant to no higher than QC 400.
- If the Rating Curve engine is used, the quality code of the transformed data is the lesser of the input series and the quality code(s) assigned to the relation.

Refer to Section 6.2.3 for explanation of 'minor' and 'significant', and the individual annexes for further guidance on code selection.

4.7.4 Guidance for use

- The basis for correction should be at least as accurate as the data itself.
- In the case of a wrong instrument configuration the offset (constant C in Section 4.7.5) will also usually be affected by the scaling error and require recalculation in terms of the new data range.
- A linear transformation may be applied using the Rating Curve engine in some software and is often the best method for 'best fit' relations and/or those required continuously but that may vary over time.
- Review, and revise if necessary, the quality code of the period altered.
- File a comment explaining the change and reason(s) for it.

4.7.5 Mathematics

Function: $Y' = mY + C$

Where Y' is the new value, Y is the original value, m is the multiplier (slope of the line), and C is the constant to be added, if applicable.

4.7.6 Example

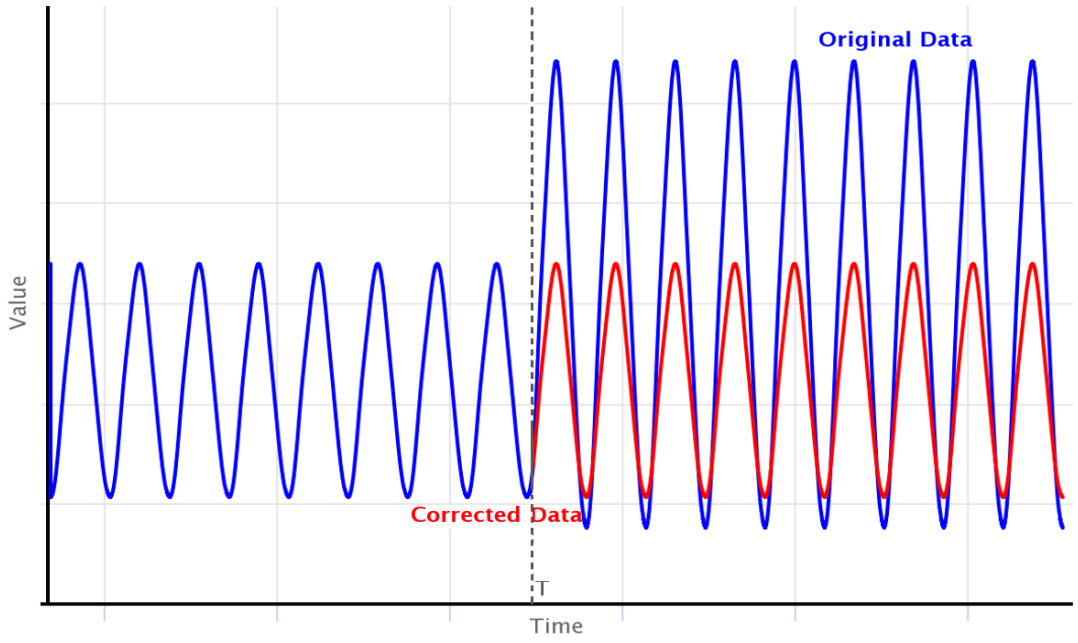


Figure 28 – An example of a linear transformation applied to data where the sensor was configured with an incorrect multiplier (and offset) at time T. The red line is the corrected data.

4.8 Change of data increment

This is a special case of a linear transformation specific to incremental (total in interval) quantities, where only the scale of the data is changed, usually to adjust the total recorded in a specified period to a corresponding primary reference gauge total.

This transformation changes the nominal resolution of the data.

4.8.1 Potential benefits

Potential benefits of and situations for applying a change of data increment are:

- compensating for factors that affect recording but are not addressed by instrument calibration, e.g. orifice height of a rain gauge
- rescaling data, e.g. if a tipping bucket gauge pulses only on one side
- minimising the effect of an incremental sensor's loss of calibration.

4.8.2 Possible risks

Possible risks of applying a change of data increment are:

- it assumes instrument calibration issues affect all data in a period the same way and to the same extent
- it has the potential to transfer unidentified error in a reference gauge total to the time-series record.

4.8.3 Effect on quality code

Quality codes for variables to which this transformation is applied are determined by the deviation of recorded from reference. Transformation of the data to compensate for the deviation does not subsequently change that quality code.

Refer to the relevant normative references and individual annexes for further guidance on code selection.

4.8.4 Guidance for use

This adjustment is required for all rainfall records where associated primary reference gauge totals are available and reliable.

4.8.5 Mathematics

Function: $Y' = mY$

Where Y' is the adjusted increment value, Y is the original value, and m is the multiplier to be applied to each increment. Usually, the multiplier is a factor equal to primary reference gauge total divided by recorded total.

4.8.6 Example

Table 2 – Example of change of data increment.

Period		Total Rainfall (mm)		Increment (mm)	
From	To	Recorded	Reference	Nominal	As filed
1/01/2011 17:15:00	19/03/2011 19:00:00	291	270	0.5	0.464
19/03/2011 19:00:00	17/10/2011 16:00:00	1561	1630	0.5	0.522
17/10/2011 16:00:00	31/12/2011 19:00:00	474	450	0.5	0.475

Also see Annex B 'Rainfall Data Processing', Figure B 5.

4.9 Non-linear or multi-variable transformation

Non-linear transformation alters each value in a specified period according to a non-linear relationship that is applied to every value in the series. Variable conversions described by power equations and complex equations to minimise the effect of non-linear calibration drift are examples of non-linear transformations.

Multi-variable transformations include secondary measurements as input to the function(s) applied to the time series. A common application in environmental data processing is compensation of a record for temperature and/or pressure.

Transformation can be regarded as a correction if applied:

- in response to a wrongly configured instrument where all necessary parameters of the incorrect and correct configuration can be established, the incorrect configuration reversed, and the measurements recovered without doubt, or
- to convert between units or variables where there is a direct physical relationship that is not subject to assumptions and/or approximations.

4.9.1 Potential benefits

Potential benefits of applying a non-linear or multi-variable transformation are:

- recovering data collected from an incorrectly configured sensor
- converting data units, e.g. dissolved oxygen (DO) concentration to saturation
- reducing errors introduced by the loss of a sensor's calibrated linear response
- converting from a surrogate variable to the variable of interest, e.g. absolute to gauge pressure, then to head of water.

Note: These conversions may be done within an 'intelligent' sensor or logger and may be multi-variable, such as conversion of DO concentration to DO% saturation, which involves water temperature and barometric pressure, or barometric compensation of absolute pressures to obtain gauge pressures.

4.9.2 Possible risks

A transformation may introduce error if the relationship is:

- inappropriate
- in any way approximate
- multi-variable and/or multi-step, with each additional variable or calculation step adding its uncertainty to the overall uncertainty, and/or
- transferred as rating curve point-pairs between different time-series management systems (see Section 5.2.2 'Exchanging a Rating between Software' in NEMS Rating Curves).

  Note: To be transferable between different systems without risk, relationships must be explicitly defined and applied using equations.

4.9.3 Effect on quality code

- A correction has no effect on the quality code for most variables.
- An adjustment, if minor, reduces quality code to no higher than QC 500, and if significant to no higher than QC 400.
- If the Rating Curve engine is used the quality code of the transformed data is the lesser of the input series and the quality code(s) assigned to the relation.

Refer to Section 6.2.3 for explanation of 'minor' and 'significant', and the individual annexes for further guidance on code selection.

4.9.4 Guidance for use

- The basis for correction should be at least as accurate as the data itself.
- Non-linear transformation is often relatively complex and not obvious from comparison of the transformed data with the original version, so data provenance and traceability are crucial and must be fully documented in the data processing records.
- A non-linear transformation may be applied using the Rating Curve engine and is often the best method for 'best fit' relations and/or those required continuously but that may vary over time.
- Transformations should be applied carefully and checked, preferably by a peer.
- Review, and revise if necessary, the quality code of the period altered.

- File a comment explaining the change and reason(s) for it.

4.9.5 Mathematics

Function: often power equations of the form $Y' = cY^m$

or of rational form, for example $Y' = cY/(1-Y)$

Where Y' is the new value, Y is the original value, m is an exponent, and c is a constant, if applicable.

or multi-variable, for example $P_g = P_{abs} - P_{atm}$

Where P_g is gauge pressure, P_{abs} is absolute pressure and P_{atm} is atmospheric pressure.

4.9.6 Example

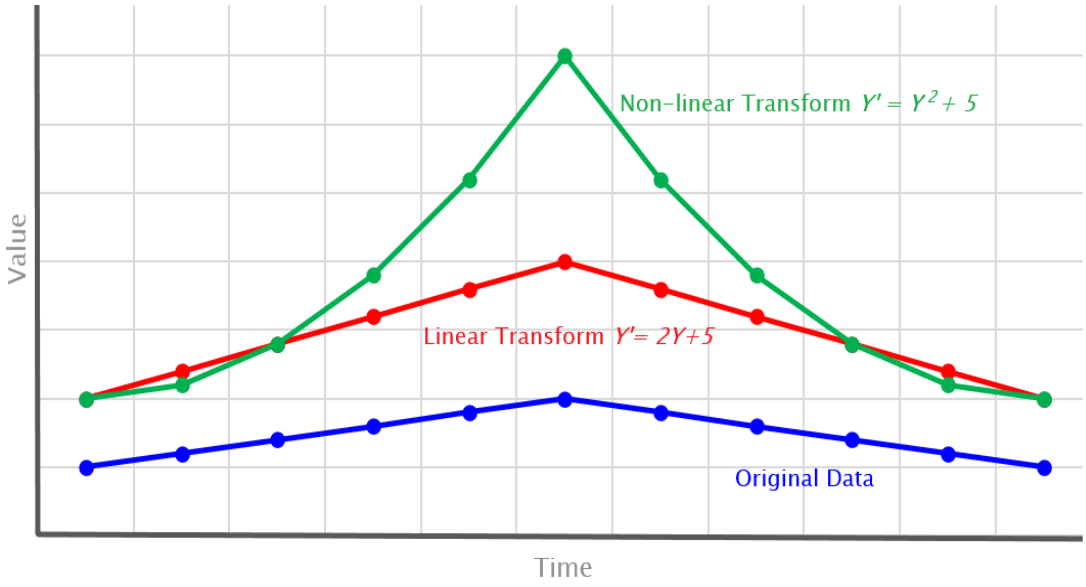


Figure 29 – An example of the difference between a linear and non-linear transformation applied to data. A linear transformation alters the scale of data but preserves its 'shape'.

4.10 Transitioning between transformations

The transformations required, for example to adjust for calibration drift or to convert a surrogate variable, may themselves vary with time, in which case it will be necessary to apply a new transformation at some time. If this is done at an instant in time it may create a step in the transformed data. To avoid this, a gradual transition between each successive transformation may be applied. This is most efficiently and effectively achieved using the Rating Curve engine, or similar functionality where that is provided in the software.

Refer to the NEMS for the variable, and/or NEMS Rating Curves, and software manuals and user guides as applicable.

Note: The method for defining a transition period differs for each of the recognised TSM's.

4.10.1 Potential benefits

Transitioning between transformations:

- allows gradual transition between different transformations over time where they must be applied continuously
- avoids a sudden change between successive transformations, which may create a step in the transformed data.

4.10.2 Possible risks

Beyond the risks associated with the transformations themselves (see Sections 4.7 and 4.9):

- selection of the time period for transition and duration of the transition has a large influence on the resulting transformed time series
- the transitions are complex to calculate and are error prone if not implemented using the Rating Curve engine (or similar functionality where that exists in the software)
- the Rating Curve engine transition method is pro-rata with time, which may not be appropriate or accurate in every instance
- transitioning between ratings can be configured to act the same way in any of the time-series management systems used in New Zealand but interpolation of curves may differ, so exchanging ratings between systems may produce different results (see Section 5.2.2, 'Exchanging a Rating between Software' in NEMS Rating Curves).

Note: To be transferable between different systems without risk, relationships must be explicitly defined and applied using equations.

4.10.3 Effect on quality code

Maximum quality code for periods in transition is the lower of the quality code assigned to the transformed data or QC 500.

4.10.4 Guidance for use

- The basis for transitioning should be scientifically defensible.
- Periods of transition should be selected with care, and based on sound assumptions such as whether the new relationship is the consequence of continual drift or an identifiable event.
- Transformations should be applied carefully and checked, preferably by a peer.

- The method applied should be consistent throughout the time series.
- All periods of transition must be identifiable to an end user beyond assignment of quality code, e.g. provision for listing the dates and times of transition periods, or filing of a comment for each period.
- Review, and revise if necessary, the quality code of the transition period.
- File a comment explaining the method applied, reason(s) for it, and assumptions made.

4.10.5 Mathematics

For a transition from time T_0 to time T between two ratings f_1:U→R and f_2:U→R, to compute a value of R, given a value of $U_{(x)}$ at time $T_{(x)}$ during the transition:

Proration with time $\quad p = (T_{(x)} - T_0)/(T - T_0) \quad T_0 < T_{(x)} < T$

then: $\quad R = [(1-p) \times f_1(U_{(x)})] + [p \times f_2(U_{(x)})]$

4.10.6 Example

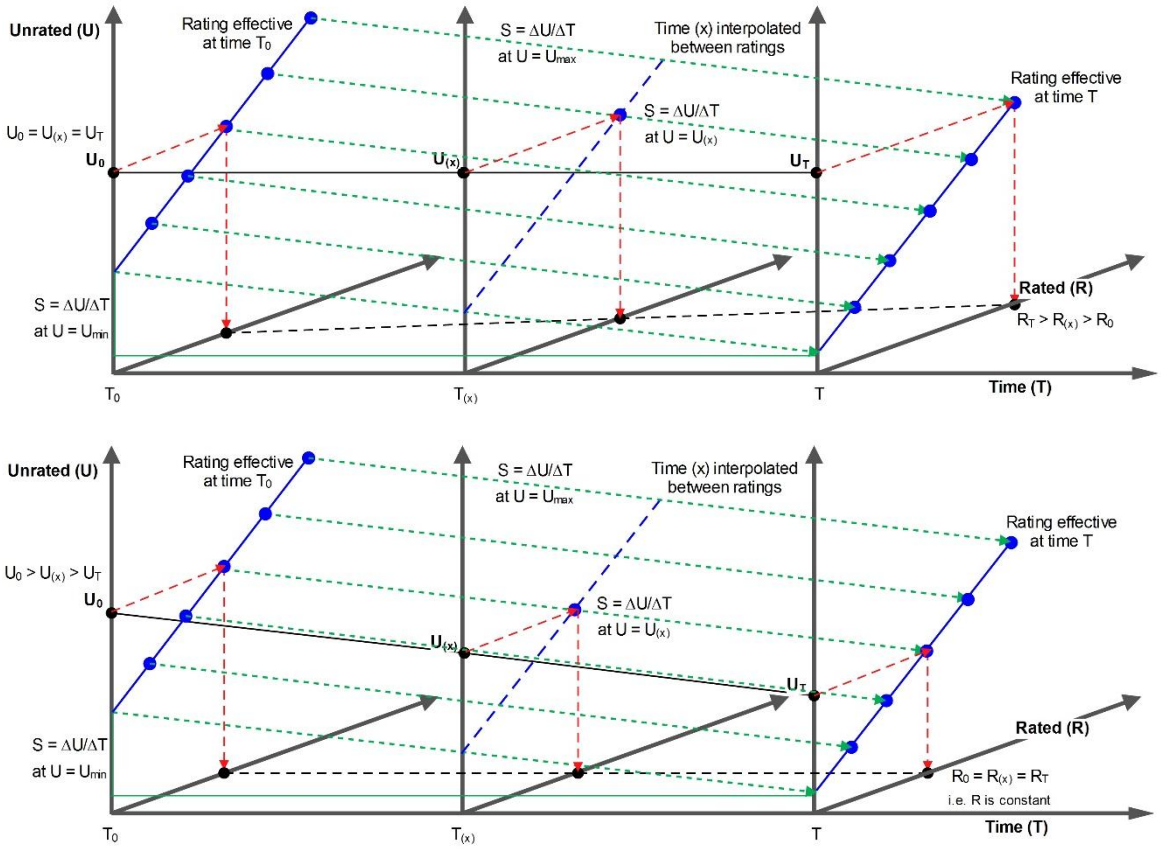


Figure 30 – An example of a transition between two ratings effective at times T_0 and T that are offset but parallel. Linear ratings are shown for simplicity, but they could be parallel curves. The interpolation slope (S) between the ratings is the same throughout their range i.e. no rescaling is applied, only a gradual increase in offset (negative in this case). Transition between offset parallel ratings has the same effect as a linear (baseline) drift adjustment applied over the same time

period, but a virtual 'rated' time-series is created instead of permanently altering the 'unrated' data.

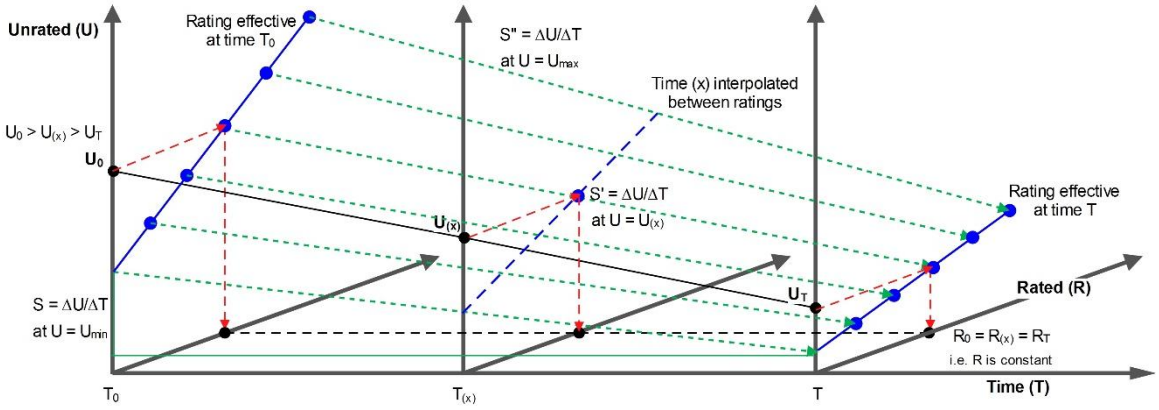


Figure 31 – An example of a transition between two ratings effective at times T_0 and T that are offset and of differing scale. Linear ratings are shown for simplicity, but they could be complex curves. The interpolation slope (S) between the ratings varies through their range. Gradual transitions between complex non-linear relations can be achieved. A virtual 'rated' time-series is created instead of permanently altering the 'unrated' data.

4.11 Spike removal

Spikes are values that are implausibly high or low compared with the values either side.

If due to fault or failure of electronics they will often be zero, the value of the sensor's current offset or full range default, or the null value assigned to a loss of signal (e.g. a NAN), but other causes will not be so definitive.

4.11.1 Potential benefits

Potential benefits of spike removal are:

- eliminating values that would otherwise skew the results
- minimising the effects of instrumentation faults
- minimising the effect of sporadic interferences in the environment, e.g. drifting debris catching on a sensor
- making the data more sensible and usable.

4.11.2 Possible risks

Possible risks associated with spike removal are:

- if assumptions about values not being 'real' are incorrect, valid values may be removed
- data of significance may be discarded
- significant amounts of data may be, possibly unjustifiably, discarded
- automatic spike filtering may delay identification of a developing instrument failure, or mask persistent interference that could be mitigated or eliminated at site.

4.11.3 Effect on quality code

- Removing known spurious data, such as values logged during a validation, has no effect on quality code.
- Replacing values, if the editing is minor, reduces quality code to no higher than QC 500, and if significant to no higher than QC 400.
- Deleting values with subsequent interpolation must be assigned a quality code of QC 300 for the modified period if:
  - duration is more than a few recording intervals (i.e. considered to be a synthetic record)
  - the frequency of spikes removed is high compared with data retained (i.e. considered to be 'estimated from limited measured data').

Refer to Section 6.2.3 for explanation of 'minor' and 'significant', and the individual annexes for further guidance on code selection.

4.11.4 Guidance for use

Whether to delete or replace the value(s) depends on:

- the variable and data type
- knowledge of the recording system,
- the need to retain regular timesteps, and
- frequency of occurrence of the spikes.

If deleted, it is usually valid and sufficient to allow interpolation across the interval between the valid values either side. However, if preservation of the timestep is integral to the data, such as for a 'value in interval' data type, or if frequent users of the data require it at regular fixed intervals (e.g. if exported to spreadsheet or served to a website), edit the value to retain its timestamp.

If the spikes are very frequent, treatment as for noisy data is required.

Spike removal can be tedious and is often semi- or fully automated. If future reference to unmodified data is possible it may be sufficient to keep a count of the spikes removed in a period. If future reference to unmodified data is not possible then spike removal must be fully traceable, for example by maintaining a log of values removed that is compiled and included with the permanent processing metadata.

- Review, and revise if necessary, the quality code of the transition period.
- File a comment explaining the method applied, reason(s) for it, and assumptions made.

Comments may be aggregated if repetitive to avoid overwhelming the comment file.

4.11.5 Example

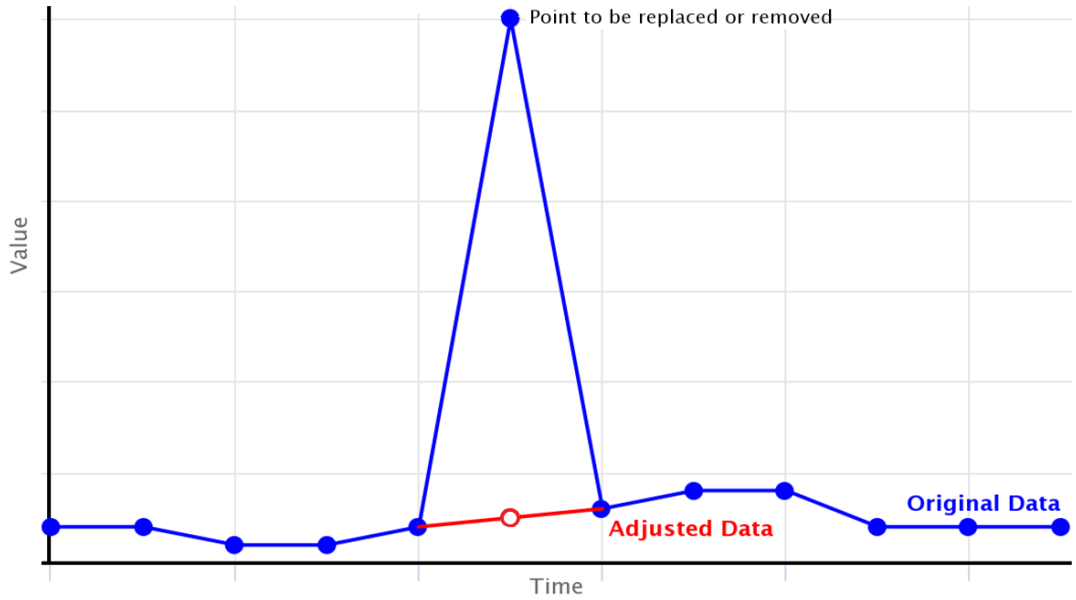


Figure 32 – Example of a spike that may be replaced (by the red circle) or removed with interpolation then connecting the values either side (red line between blue dots).

4.12 Filtering or resampling noise

Some datasets exhibit unacceptable noise that obscures the meaningful data. All or part of a time series may be filtered or resampled to reveal a signal more representative of the measured variable.

Noisy data, when graphed, appear 'furry' or have a 'fatter' trace than unaffected periods. Noise can arise from a variety of situations, including the actual behaviour of the quantity being measured, i.e. it may be 'real' but still be an undesirable feature of the record. Understanding the cause(s) of the noise, the normal behaviour of the quantity being measured, and the purpose of the data is essential to deciding if, when, and how to edit it.

4.12.1 Potential benefits

Potential benefits of filtering or resampling noise are:

- improving presentation of the data, i.e. the data look more sensible when graphed, especially to a person unfamiliar with the measurement process
- avoiding incorrect conclusions being drawn about what the variability represents
- minimising the effects of noise caused by interference or faulty equipment, e.g. electrical or radio interference, insufficient power supply, accumulation of debris, or instrumentation about to fail
- not transferring and possibly amplifying noise in a surrogate variable's measurements to the target variable's time series. For

example, to be reliable, determination of flow using rating curves requires a static water level free from the influence of wind, waves, and pressure variations.

4.12.2 Possible risks

Possible risks associated with filtering or resampling noise are:

- the modified data appear to have greater accuracy than is real
- masking certain values may disguise errors that could otherwise be detected
- moving averages can induce significant hysteresis in the modified data
- removing information that may be useful for other purposes, e.g. wave lap in a water level record may compromise determination of volume or flow but be useful for erosion or hazard studies
- wrong assumptions about cause of the noise leading to inappropriate, and possibly biased, editing
- loss of resolution.

4.12.3 Effect on quality code

- Quality code applied cannot be QC 100 or QC 600.
- Unless the modification can be considered 'minor', quality code cannot exceed QC 400 for the altered period.
- In the case of biased noise (see Section 4.12.4) it should be kept in mind that the minima or maxima selected may still be compromised, and hence the maximum quality code achievable is QC 400.
- Data producers must exercise responsible discretion as to when QC 300 may be more applicable than QC 400. That is, the filtering or resampling applied may have removed enough of the original resolution for the data to be more truthfully described as 'estimated from calculations, or limited measured data' rather than 'measured data that have undergone significant modification'.
- QC 200 (of unknown quality) may be applied if a 'higher' code cannot be settled on.

Refer to Section 6.2.3 for explanation of 'minor' and 'significant', and the individual annexes for further guidance on code selection.

4.12.4 Guidance for use

Whether to suppress the noise, and which method to apply, depends on:

- the variable
- cause of the noise, and

- the purpose of the data.

If the affected variable is a surrogate, consider the effect on the target variable.

If the noise is random, such as wave action affecting a surface reflection water level sensor, a moving average (or median) filter, centred on the averaging interval, is appropriate. Results of applying the moving average must be carefully assessed, especially if the underlying signal is changing rapidly, e.g. at onset and over the course of a river fresh, tide or diel cycle.

If the noise is biased high, such as may be due to electrical interference or burial of a pressure sensor, minimum values should be retained and higher values discarded.

If the noise is biased low, such as may be due to insufficient power supply to a sensor, maximum values should be retained and lower values discarded.

Results are sensitive to the filtering or resampling interval. The minimum interval to achieve the desired suppression should be used. This may require some trials. Centring on the interval may not prevent induced hysteresis.

A consistent approach should be taken for noise due to the same cause.

Filtering or resampling must not be applied again on the results of a previous attempt.

Often the results of filtering or resampling noise should technically be stored as a different data type, e.g. a period of noise in a water level record that is smoothed using a fixed interval average should also be changed from instantaneous (continuous) to 'average in interval', but a time series cannot contain both types (see Sections 1.1 and 4.14). This means the final filed result is often yet another approximation.

Results must be graphed with the unmodified data and with a comparison site to confirm the transformation has not introduced other problems and is an acceptable representation of the variable.

A cautionary approach is recommended with conservative principles, particularly if the normal behaviour of the variable is not well understood; however, in such cases the metadata should be clear to a user of the data where such uncertainty exists.

- Review, and revise if necessary, the quality code of the filtered period.
- File a comment explaining the method applied, reason(s) for it, and assumptions made.

4.12.5 Mathematics

Function: A statistical algorithm such as a fixed or moving interval average or median, or

A resampling filter, for example, selecting each maximum or minimum in a specified interval or discarding values according to some threshold rate of change rule.

4.12.6 Example

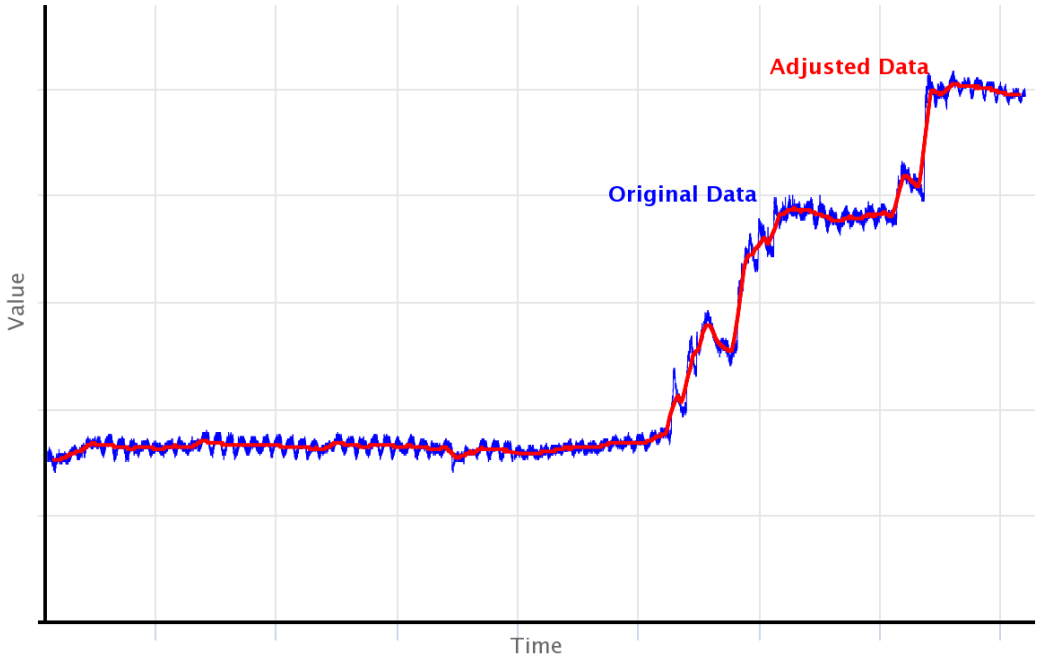


Figure 33 – Example of noisy data smoothed using a moving average centred on the interval, i.e. shifted back by half the averaging interval.

4.12.7 Noise induced by data collection method

4.12.7.1 Multiple data streams

Noise can arise when values from more than one data source for the same measurement are collected then merged into a single time series. Examples are:

- readings from two turbidity sensors at the same site, each with different range (to obtain range coverage while preserving low end resolution), and thus two different values are captured for the same recording interval
- data collected from a sensor via two paths using different and unsynchronised clocks, e.g. direct transmission of values via satellite and radio polling of at-site logged data, so that the same value may be assigned two slightly different timestamps.

Managing the successful merging of the data requires policy about which data source takes precedence and when. The policy must be documented, implemented as required, and summarised in one or more relevant comments.

4.12.7.2 Supervisory Control and Data Acquisition (SCADA) systems

Noise and data loss are both possible in a time series collected by SCADA systems due to disparities between remote device clocks and the base clock. The issues have most

impact on the recording of incremental (totalling) data, so further detail is provided in Annex B, 'Rainfall Data Processing' and Annex F, 'Water Meter Data Processing'.

4.13 Repacking data

Repacking is when a time series of interpolating data type is recalculated or resampled at regular intervals. The new interval may be different from the original timesteps, whether regular or irregular. Examples are:

- values aggregated and/or apportioned into regular intervals of a different duration, or
- values interpolated at a regular and/or different timestep.

Repacking is known as resampling in some time-series management systems.

4.13.1 Potential benefits

Potential benefits of repacking are:

- may reduce data file size if the new timesteps are larger
- may make the data more useful for a particular user, for example:
  - providing a series of daily means instead of 15-minute samples
  - converting irregular timesteps to fixed interval data for use in systems that do not have a true time facility, or do not support irregularly spaced samples
  - synchronising samples across multiple series, e.g. values at noon.

4.13.2 Possible risks

Possible risks associated with repacking are:

- apportioning assumes a constant accumulation rate that may be untrue
- loss of definition if new timesteps are larger
- extra values could give the impression of providing more definition than is real if new timesteps are smaller.

Note: Repacking data to smaller intervals usually has no advantage except to establish regular intervals or match other datasets.

4.13.3 Effect on quality code – data repacked to a shorter timestep

The quality code of repacked periods shall be downgraded.

- Quality code applied cannot be QC 100 or QC 600.

- Quality code cannot exceed QC 400 for the altered period unless the modification can be considered 'minor'.
- Data producers must exercise responsible discretion as to when QC 300 may be more applicable than QC 400. That is, when the repacked or resampled data are more truthfully described as 'estimated from calculations, or limited measured data' rather than 'measured data that have undergone significant modification'.
- QC 200 (of unknown quality) may be applied if a 'higher' quality code cannot be settled on.

Examples: Repacking daily or hourly rainfall, or daily staff gauge readings to a smaller timestep significantly mis-represents the data, and is considered to be a significant change, which requires the quality code assigned to the repacked data to be reduced to no greater than QC 400.

Refer to Section 6.2.3 for explanation of 'minor' and 'significant', and the individual annexes for further guidance on quality code selection.

4.13.4 Effect on quality code – data repacked to a longer timestep

The quality code of data that has been repacked to a longer timestep shall be no greater than the lowest quality code that has previously been assigned to any data point within the repacked interval.

The quality code assigned to repacked data shall be downgraded if the start and finish timesteps of the original data, and the aggregated data do not align.

Metadata describing the data aggregation must be provided in a Data Processing Comment.

Examples: Where 5-minute flow data is repacked to daily mean flow it shall be assigned the lowest quality code that any of the 5-minute data has been assigned, or, where rainfall intensity data has been recorded as event, or 6-minute, data and has been repacked to hourly, or daily, data it shall be assigned the lowest quality code that any of the underlying data has previously been assigned

Refer to Section 6.2.3 for explanation of 'minor' and 'significant', and the individual annexes for further guidance on quality code selection.

4.13.5 Guidance for use

Repacking data should only be part of a process for data analysis or preparation for export. However, with respect to data processing, data analysis may include:

- comparing two or more 'value in interval' time series for quality control purposes, or
- preparing synthetic data to fill a gap.

A change of data type may be necessary to ensure proper subsequent treatment and interpretation of the resulting series (see Section 4.14).

Repacking should not be necessary after processing and before archiving the verified processed data (e.g. to re-establish the recording interval in edited data). The same interpolation engine usually performs this function on demand as data are subsequently read from the archived series. However, there are two exceptions:

- it may be more efficient to repack data to regular intervals during data processing if it is routinely exported or served to systems that do not support irregular intervals in continuous data
- some time-series software can deliver data at any desired interval as part of the export/delivery process so there is no need to repack data in these systems prior to archiving. However, others export the data exactly as archived, so if fixed interval data are required, the data must be archived at fixed intervals and repacking may be needed as the final data processing step before archiving to ensure this.

Data that has been repacked when archived cannot be quality coded QC 600 (see Section 4.13.3) unless the start and end timesteps align. Periods of data that have been repacked must be explained in a Data Processing Comment (see Section 6.2.4.7).

4.13.6 Example

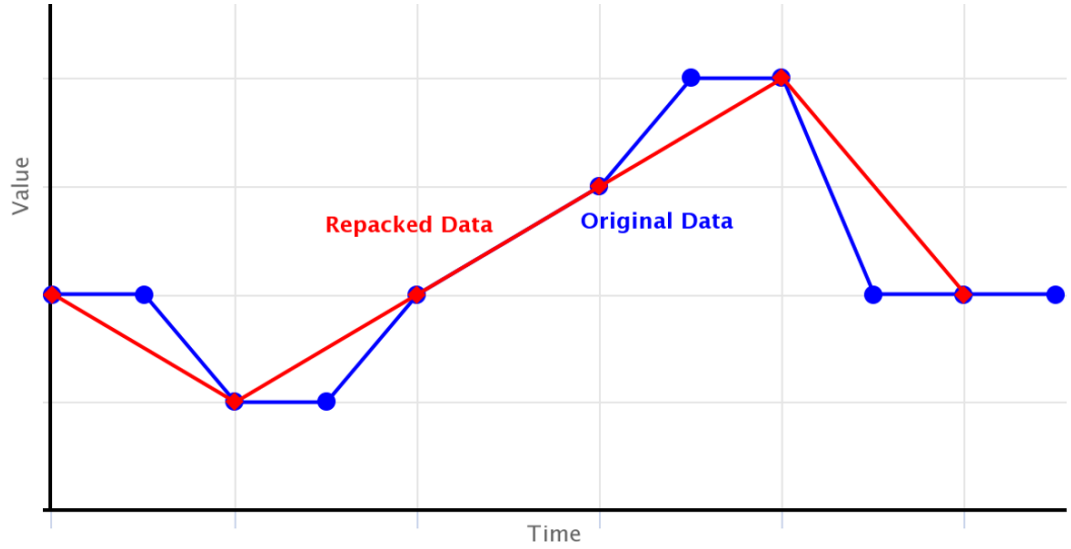


Figure 34 – Example of an instantaneous (continuous) dataset before (blue) and after (red) it has been repacked (resampled) to intervals twice the original timesteps.

4.14 Changing the data type

Data types are explained in Section 1.1. The data type of a time series can be changed, which will change the 'kind' of data, i.e. how the data are to be interpolated (or not) and what the values represent.

In some systems the interpolation method can be changed independently of other characteristics. For example, totals (in preceding interval) can be interpolating, where

portions of totals can be assigned to different intervals (apportioning), or discrete, where values can be tallied (aggregated) into larger intervals but not 'spread' (apportioned) across smaller intervals.

Some systems allow interpolation method to vary within a time series so that discrete samples and continuous data can be combined in the one dataset, with each interpreted and treated appropriately without further manipulation.

Reasons for changing the data type and the methods to do so are therefore also dependent on the system and software used to store and manipulate the data.

4.14.1 Potential benefits

Changing the data type may:

- better represent the data
- make the data better suited for analysis, or
- correct a mistake made at set-up of the data type definition for the time series.

4.14.2 Possible risks

Changing the data type of a time series has far-reaching effects on how the values are interpreted and treated, some of which may be unanticipated and significant.

4.14.3 Effect on quality code

It is unusual for the data type of verified data to be changed for the purpose of archiving unless to correct a mistake with the initial data type specification. Quality codes should not be affected but should be reassessed against the requirements for the variable in question to confirm.

If the data type is changed in conjunction with repacking the data, quality code is determined by the repacking (see Section 4.13.3).

4.14.4 Guidance for use

Unless a mistake was made with the initial data type definition for the time series, the data type should be kept as originally defined, for the purpose of archiving verified data. This has implications for data that have been filtered, resampled, repacked or created to fill a gap (see Sections 4.12, 4.13 and 4.20) in that the values filed may ultimately be interpolated differently to how they were obtained and what they therefore represent.

If some arithmetic is performed on the data or a transformation applied, and the results are to be written to a new time series, a change of data type may be necessary to ensure proper subsequent treatment and interpretation of the resulting series. Change of data type may be done automatically by the time-series software as part of the calculation process but other software requires the user to specify how the results are to be stored.

Common examples are:

- a time series of daily mean flows calculated from 5-minute instantaneous (continuous) data that should be written to a time series with data type 'average in preceding interval'
- a series of cumulative totals calculated from incremental totals, or vice versa.

4.15 Compressing data

The various time-series managers offer different types of data compression and different levels of system and user control. In the context of this NEMS, compressing data refers to the lossy process of removing redundant values from a time series by virtue of them being on or close to a straight line between adjacent points. Definition and implementation of 'on' and 'close to' also differs between the software.

Historic data may be heavily compressed, partly due to data storage and computation constraints, but often too as a crude method of suppressing noise. A time series of historic data may contain periods with different levels of compression applied.

4.15.1 Potential benefits

Potential benefits of compressing data are:

- removing unnecessary values; for example, there is a significant amount of redundant data in a fixed interval rainfall series during dry periods
- reducing file size, and potentially machine computation time
- reducing the number of values to be transmitted.

Note: Compressing data may become an important consideration again as more systems migrate to the cloud because of the costs and limitations of internet services in New Zealand.

4.15.2 Possible risks

Possible risks associated with compressing data are:

- using a non-zero range compression can smooth data unnecessarily and reduce its resolution
- the various software differ as to how compression range is specified into the process; some apply the specified range as ± and others as a band that is halved to achieve a ± range. For example, a 3 mm compression in some systems is the equivalent of 6 mm compression in others (see Figure 37)
- removing redundant values with a range zero compression poses no risk to integrity or accuracy of the data, and the uncompressed data are fully recoverable if repacked to recording interval using the

same software, provided the compression has been performed only once on the data

- because data type and number representation also play a part, repacking data compressed to range zero by another system, in an attempt to recover the initial uncompressed series, may not be straightforward and may result in different, although possibly no less accurate, values to those in the initial uncompressed series.

Note: Most historic data in New Zealand were processed and archived originally in TIDEDA. Because it is limited to storing data as integers, TIDEDA adds 0.5 to the specified compression range when the process runs, so TIDEDA's 'zero compression' removes more than just duplicated values, unlike other systems. If data compressed in TIDEDA to a specified range of zero are migrated then repacked using one of the other time-series managers, the results may not be identical to the values originally stored in TIDEDA but may be no less accurate because the other systems can store values in floating point form that TIDEDA had to round up or down.

4.15.3 Effect on quality code

The quality code cannot be QC 600 if a non-zero compression is applied.

The quality code to be applied to the compressed series must take into account:

- the descriptions of what constitutes 'minor' and 'significant' modification of the data (see Section 6.2.3), and
- the relative size of the compression range applied, compared to the quality code data resolution thresholds for the variable.

Refer to the individual annexes for further guidance on code selection.

4.15.4 Guidance for use

Compression to remove only redundant duplicate values may be applied if desired, without need for change of quality code or commenting of each instance, to:

- any instantaneous (continuous) time series
- any run of zero values in an incremental time series.

Non-zero compression is not recommended when preparing verified data for archiving.

If compression is used:

- data producers must understand how their system applies the specified range, in order to choose an acceptable range
- compression must not be applied again to the results of a previous attempt, i.e. no data should be compressed more than once
- results must be graphed with the unmodified data to confirm the compression has not removed an unacceptable amount of detail and the data remain representative of the behaviour of the variable

- a cautionary approach is recommended with conservative principles, particularly if the normal behaviour of the variable is not well understood
- review, and revise if necessary, the quality code of the compressed period
- file a comment for the period that records the software used, the compression range applied, what the range means in terms of C or C' in Figure 37, and the reason(s) for compressing the data.

4.15.5 Example

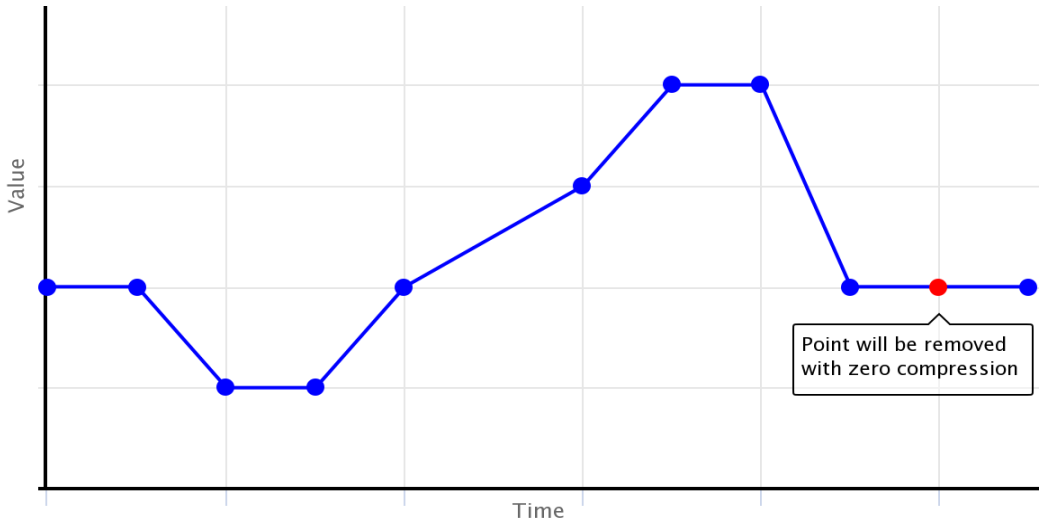


Figure 35 – Example of a time series with a redundant point that would be removed if range zero compression were applied.

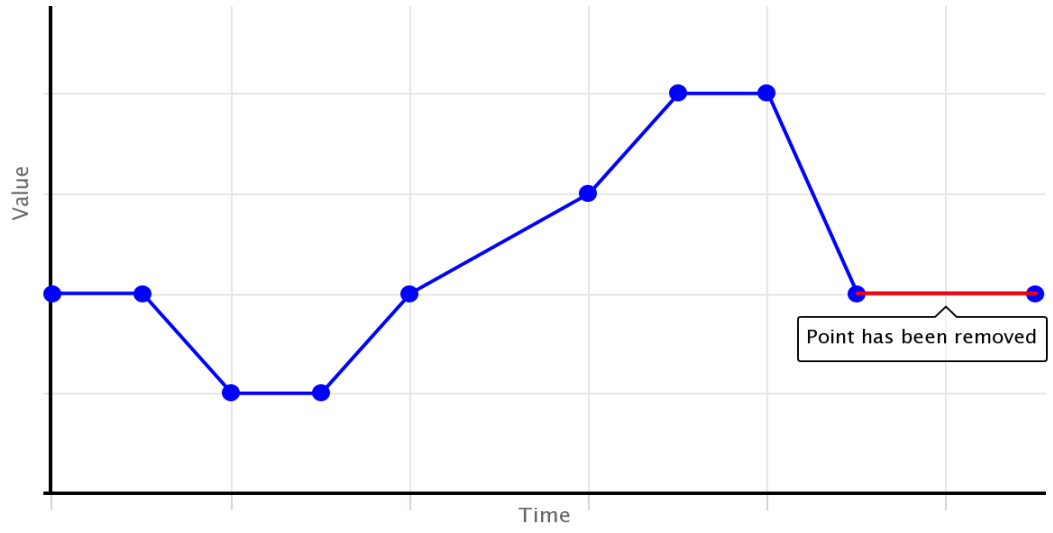


Figure 36 – Example of the time series in Figure 35 where the redundant point has been removed by range zero compression.

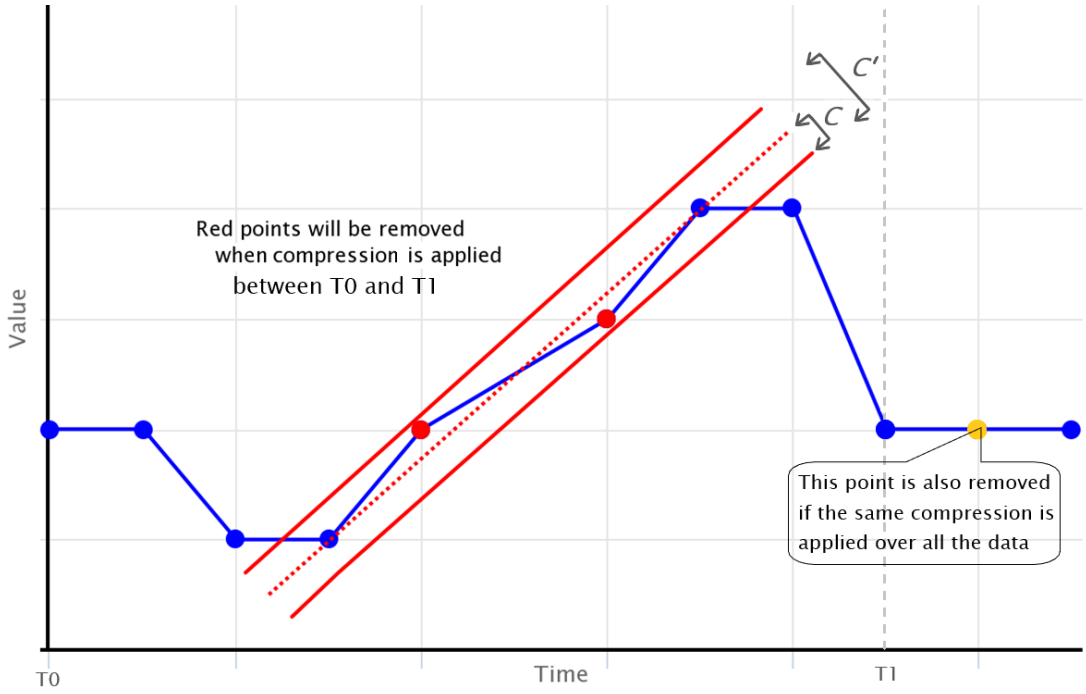


Figure 37 – Example of a time series with two redundant points (red dots) if non-zero compression is applied between T0 and T1. If applied over all the data, the orange point is also removed. Range specified to the process is C or C', depending on the software used.

4.16 Marking gaps

If the time-series data type is interpolating, any gap in the data series must be identified to prevent interpolation over the relevant period. This is achieved in the software by some form of flag or marker or 'valid data' period boundary in the series and shows in a plot of the data as a break (empty space) in continuity of the trace.

An interpolating data series must be inspected for any periods of missing data that have not been marked as gaps. If the data are fixed interval, search for timesteps that exceed that interval. Otherwise, search for timesteps that exceed some suitable nominal

interval and/or inspect the trace of a plot of the data for any unusual pattern that may indicate data are missing, e.g. a straight line where you would expect to see a curve.

Where a gap flag or marker should be present but is absent, and the gap is not to be closed or filled prior to final archiving, it must be manually applied. The period of the gap must be assigned quality code QC 100 and be accompanied by a Data Comment (see Section 6.2.4.6).

Gap markers are not applicable to discrete data types, but data may still be missing. Relevant periods must be quality coded QC 100 and be explained by a Data Comment (see Section 6.2.4.6).

If infilling is attempted but fails, the Data Comment filed should include explanation of what methods were attempted and why they failed. Future methods, technology or data may permit these gaps to be filled at a later date and such guidance will be valuable.

If the gap is for an extended period, and especially if it is a result of significant site maintenance or change of location, consider whether the gap should instead be treated as a temporary or permanent site closure.

4.17 Closing gaps and interpolation

A gap in a time series that is stored with an interpolating data type can be closed by removing the gap flag, gap marker, or gap period boundary, and thus re-enabling interpolation between the adjacent values.

If the time interval is short, and/or linear interpolation at constant rate with time is valid between the adjacent values, this may be all that is required; commonly when a logger or sensor is shut down briefly for servicing and personnel can observe that it is valid to interpolate the missed data.

If the interval is longer or the data type is discrete, extra values can be inserted by interpolating manually between adjacent values using the equation given in 4.17.5.

Note: If the series is of interpolating data type and linear interpolation at constant rate with time is valid, it is not necessary to add values into the interval regardless of its length; the interpolation engine of the time-series manager will derive values as and when required at any time in the interval.

4.17.1 Potential benefits

Interpolation is usually valid if the time between the adjacent values is short compared with the time taken for the variable to change under the natural processes occurring at the time, and the reason for the gap is known. Interpolation avoids small, unnecessary gaps in the data record, which may interfere with data analyses.

4.17.2 Possible risks

The validity of interpolation depends on the time period filled in relation to changes in the variable, and evidence that no change occurred that is not reasonably represented

by the interpolation. There is risk that an important event or unexpected change was missed and thus this action should only be done if there is corroborating evidence that no such event or change occurred during the gap.

4.17.3 Effect on quality code

The interpolated period shall be QC 300 (as synthetic data) if duration is more than a few recording intervals.

An exception is when personnel on site were able to observe and note that the variable did not change or it changed uniformly over the period, such as during equipment maintenance. In this case, given that the behaviour was observed, the quality code can remain unchanged from the adjacent record.

4.17.4 Guidance for use

Interpolations of longer than a few recording intervals should be allowed with caution, considering the above points. Should the verified data have this method of data correction applied, then this must be documented in the associated comments. Comments may be aggregated if repetitive to avoid overwhelming the comment file.

4.17.5 Mathematics

The following is a simplistic depiction to determine the interpolated point Y':

Function: $$Y' = \left(\frac{Y_2 - Y_1}{T_2 - T_1}\right)(t' - T_1) + Y_1 \quad \text{if } T_1 \leq t' \leq T_2$$

Where Y_1, Y_2, are the original series values and Y' is the value interpolated.

4.17.6 Example

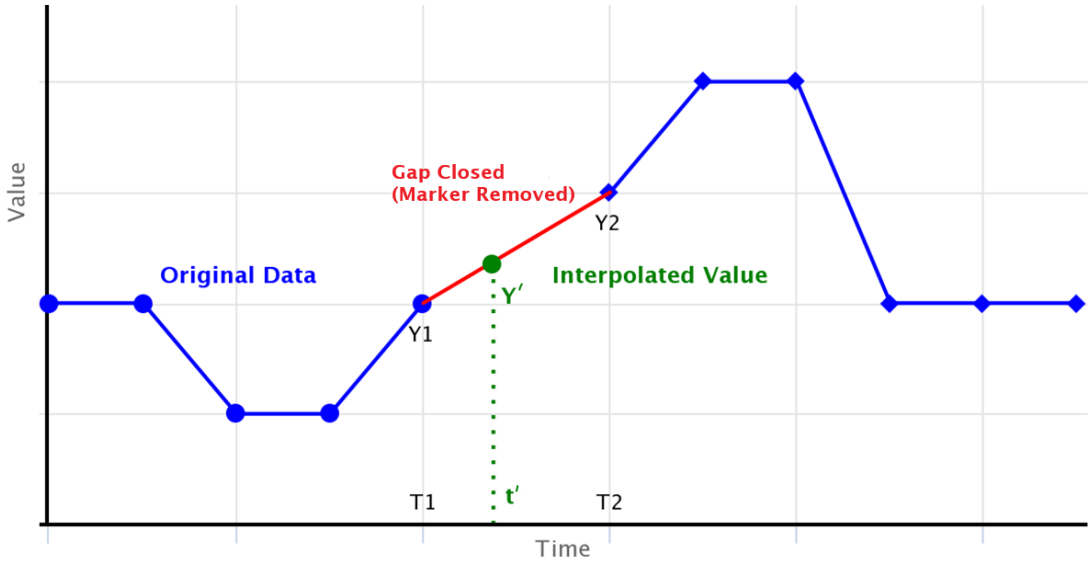


Figure 38 – Example of closing a gap between Y_1 and Y_2 so that values may be interpolated at any time t' between T_1 and T_2.

4.18 Infilling a gap with observations

Some or all of a gap in a data series may be filled by inserting values observed or measured while on site, most commonly from the primary reference and when the gap either immediately precedes (due to recording fault), or is caused by, activities during a site visit.

If the time interval is short and the observations are adequately representative of the behaviour of the variable, this may be all that is required. Otherwise, other methods of infilling must be employed.

Available periodic actual observations and/or retrospective measurements such as a surveyed peak flood level must be used to verify synthetic data generated by other infill methods and be incorporated into the final record.

4.18.1 Potential benefits

Infilling a gap with observations is valid for the duration over which the behaviour of the variable is observed with sufficient time resolution to be representative of that behaviour. Doing so minimises the number and extent of gaps in the record that may interfere with data analyses.

Periodic observations and/or retrospective measurements enhance the reliability of results of other infill methods by providing some certainty, for example, to the estimation of a significant event such as a peak flood level.

4.18.2 Possible risks

Validity of the infill is dependent on frequency and timing of observations in relation to changes in the variable. If observations are sparse there is a risk that the actual variation is under-represented in the data.

4.18.3 Effect on quality code

If the observations provide a suitably complete record, quality code for the relevant period can be one of QC 400, QC 500 or QC 600 depending on assessed accuracy of those observations. Otherwise, quality code must be QC 300, either by way of the infill being largely synthetic data or estimated from limited measured data.

4.18.4 Guidance for use

Each period infilled with observations must be explained with a comment. Use of the data should be guided by the general implications of the assigned quality code and the information provided in the relevant comment(s).

4.19 Infilling a gap with a curve

A gap in a data series may be filled by inserting values that:

- complete the curve that can be reasonably inferred from the trace when a short period of data surrounding and including the gap is plotted, and/or
- mimic the curve evident in a comparison plot of the simultaneous period of reliable data for the same variable from a nearby site, or
- follow the curve evident in a reference plot of a similar period of reliable data for the same variable at the same site.

4.19.1 Potential benefits

Infilling a gap with a curve is usually valid if the duration of the gap is short, the behaviour of the variable under the natural processes occurring at the time is well understood, and the reason for the gap is known. Doing so avoids small, unnecessary gaps in the data record, which may interfere with data analyses.

4.19.2 Possible risks

The validity of infilling a gap with a curve is dependent on the time period filled in relation to changes in the variable and whether fitting a curve is appropriate. There is risk that an important event or unexpected change was missed and thus this action should only be done if there is corroborating evidence that no event or deviation from the curve occurred.

4.19.3 Effect on quality code

The inserted data values shall be quality coded QC 300 (as synthetic data).

4.19.4 Guidance for use

Use with caution, considering the above points. Each period infilled with a curve must be explained with a comment.

4.19.5 Example

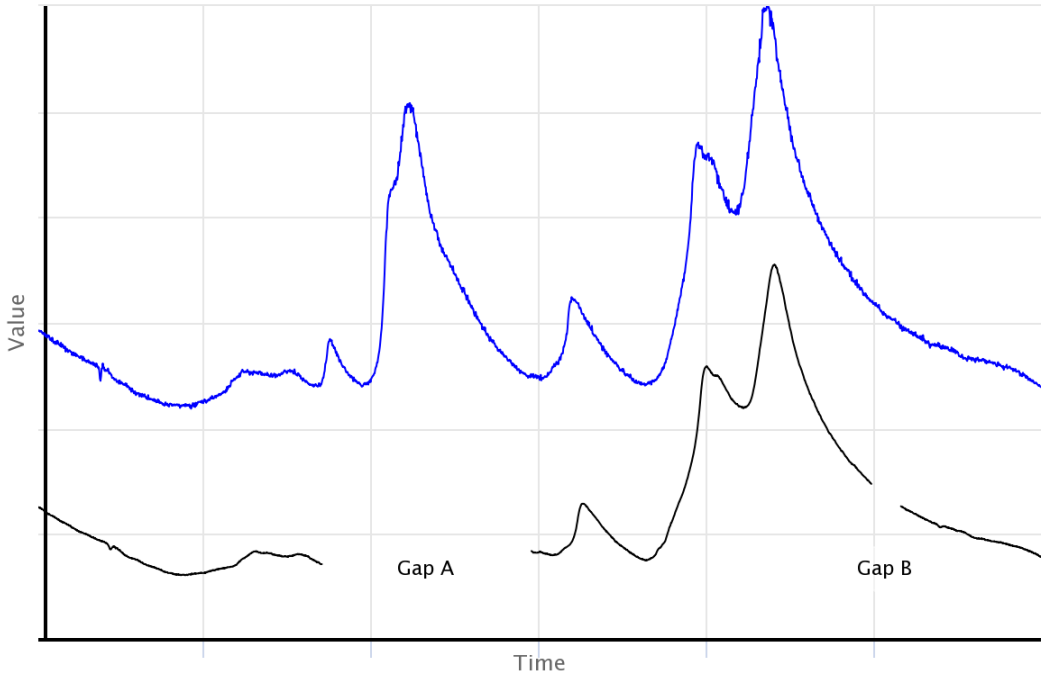


Figure 39 – Example of period with missing data (black trace) and comparative site (blue trace) overplotted. Gap A should only be filled using methods described in Section 4.20, whereas Gap B could be filled by a curve as described in Section 4.19.

4.20 Infilling a gap with synthetic data

A gap in a data series may be filled with synthetic data if a suitable predictive relationship can be derived with one or more variables from one or more adjacent or nearby sites.

4.20.1 The process

Follow these steps when creating a synthetic record:

- gather all available information that may assist with synthesising a record to fill the gap
- explore relationships useful to building models able to generate the necessary synthetic data
- decide the interval (timestep) of the synthetic data to be created
- decide the model to be applied
- create the model
- test the model and, if acceptable,
- apply the model to generate the required synthetic data
- review the synthetic data and, if acceptable,
- incorporate it into the record to be archived, with quality code of QC 300 applied

- describe the model and the accuracy of the synthetic data in a filed comment
- preserve and retain all working
- if desirable, retain the model for future use.

Method detail, including any provisos and exceptions relating to synthesising data for a specific variable is provided in the relevant annex for that variable.

4.20.2 Potential benefits

Because gaps can interfere with data analyses, filling a gap with synthetic data is preferred to leaving the period as missing. Depending on the variability of the data and the reliability of the relationship used to generate the synthetic data, periods of two to three weeks of synthetic data may be reasonably estimated.

4.20.3 Possible risks

The synthetic data generated by some methods may not be fully compatible with the data type and/or resolution of the time series into which they will be incorporated. For example, synthetic data intended for an instantaneous series may be generated from a relationship between hourly or daily averages. Most time-series management software do not permit the mixing of data types within the same time series, so the synthetic data derived will not be represented as averages once included in the record.

Results of regression may be overly affected by outliers or may under-represent actual extremes during the period of infill.

An event may occur at one site but not the other, leading to unreliable results unless other information is available to assist.

4.20.4 Effect on quality code

All synthetic data shall be quality coded QC 300.

4.20.5 Guidance for use

Use with caution, considering the above points. Each period infilled with synthetic data must be explained with a comment.

Synthetic data should not be included in model calibration or extreme event analysis without due consideration of its potential influence in the context of each specific project (McKerchar et al, 2010).

5 Applying Adjustments to Data

This section contains the rationale and general procedure for making any necessary modifications to the raw data.

5.1 Principles

- Data shall, whenever possible, be corrected or adjusted for value and/or time when it fails a relevant quality control test (see Section 3.6).
- Data that pass all relevant quality control tests need no modification.
- All modifications to data that are intended for archiving must be verified as necessary and appropriate.
- Data should not be routinely edited or adjusted to every verification value (e.g. by automatic adjustment often referred to as 'calibration' of the record).
  - Other checks of the data, and diagnosis of the cause of anomalies and deviations, are required.
  - Random variation in the verification data (i.e. primary reference readings) may distort and/or add uncertainty into an otherwise consistent and reliable record from the sensor.
  - Maximum quality code of QC 400 will apply because duration of the adjustment is significant (see Section 6.2.3).
- Automated quality control and processing may be applied but periodic review by a suitably trained and experienced person is required (see Section 7).

Note: Success of automated quality control and/or processing depends on redundancy in the data production system, e.g. more frequent verification data, backup sensors at site for the same variable, and/or similar nearby sites in a network.

5.1.1 Modifications to data

Any modification to data shall be:

- conservative
- traceable
- documented
- performed or approved by experienced personnel
- described in a time-bounded, time-stamped comment, and
- quality coded appropriately.

The goal for any environmental monitoring programme should be the collection of complete and reliable data. Unfortunately, equipment failure, vandalism and

environmental conditions sometimes cause data loss or the collection of biased or erroneous data.

Any data intended for final archive must be representative of the variable measured. If the data collected are not representative it must be repaired, replaced, or removed prior to archiving. However, personnel dealing with environmental data have a duty to be conservative when altering or discarding any recorded data.

Any action on the data should be accompanied by efforts to minimise the future need for such intervention, given that the objective of best practice data collection is for each station to be configured and operated so that a continuous record is obtained from the measurements with minimal subsequent modification of the data necessary.

If verification indicates that the measurement system is operating as expected and recorded data are within tolerance of the primary reference, there should be no need to modify the data collected. Exceptions are:

when isolated small spikes in a surrogate variable impact useful and reliable determination of the target variable

when a small bias within tolerance persists until the source of the bias is found and the measurement system is adjusted accordingly. The data collected prior to the measurement system adjustment should then be adjusted similarly to remove its known bias.

Cause and extent of any issue detected in the data needs to be established to select an appropriate remedy, which may include addressing uncertainty or reliability issues with the reference(s). For this, and the above reasons, routine adjustment of data to reference, whether at site or during data collection or processing, is discouraged.

5.1.2 Traceability and data integrity

Data modification must always be done based on evidence and logic, not guesswork. All assumptions on which any modifications are made shall be defensible and recorded.

The process must be tracked via record keeping and associated documentation to ensure traceability of the work done so that alterations can be checked and reversed if necessary, including if the original data are subsequently unavailable.

Reprocessing of the original data may be required in the future based on new evidence, such as a site survey, instrument calibration, or collection of further data.

In some cases, the values as measured may need to be recovered to remedy a recording error.

5.1.3 Modifications explained

Any change to measured values must be identified and explained.

This is especially important when alterations are such that the resulting archived time series is recommended to be used with caution.

Change as a result of pre-processing, such that the original data are modified from raw must be:

- set out in the data processing system documentation (see Sections 3.1.1 and 8.2.1)
- noted in the records of data acquisition (see Section 6.2.1)
- documented in the records of data processing (see Section 6.2.2)
- described in one or more Data Processing Comments (see Section 6.2.4.7).

Changes to original data must be:

- documented in the records of data processing (see Section 6.2.2)
- assigned an appropriate quality code (see Section 6.2.3 and the guidance in each relevant Annex)
- explained in a comment attached to the edited data (see Section 6.2.4).

5.2 Processing steps

The processing should be planned and outlined in the organisation's procedures. Broadly, the processing steps shall include:

- assessing the data by running routine checks (see Section 3.6)
- comparing with field checks and references (see Section 3.6)
- assembling other evidence, such as calibration data, transformations made in the logger and/or telemetry system and any other transformations applied or required

Note: Pre-repair calibration of an instrument can be useful to help reconstruct a reliable record.

- making an initial assessment against relevant NEMS
- reviewing relevant existing comments
- performing any editing required
- quality coding and adding any necessary comments (see Section 6)
- independent review of any editing and comments (see Section 7)
- a longer-term context data audit certified by an independent, authorised reviewer (see Section 7).

5.3 Order in which to apply adjustments

Adjustments to data should be made in this order, as and if required:

- time corrections
- linear transformations to the final measurement units (e.g. converting water level data measured in hPa to mH_2O)
- removal of sporadic and intermittent spikes
- linear transformations to correct for instrument configuration error (e.g. a wrong multiplier and offset)
- filtering, resampling, or replacing data to mitigate excessive noise (e.g. when rapid fluctuations in a water level record due to sensor fouling or wind will adversely affect the determination of flow)
- offset corrections
- other adjustments to minimise the effect of recording faults and/or to achieve conformance with field verifications (e.g. for drift or fouling)
- other linear or non-linear transformations as may be required (e.g. adjusting a 'clean' rainfall record to the primary reference totals)
- addressing any gaps.

5.4 Missing data

Avoiding loss of data should be a high priority for all organisations.

A gap in a series, created by missing data, must either be closed, infilled, or marked to prevent interpolation through the period of the gap if the data type is not discrete.

The decision to close or infill a gap, or leave the period as missing, must weigh up:

- duration of the gap
- desired reliability of the interpolated or synthesised data
- impact on usefulness of the overall record if not filled
- usual variability at the site
- availability of primary reference readings
- possibility of events having occurred in the missing period
- availability of the information needed to synthesise a record.

5.5 Infilling gaps

Infilling gaps should not be attempted until the actual record either side of the gap is available with duration at least 2–3 times the gap interval before and after.

Methods described in this Standard are not intended for record extension, nor for large-scale infill of multi-site datasets. As such, machine-learning methods are not included. If

data are missing at the start (or end) of a time series, the start (or end) date and time of the dataset should be brought forward (or moved back) rather than attempting to fill the gap.

5.5.1 Choice of methods for infilling

Methods used to fill gaps shall be one of, in decreasing order of preference:

- inserting backup/secondary sensor data from the site
- inserting suitably frequent at-site observations, such as manual gauge readings
- interpolating a line or infilling a curve over a short period under stable conditions
- correlating from adjacent station data that have been checked for suitability
- using modelled data (preferably supported by observation or measurement, e.g. a flood level surveyed from debris marks), or
- estimated/synthesised by other means (which must be fully explained).

For recommended procedure and guidance in applying regression analysis see Appendix 2.

For method detail specific to a measured variable, see the Annex for that variable.

5.5.2 Infilling with synthetic data

Organisations shall provide synthetic data, where feasible, to fill gaps in datasets and to replace erroneous data except where explicitly stated otherwise, e.g. rainfall data (see Annex B).

The rationale is that:

- continuous datasets are of more use to most users
- all users will have access to the same records, and
- synthetic data generated by those closest to the data collection are likely to be better than that generated by the majority of end users.

However, it must be clear to data users where synthetic data exists.

Interpolated data are a special case where data are created only within the range of known data. Thus, in environmental applications where time and magnitude are relevant, we might synthesise but cannot interpolate a peak or a trough. We may interpolate between reference readings if confident the actual variation is represented and remained within the range of the bounding reference values.

Generally, it is unwise to fill gaps of more than two months duration, other than in a series of monthly observations or statistics (McKerchar et al, 2010). A lesser limit is

prudent in some situations and for some variables. Refer to the relevant Annex for further details.

Quality code QC 300 must be assigned to identify which data are synthetic. Data Comments are also required to further define these periods and provide descriptions of how the data were synthesised and likely limitations on their usefulness (see Section 6.2.4.6).

Synthesised data must not alter extreme values for the record unless there is excellent corroborating evidence, such as incorporating a reliable and surveyed flood mark.

Generating the synthetic data and/or the description of their reliability may need to be redone if there is any change in future to the data used to generate the infill, for example, as a result of data audit or the collection of new data over an extreme event.

5.5.3 Describing accuracy of the infilled period

Accuracy of any relationship used to derive a synthetic record must be described in some way.

Useful statistics are:

- the correlation coefficient (r), which describes the strength of association between two sets of data, such as from a donor and a recipient site
- the regression coefficient (R^2), which is a relative measure of how well the recipient site data can be explained by, and therefore predicted from, the donor site(s)
- the standard error of the estimate (SEE), which is an absolute measure of the accuracy of prediction, being one standard deviation of the residuals from the equation of prediction. SEE is valid for non-linear regression. Most regression tools will provide this statistic.

A description of the process used to create the synthetic record is necessary and should include commentary on the suitability of the donor site or model, and other aspects relevant to give users an appreciation of how reliable the synthetic data are.

6 Metadata

Metadata describe the data, from where and how it has been measured to information about the data, including what has been done to it subsequent to its recording and key characteristics of the final dataset.

All required metadata must be created, collected, and/or collated, then verified and permanently archived.

Where backup data are incorporated in a time series intended for final archive the metadata requirements described in this section apply to the backup records as well.

6.1 Site metadata

Site metadata shall include:

- site and equipment details (including photographs, maps, plans, and relevant imagery)
- station and instrument calibration history (including pre-deployment checks and field validations)
- any assessment(s) to determine maximum quality code that the site is capable of achieving for the variable(s) measured
- legal and proprietary information, and
- all site visit records.

Note: Site visit records include verification measurements collected during the visit, results of recorder inspections, and any other noted observations.

Detailed site metadata requirements for each variable measured at the site are set out in the relevant normative reference(s) and Annex(es) of this document.

Site metadata are normally stored in some form of site file or station history and may include use of document and/or asset management systems.

If imagery such as aerial photographs and surveys (e.g. LiDAR) has been obtained as part of operating the site it shall be documented, managed, stored, and preserved as for other forms of site metadata.

Note: Imagery may also exist historically, and/or as a result of other projects or the activities of other organisations also working in the area. Where such imagery is known to exist, including a descriptive summary of it in the site metadata is helpful.

Site metadata relevant to the time series being processed must be readily available as and when the data are processed to:

- facilitate verification of the data
- support data processing decisions, and

- provide any site information needed to produce the metadata that is required to be attached to, and archived with, the time series.

6.2 Time-series metadata

Time-series metadata shall include:

- records of data acquisition, including data missing
- records of data processing decisions and actions
- quality codes
- comments
- results of quality assurance tests (see Section 7), and
- any data access agreements and/or waivers that constrain dissemination of the data.

6.2.1 Records of data acquisition

Data acquisition records include one or more of:

- an incoming data register
- a telemetry log
- a sample register
- laboratory test method(s) used, and
- 'office chits', i.e. recorder logbook or electronic field sheet entries made while in the office to document, for example, recording configuration changes initiated from the base rather than during a site visit.

Records relevant to the time series being processed must be readily available as and when the data are processed to:

- facilitate verification of the data
- support data processing decisions, and
- provide information needed to produce the metadata that is required to be attached to, and archived with, the time series.

Records required to ensure traceability of data processing shall be permanently archived.

Periods of missing data must be verified as missing and, if the gap is not subsequently closed or filled during processing, assigned quality code QC 100 and accompanied by a Data Comment (see Section 6.2.4.6).

6.2.2 Records of data processing

Any alteration to, or discarding of, original data shall be documented and/or recorded in a way that future generations can follow what has been done and why. It should not be necessary to refer to the person(s) who carried out the data editing for explanation.

Alterations to, or deletions of, raw data to be documented in this way include those actions applied:

- in the field to data already logged, and
- automatically by data acquisition systems, e.g. spike filtering, range censoring and any transformations of incoming telemetered data.

These records shall be permanently archived, such that all actions on the measured values contributing to the form of the final archived dataset are traceable and reversible at any time in the future.

6.2.3 Quality codes

Quality codes are coded metadata attached to the time-series data as tags or as a concurrent time series, to help convey provenance and reliability of the data. Quality codes facilitate valid data analysis and comparisons within and across multiple data series.

Quality coding shall be applied to the data according to:

- the NEMS National Quality Code Schema, and
- the specific requirements of this Standard, and
- the Annex of this document relating to each variable, and
- each relevant NEMS normative reference.

Quality codes shall be applied prior to any provision of data to users, including raw data delivered automatically.

Within the national schema, deciding between quality codes QC 500 and QC 400 often requires differentiating between ‘minor’ and ‘significant’ modifications to the data. Data producers must exercise some professional judgment. However, generally, modification can be regarded as ‘minor’ (QC 500) if it is:

- for a short period of no more than a few recording intervals that do not exceed one hour, or
- a small change to values relative to tolerance, and/or
- a small change to timesteps relative to recording interval, and or
- applied over no longer than the course of a single event or cycle.

Any modification beyond the above in terms of duration or degree of alteration of values or timesteps should be regarded as ‘significant’ (QC 400).

6.2.3.1 Guidance

A few recording intervals: - dependent upon how data is recorded (i.e. fixed interval or event). For most variables, more than one hour is considered to be more than a few intervals. However, where data is missing due to on-site maintenance, validation or calibration activities, the data can be infilled, or interpolated, and quality coded as per preceding and/or subsequent data (as appropriate), provided verification observations are undertaken throughout the period of missing record, these are documented and applied during data processing.

- A small change to values: - if the maximum adjustment is more than the measurement tolerance defined within a NEMS for a particular variable, it is more than a minor regardless of the duration, and therefore significant.
- Single event: - What might be considered a single event can vary significantly depending on the variable being measured. For water level data, a single event is considered to be, a single hydrograph, or one tide cycle.

For variables that have regular cycles, such as tide, lakes, dissolved oxygen or water temperature data, an adjustment over more than one cycle is considered to be more than minor.

- Small change to timestep: - less than ±5 minutes/month.

6.2.4 Comments

Comments are textual metadata associated by timestamp with the data that provide key information about the site, data, and dataset, and explain unusual features or events in the record that users of the data should be aware of but that are not readily conveyed by a quality code.

6.2.4.1 Comment formats

There are a number of advantages in having comments that follow standard formats and wording, primarily:

- standard wording and phrases minimise errors, help regulate style, and reduce ambiguity by reflecting consensus on the best way to describe a situation or action
- common terminology can provide easier searching within a comment database or listing.

As a minimum, a comment shall:

- specify, or be specific to, the site and measured variable(s) to which it applies
- be timestamped at the start of the period to which it applies; for example, a gap or synthetic data comment will be filed at the

timestamp of the last actual value collected, and an event comment will be filed at the time of the start of the event

- specify the period over which it applies in the body of the comment (i.e. in addition to the timestamp)
- use dates that conform to common usage standards in New Zealand, i.e. not use American date format (see Section 1.2.1)
- specify times in NZST (UTC+12h) using a 24-hour clock and 1-second resolution (e.g. hh:mm:ss or hhmmss) (see Section 1.2.1 and 1.2.2)
- use New Zealand (UK) English
- comprise standardised wording whenever possible
- use plain, impersonal, unambiguous language
- minimise use of symbols, acronyms, codes, and abbreviations unless defined elsewhere in the comment set or in the NEMS Glossary
- be checked for correct spelling, punctuation, and grammar.

Note: Omitting correct and complete punctuation and grammar in the interests of brevity often causes ambiguity and incorrect interpretation.

Most time-series software packages provide several ways to build or connect to a database of comments.

Comments can be entered into one or more plain text files, spreadsheets or documents, or database. If the comments are entered into an Open Database Connectivity (ODBC) database, they can be accessed by any ODBC-compliant software. Therefore, this method is recommended.

Design of a system for storing, managing, and reporting comments should include capability to report them in an interoperable exchange format such as XML and more specifically OGC's WaterML2 (OGC, 2014).

The organisation may set standards for presentation (font, size, case, styles, numeric form etc.) and branding, but these should not compromise accurately conveying the information.

6.2.4.2 Comment categories and content

Comments shall include, but not be limited to:

- information about the site, installation, and characteristics of the data
- alerts and supporting information intended for end users of the data
- aspects not easily quality coded or otherwise quantified, and
- the NEMS documents and versions referred to.

Organisation of comments into categories helps with:

- prompting what comments are required and what they need to contain

- filtering and sorting comments from a large set to customise output for individual end users
- efficient data entry, particularly if standard content templates are also developed
- design of form-based applications to support data entry.

The following comment categories should be used:

- site/initial
- equipment
- operational
- data
- data processing (including corrections)
- transformations
- stationarity, and
- miscellaneous.

These comment categories are further explained in the following sections.

Optionally, the relevant measured variable(s) may be useful as a sub-category to aid in filtering comments.

Organisations without an integrated document store should consider including a Document Reference comment category to facilitate reference to related documents such as standard operating procedures, calibration certificates, scanned plans etc.

6.2.4.3 Site/Initial Comments

Historically, every time series stored, i.e. every site and measured variable combination, required an Initial Comment. Information common to all variables measured at a site was repeated in each Initial Comment. With modern storage systems it is possible to have a single Site Comment linked to the time series of all variables measured at a site.

Whichever configuration is implemented, these comments include:

- the site name and past and present aliases (if any)
- the site's geographic location, preferably to the nearest 1 m but at least to the nearest 100 m, in a coordinate system supported by Land Information NZ

  Note: For precision to the nearest metre, latitude/longitude coordinates, e.g. WGS84, must be expressed to five decimal places.

- names, and/or indices if applicable, of relevant environmental features, including whether the site is representative of a catchment, river, lake, coastal feature, and/or aquifer.
- names and/or indices of the relevant physical features, zones, and authorisations (e.g. airshed, bore number, consent number)

- the site's purpose (e.g. a brief description of the research programme)
- the variable(s) measured at the site (including any supplementary data)
- the variable(s) calculated from measurements at the site, i.e. variables for which data recorded at site are a surrogate
- brief details of other relevant site characteristics and influences (e.g. bore depth, altitude, nearby activity, and persistent issues affecting data quality)
- whether data are auto-checked and/or auto-processed, fully or partially
- the recording agency/agencies, past and present
- the start, and end date (if applicable), of the records
- list of other monitoring at the site, past and present, and
- any related sites and brief summary of their records (e.g. data used as supplementary, predictive, or in combination).

6.2.4.4 Equipment Comments

Equipment Comments include:

- details of the sensor(s) and data logger (e.g. type, power supply, deployment details, sampling regime, storage media, on-board processing algorithm(s))
- the range, resolution, and accuracy of the sensor(s)
- description of any structures, their purpose, and critical dimensions and levels (e.g. artificial level or flow controls, gauging structures, instrument mounting platforms, recorder towers, access ladders, well heads)
- primary data collection method (e.g. manual download and/or telemetry)
- type of reference(s)
- calibration and validation frequency.

Note: Include type as described in the NEMS documents in preference to use of brands, models, and/or serial numbers that a future data user may find difficult to interpret.

6.2.4.5 Operational Comments

Operational Comments describe:

- sensor relocation or operating environment changes, such as sensor elevation, aspect, exposure, relative position in a water body

- changes to references, including a change of datum
- compromised verifications (e.g. interference with references, poor on-site conditions, incomplete inspection)
- significant calibration issues affecting quality of the data (routine calibration data should be in a site metadata or instrument management system)
- significant site maintenance, and
- restrictions related to data access (e.g. authorisations, confidentiality, intellectual property).

6.2.4.6 Data Comments

Data Comments give details of:

- period of and reason for inclusion of backup data
- period and cause of missing record (gaps) not filled, with explanation of any failed attempts to infill where applicable
- period of and reason for synthetic record, how it was derived (e.g. other sites and data used, description of correlations and models), estimate of uncertainty/reliability/statistical confidence, and any limitations on usefulness
- method of data capture if not collected from a data logger (e.g. digitising, manual entry, CSV import)
- period and range of any data compression applied
- data stored as supplementary to the processed time series
- time-related events that affect the data
- observations that may assist with interpretation of the data
- any other reasons for downgraded quality codes not covered by other comments, and
- period of and reason for any other limitations on usefulness of the data that an end user should be made aware of.

6.2.4.7 Data Processing Comments

Data Processing Comments include:

- descriptions of:
  - pre-processing applied within the data logger or data collection system (e.g. telemetry or import software)
  - automated quality control methods, algorithms, and actions
  - automated processing applied to the data
- periods over which any of the above apply
- details of the editing carried out, including the reasons for it, errors found, assumptions made, and process applied
- the start and end dates and times of the period that has been modified

- a summary of the evidence confirming validity of the change
- name of the person carrying out the editing, and
- date the editing was done.

Where quality coding is implemented and suitably identifies affected data, comments about repetitive issues and editing of data may be aggregated to avoid overwhelming the comment set for the site.

6.2.4.8 Transformation Comments

Transformation Comments give details of any transformations applied to the data before archiving. Transformations may be applied to address issues of calibration, compensation, units of measurement, or conversion to another variable.

Adjusting rainfall data to the primary reference is a special case that is addressed in Annex B.

A calibration fail may compromise instrument stability as well as span and/or linearity. For this reason, instances of calibration fail must be identified, and the nature of the failure explained by an Operational Comment as well as any Transformation Comment that may be required.

In the case of variable conversion, the surrogate variable's Site/Initial Comment shall state the intended transformation as part of that site's purpose and list of associated variables (see Section 6.2.4.3), while the Transformation Comment must be filed with the archived target series. Where the target series is generated but not archived, e.g. conversion of stage to flow using a rating curve engine, requirements for comments about the transformation(s) are included in the NEMS that covers development of the model (e.g. NEMS Rating Curves) and are excluded from scope of this NEMS.

Transformation Comments should describe:

- the reason for the transformation
- the applicability and validity of the transformation, including assumptions made and evidence relied on
- the method and parameters of the transformation
- the start and end dates and times of the period modified
- name of the person(s) who derived and applied the transformation, and
- date the transformation was applied.

For further details, see the Annex covering the relevant variable.

6.2.4.9 Stationarity Comments

Stationarity Comments describe any event, or change in methods, measurement location or conditions that has occurred at a spatial and/or temporal scale that may cause loss of homogeneity in a long record. Examples are:

- significant changes of land cover and/or use (e.g. planting or milling a forest)
- historic data collection that is in some way significantly different (e.g. manual observations by a volunteer or nominated public observer)
- change in principle of a method (e.g. the definition of 'event' rainfall measurement, change of standard method or analytical standard)
- construction of a dam or diversion, or an irrigation or flood control scheme that impacts the site
- change of site purpose (e.g. from flood warning to full flow range)
- change in achievable data quality at a site (e.g. from a site assessment matrix)
- reference to the Standard(s) and version used.

This comment category may also be used to alert a user to the possibility of combining two or more at-site records under the assumption they are homogenous, for example, when a site is moved to another location but the intention is that the two records be regarded as a continuous dataset.

6.2.4.10 Miscellaneous Comments

Miscellaneous Comments are any other related comments that may assist a data user. Use of this comment category should be minimal.

7 Quality Assurance

Datasets shall be reviewed to confirm that they have undergone all necessary procedures to enable them to be used with confidence.

Less formal quality review occurs prior to archiving as each batch of processing is completed. A regular but much less frequent cycle of more formal audit of archived data is also recommended.

Processed data that have been quality controlled and/or edited and/or adjusted entirely by machine algorithms must be reviewed at least every two years by a suitably trained and experienced person. This review may be informal prior to archiving (see Section 7.2) or a formal audit (see Section 7.3).

Note: For clarity, data that are archived as verified and processed must be subjected to biennial audit if the processing is not performed and/or reviewed by a suitably trained and experienced person prior to archiving.

7.1 Requirements

All agencies shall implement standard methodologies for:

- verification, documentation, and quality control of new data
- review of all editing to ensure that all changes are necessary and appropriate, and no necessary changes have been missed
- review of metadata compiled for accuracy and completeness, including the quality codes assigned and comments to be filed, and
- periodic, more formal audit of archived data.

How these requirements are implemented will depend on each organisation's time-series management software.

7.2 Quality review

Quality review shall be undertaken by a suitably trained and experienced practitioner who is preferably not the person to have processed the data.

Completed reviews shall be signed and dated by the reviewer and tracked in the processing records (see Section 3.3).

Quality review sign-off should be part of an organisation's procedure to formally authorise update of the period of data and associated metadata to the final archive(s).

7.2.1 New data

For new data, confirm:

- there are no data missing that have not been marked as gaps or infilled
- no issues or anomalies have been overlooked
- differences between logged and reference values are acceptable
- all data are appropriately quality coded
- all other necessary metadata are present and accurate
- the data look sensible when plotted with:
  - previous data for the same variable at the same site, and
  - the same variable at a nearby site, and/or
  - a related variable at the same site
- data extremes are reasonable
- patterns in the data are believable, represent expected behaviour of the variable, and are not the result of interferences.

7.2.2 Editing applied

If editing has been applied, reconcile:

- gaps in the original and processed data, before and after editing
- gaps and periods of synthetic infill with the comments and quality coding
- the adjustments applied with the differences between logged and reference values, before and after editing
- the adjustments applied with comparison between the original and final verified time series
- the quality codes applied with the above tests, and with the results of quality control deviation tests, the processing log, and filed comments.

If editing has been applied, confirm:

- all assumptions, decisions, and explanations are reasonable
- all intended adjustments are done
- adjustments made are what was intended
- adjustments made are valid and justified
- editing did not create spikes, bias, steps, or distortions in the data, or make unintended time adjustments.

7.2.3 Metadata

Reconcile the quality coding and comments against:

- any editing applied
- a listing of all gaps
- each other
- the relevant field notes, and
- other records of actions such as instrument or configuration changes, annual inspections, etc.

Confirm:

- requirements of this Standard are met
- comments are present for changes in quality code that need to be further explained, e.g. periods of synthetic data
- quality codes align with comments, with respect to time and content
- reliability and accuracy of the data are adequately described
- comments intended for end users of the data are unambiguous and free of spelling errors, jargon, and poor language.

7.2.4 Tests for quality and accuracy

The following are some generic examples of data presentations and analyses useful for quality review:

- overplots of original and processed data vs. time, with
  - comments and gaps marked, and
  - quality code identified, e.g. by trace colour(s)
- auto-scaled overplots of processed data with corresponding reliable data at another site, or a related variable at the same site
- auto-scaled overplots of surrogate and target variable(s) vs. time
- quality plots reproduced using the processed data (see Section 3.6.4)
- plots of difference between original and processed data vs. time
- cumulative departure of original from processed data
- comparison of the distributions of original and processed values for the same period
- tabulations and/or scatterplots of deviations from reference values, before and after processing
- mass or double-mass curves of:
  - original and processed data
  - processed data with corresponding reliable data at another site
- Analysis of timesteps, e.g. by ranked maxima or plot vs. time.

Specific examples for each variable can be found in the Annex for that variable.

7.3 Audit

An audit is a more formal quality check of data already archived. Review of the data presented for audit is recommended to be carried out by a suitably qualified and experienced practitioner who is independent of the recording agency.

Once audited it is very unlikely for data to be altered in future unless new information relevant to the period of data is obtained.

7.3.1 Benefits of audit

An audit reviews longer periods of data that are the result of several archive updates. As such, in addition to a final check on appropriateness, integrity, and completeness of the data processing and complied metadata, it considers:

- continuity between successive updates
- stationarity, and
- comparison with other data in a broader context, including opportunity to review data for related variables together, e.g. a combined audit of the stage record, gaugings and ratings for a site.

Following review, the data should be free of unexplained errors and uncertainty. Some deficiencies may remain in the data after audit, but the user of the data is made fully aware of them from the audit and can decide to proceed or not on that basis.

Further alteration of data that have passed an audit shall be formally controlled.

Information resulting from an audit about reliability, accuracy and utility of the data shall be collated into a formal report that is understandable by a knowledgeable third party and can be stored and retrieved in the future.

7.3.2 Audit cycle

A data audit shall:

- be undertaken at regular planned intervals appropriate to the needs of the agency and data users, or
- as defined by an organisation's quality management system, and
- generally, include no less than two consecutive years' data, and
- where the dataset includes transformations, include all periods of amended and new transformations since the last audit plus a period of 12 months preceding, or since station inception if less than 12 months prior.

7.3.3 Minimum audit requirements

As a minimum, for any variable, the analyses and information required for an audit are:

- site and deployment details:
  - location map with all relevant station locations identified
  - site details summary:
    - identify the water body and catchment or region, or airshed, as applicable
    - identify the site purpose and any projects and stakeholders related to the record
    - state any limitations for data use
    - include associated variables, if available
    - identify stations used for comparison
    - for each station identify:
      - period of record included (using NZST)
      - station name and/or number
      - map reference
      - altitude, and
      - sensor type
  - instrument and installation details summary:
    - type(s) deployed
    - expected accuracy and resolution of each
    - summary of calibration history
  - photographs of the site and key features of the installation, with dates, location, and direction of view referenced
  - data verification method(s) summary
  - details of any supplementary measurements, and compensations or conversions applied to the data
- the comments and quality coding attached to the records, reconciled with the data plots and/or tabulations, and summarised for overall quality achieved

  Note: A year-by-year % stacked column chart of the quality coding applied provides a useful overview of quality achieved.

- data tabulations:
  - listing of gaps
  - listing of periods transformed and each transformation applied
  - listing of periods of synthetic data, and
  - extremes of data range for the full period
- data plots:
  - for the period of audit plus the year prior

  - for the decade, i.e. audit period plus previous nine (9) years
  - full scale of data recorded, and
  - partial range, to permit inspection of low to medium range if the data are highly skewed

    Note: Trimming the range at the upper quartile of the dataset usually suffices.

- deviation plots and/or tabulations:
  - before and after adjustments to reference(s)
  - demonstrating goodness of fit of any relationships applied
  - before and after transformations, including compensations and variable conversions (e.g. a bed plot for a rated flow station)
- timestep analysis

  Note: This is useful to identify unmarked gaps, and changes in method such as sampling interval or data compression that should reconcile with comments filed. The analysis may include plots of timestep vs. time, a distribution of the timesteps, and/or tabulation of their ranked maxima.

- data comparisons with at least one other suitable site and/or variable, to demonstrate that there are no obvious remaining anomalies in the record

  Note: "Suitable" should be determined by mutual agreement between the recording agency and auditor. Statistical techniques such as double mass curves, direct comparisons of variables, or relationships between stations and/or variables (e.g. difference or correlation) may be employed.

- summary of annual station inspections that cover the period of audit, beginning with the most recent inspection prior to the period of audit
- summary of reference(s) used and their reliability
- assessment of stationarity, evaluating:
  - potential causes of loss of stationarity, such as:
    - change of instrumentation type, precision, or range
    - a different surrogate variable measured
    - change of laboratory provider
    - change of measurement location, perhaps due to changes in a riverbed or other conditions
    - change in conditions at the site, e.g. a new water take or discharge, or significant vegetation growth

        - changes in a natural system such as a catchment, perhaps related to planting/harvest and other land use change, and
        - effects of climate change
    - changes in statistics, such as annual or seasonal maxima or minima
    - persistent non-conformance with expected verification tolerances
    - for some variables, a discontinuity in double mass curves or their equivalent.

7.3.4 Other requirements

7.3.4.1 Audit content

Requirements specific to a variable, in addition to those listed in Section 7.3.3, can be found in the relevant Annex for that variable.

Audit of variables derived from surrogates, such as flow from stage or suspended sediment from turbidity, should include the target and surrogate series and the relationship calibration data.

It is prudent to audit at-point data within a region or water body together, for example, all rainfall records from a catchment or all water quality data from a lake.

Records other than those under review may be included in the audit. Where available, reliable records from other agencies may be used.

7.3.4.2 Audit outputs

Recommended audit outputs include:

- a mandatory electronic report, and
- an optional hard copy report.

7.3.4.3 Audit certification

The completed audit report shall contain:

- a list and/or summary of tests applied
- a list of any periods that have not passed audit, with reasons
- the name and signature of the auditor, and
- the date that the audit was signed off as completed.

8 Preservation of Record

8.1 Archiving policies, procedures and systems

The recording agency shall develop, maintain, and implement policies, procedures, and systems for the permanent archiving of records, including those needed for traceability of the data and the assessment of stationarity and fitness for purpose. These policies, procedures, and systems shall address:

- identification of records to be permanently retained
- provision of suitable secure and permanent storage for those records
- requirement for backing up electronic data
- future data format changes
- future obsolescence of hardware and/or software
- potential deterioration of media
- ability to access records as and when required
- the need for off-site duplication of records, and
- the organisation's disaster recovery plan.

8.2 Records required to be archived

The following records shall be stored, retained indefinitely and, if electronic, backed up regularly:

- original data as defined (see Sections 3.1.1, 8.2.1 and 8.2.2)
- final data as verified
- supplementary data, preferably registered, and quality reviewed (see Section 7.2) with gross errors addressed if not fully verified and processed
- all required metadata (see Section 6 and relevant Annexes)
- additional time series and/or metadata as specified in the 'Preservation of Record' section of the relevant Annex.

Note: Paper records may be scanned and stored electronically.

8.2.1 Original data

When pre-processing is carried out on the data logger or by a telemetry system, or the data are changed on import (e.g. compressed or transformed), the first write of the data to the time-series management system that will be used to process and permanently store the data is not the raw data as captured.

In such cases, recording agencies may, as appropriate to their systems and the incoming data, retain original data by a suitable combination of the following methods:

- storing the raw and the modified data on the data logger (or telemetry system) and retrieving (and retaining) both
- storing the files from the field stations as received, prior to writing the data to the time-series management system (possibly in a variety of formats, which may make subsequent retrieval difficult)
- writing incoming data simultaneously on receipt to an unmodified raw data time series and to the telemetry/production system,
- accepting the first write to the time-series management system as the original data provided all pre-processing is fully documented, traceable, and reversible by, for example, also permanently storing all logger code and reporting all changes made during pre-processing.

The raw (as measured) data may be required at a later date, should the processed and archived final data (and/or the archived original data if pre-processed):

- be found to be in error
- become corrupted, or
- be lost.

Note: Data stored in a multitude of small files of various formats that require reimport may make future retrieval of that data very difficult.

8.2.2 Archiving non verified data

A recording agency may choose to permanently archive, as a final version of the data, a record that is not verified. Usually, the record is a time series of original or supplementary data.

Original data (non verified) that are permanently archived as a final record must:

- be identified as such in a Data Comment (see Section 6.2.4.6)
- be described by Site, Equipment and Operational Comments as for a processed and verified record (see Section 6.2.4)
- retain a quality code of QC 0 (non verified), and
- have their site metadata (see Section 6.1) and data acquisition records (see Section 6.2.1) permanently retained and accessible from an associated station history or site file, or similar.

For supplementary data that are permanently archived as a final record but not fully verified and processed, the following are required in addition to the requirements as listed above for original data:

- a quality code of QC 200 if data are edited and/or quality reviewed (see Sections 3.1 and 7.2)
- Data Processing Comment(s) to explain any editing (see Section 6.2.4.7)
- any variable-specific requirements in the relevant Annex.

8.3 Housekeeping

Data processing can create several copies and versions of information that must be managed, but many will be working versions and temporary files not required to be permanently retained.

If the time-series manager and existing document management system(s) do not provide or enforce housekeeping procedures to control proliferation of unwanted files and data, and prevent corruption, loss or muddling of data that are required to be permanently retained, the recording agency must develop, maintain, and implement the necessary policies, procedures, and systems separately. These should include:

- update/archiving register(s)
- physical authorisation procedures
- establishing filing protocols and systems
- establishing indexing systems
- file and/or time-series naming conventions
- establishing personal and shared work areas and protocols for their use
- protocols to regularly clear junk files.

Housekeeping procedures must also be developed and implemented to ensure referential integrity and security of any verification information and/or required metadata that are stored and maintained separately from the time-series management system, for example, instrument calibration records stored in an unlinked asset management system.

8.4 Storage of physical records

Physical records should be stored in suitably dry and secure storage indefinitely, with an adequately maintained indexing system to enable retrieval of specific items when required.

Some safeguards are required to prevent deterioration, for instance due to mould, insects, vermin, or birds. A digitised or scanned version of a paper record can be kept in preference or as an additional safeguard.

Some media may gradually become unreadable for other reasons. For example:

- dust accumulation on, or age deterioration of, magnetic media
- ink degrading due to light
- foil-backed punched-tape binding to itself if tightly wound
- required hardware and software becoming obsolete (e.g. tape and datapak readers, floppy disk drives).

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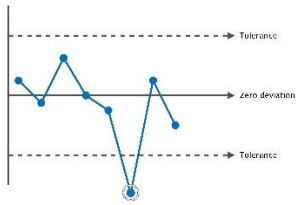
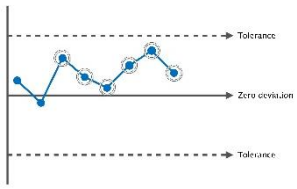
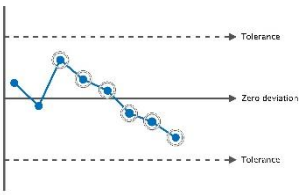
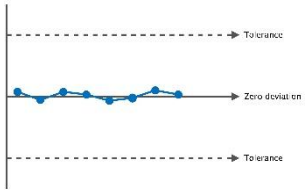
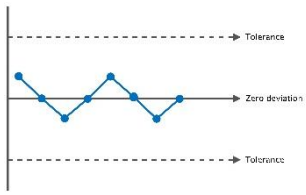
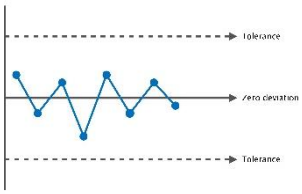
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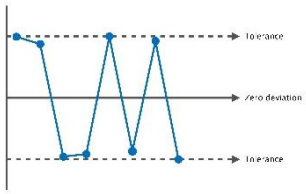
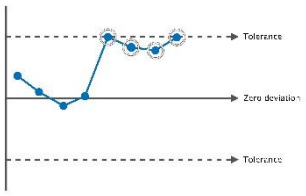
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Appendix 1 - Interpreting Control Charts

The following table explains the features identified by control charts that should be followed up with diagnosis and remedy on site and editing of the data as needed to minimise the effect of the fault discovered or assumed to have occurred (after investigation).

Table 3 – Guide to interpreting control charts.

	A single value considerably beyond tolerance. The anomaly may be a spurious error, which are often human in origin.
	A run of deviations (although possibly within tolerance) but all biased in one direction. This is a systematic error, usually associated with method, i.e. something has 'shifted' in the measurement system.
	A trend in deviations (although possibly within tolerance). This is a systematic error indicating some drift in the measurement system.
	Deviations closely hugging zero compared to the tolerance. This may indicate the tolerance is too wide and the analysis is therefore not delivering the desired 'control' information.
	Deviations cycling (although possibly within tolerance). This anomaly may indicate interference of some kind that has a regular cycle, e.g. seasonal effects, weed growth, abstraction activity etc. It may not be feasible or appropriate to modify the installation and/or the data but any such behaviour identified should be explained in a Site Comment.
	Oscillating deviations (although possibly within tolerance). This is abnormal. Deviations should be random. This anomaly may be associated with unnecessary adjustment of the measurement system at each visit.

	Deviations hugging tolerance. This anomaly indicates the measurement system may not be delivering the desired resolution, or that deviations are from a mixture of 'samples', e.g. from use of two or more different reference instruments, such as multiple staff gauge boards with slightly different zeros or that are sited in different flow conditions.
	A 'step' in the deviations. This anomaly is similar in cause and effect to a run but is usually obvious sooner than for a run.

Appendix 2 - Using Regression Analysis to Synthesise Record

The recommended procedure for using regression analysis to synthesise a record is:

- compile the data for analysis
- scatterplot the data, with the donor site as the X-value and the recipient site (i.e. the site with the missing data) as the Y-value
- if no relation is evident do not proceed
- if the relation is apparently non-linear, fit a curve rather than a straight line, or transform the data, e.g. by taking square-root or logarithms, so a straight line may be fitted
- assess the goodness of fit (usually consideration of the regression coefficient R^2 is sufficient)
- inspect the residuals; they should be small and randomly spread without apparent trend or cycle
- apply the regression equation to predictor (donor) site values to synthesise predicted values for the recipient site
- plot the modelled data with the actual data to check its suitability
- apply quality code QC 300 to the period of synthetic data incorporated in the final record
- file a comment that explains the cause of the missing data and describes the regression including the donor site(s), period used for analysis, timestep and form of the data analysed, sample size, equation applied to generate the synthetic data, and the regression coefficient (R^2).

There are several aspects to consider when performing regression analysis.

- Because predictive power of a regression is a trade-off between bias and variance, analysis is usually best carried out using as long a concurrent record from suitable donor and recipient sites as possible.
- However, regression analysis models the average behaviour between two variables and is therefore an over-simplification that may not be a good representation for an individual period of missing record. Reliability may be improved by regressing shorter periods of concurrent record closer in time to the period of the gap (McKerchar et al, 2010).
- A suitable period and timestep for the input data must be decided, and whether the data will be transformed in some way, such as by taking daily means or logarithms. Interval of the data to be analysed should match the desired interval of the synthetic data to be generated. Regression analysis may need to be repeated several

times to explore what form is best, and to check for seasonal bias. If synthetic data are required to be filed at a different timestep, a new regression equation must be derived.

- Usually, because of its simplicity, least-squares regression is preferred, but the method may cause reduced variation in values at the recipient station (Johnston, 1999) leading to under-representation of extremes. Extremes must therefore be independently corroborated.
- X and Y are not interchangeable as they are for correlation. The equation obtained from regressing X on Y (i.e. using values of Y to predict X) cannot be used to predict Y from X by simply rearranging it mathematically if you happen to analyse the data back to front.
- Least squares regression is sensitive to outliers. An extreme value in the analysis creates a long 'lever' to the relationship and often falsely improves the regression coefficient (R^2).
- The regression equation could be linear or curvilinear, and/or developed from multiple donor sites.
- The regression coefficient R^2 is not valid for non-linear regression but fitting a curve to your data is not necessarily non-linear regression. Linear regression refers to linearity of the model parameters (i.e. the regression equation looks like $Y = a_0 + b_1X_1^n (+ b_2X_2^n \ldots)$) so you can fit a curve by raising the independent (X) variable to some power, or have multiple equations added together and still use R^2 as an indication of goodness of fit.
- Transforming back from logarithmic to natural space introduces a transformation bias that, if significant, should be compensated for prior to filing the synthetic data.
- Best modelling practice is to partition the input data, derive the relation using one half of the data, then test goodness of fit/describe the accuracy of prediction using the other half.

Further guidance may be found in Helsel and Hirsch (2002) but be aware that the United States does not use the metric system so quoted formulae may carry additional constants to convert the units.

Appendix 3 - Significant Figures and Decimal Places

Real numbers are recorded with a number of significant figures and decimal places. Significant figures are those that are known with some degree of reliability; for example, 13.2 has three significant figures and 13.20 has four. The number of digits following the decimal point is known as the number of decimal places (DP); for example, 13.2 is written to one decimal place (1 DP) and 13.20 to two (2 DP).

The position of a zero makes a difference. If a decimal number starts with a string of zeros, they are leading zeros and if it ends with a string of zeros, they are trailing ones. In the examples below, red digits are leading zeros and blue digits are trailing zeros.

0.01204	**103.450**	**10300**	**0.1234560**
leading zeros	*trailing zeros*		*leading and trailing*

There are five main rules in deciding how many significant figures a number has:

- All non-zero digits are significant.
- Zeros between non-zero digits are significant (e.g. 103 has 3 significant figures).
- Leading zeros after a decimal point are not significant; they only indicate position of the decimal point (e.g. 0.012 has 2 significant figures).
- Trailing zeros before the decimal point are not significant (e.g. 120 has 2 significant figures).
- Trailing zeros after the decimal point are significant (13.20 has 4 significant figures).

When performing calculations:

- The least precise measurement, in general, determines the number of significant figures in the result.
- When adding or subtracting, round the result to the same least significant digit position (i.e. number of decimal places) as the least precise measurement, for example:

  100 + 23.6 = 123.6 round up to 124

  100.0 + 23.6 = 123.6 as is

  100.02 + 23.6 = 123.62 round down to 123.6

- When multiplying or dividing, round the result to the same number of significant figures as the measurement with the least number of significant figures, for example:

  3.0 ∗ 12.60 = 37.800 round up to 38

3.00 ∗ 12.6 = 37.800	truncate to 37.8
3.0001 ∗ 12.60 = 37.80126	round down to 37.80
3 ∗ 0.01260 = 0.0378	do not round up to 0.04

(see exceptions below)

- When averaging, round the result to the same number of decimal places as the sum of the measurements (which should all be to the same resolution), for example:

  130 + 42 + 15 = 187, divided by 3 = 62.333, round down to 62

- Carry as many digits as possible through a calculation then round the final result, for example:

  (5.00/1.235) + 3.0 = 7.04858, round down to 7.0

Exceptions:

- If converting between units, loss of significance as a consequence of the above rules may imply more uncertainty in a result than is reasonable.

  Example: A measurement of 8 inches implies uncertainty of ± 0.5 inches or ± 1.27 cm. Converting to cm, 8 ∗ 2.54 = 20.32 cm, which rounds to 20 cm with implied uncertainty of ± 5 cm. In this case the trailing zero in the rounded result might be considered significant such that the implied uncertainty is ± 0.5 cm.

- If multiplying or dividing by an integer (e.g. a count), treat the calculation as repeated addition or subtraction.

  Example: 3 ∗ 0.01260 = 0.0378 rounds to 0.04 under the multiplication rule whereas 0.01260 + 0.01260 + 0.01260 = 0.03780 with no rounding as addition.

Annex A Water Level Data Processing

1 General Overview

This Annex contains further processing guidance specific to continuous water level data captured and stored as data type instantaneous (continuous) (see Section 1.1.1).

1.1 Normative references

This Annex shall be read in conjunction with the following references:

- NEMS Water Level – Continuous Measurement of Water Levels for Environmental Monitoring Purposes
- NEMS Site Surveys – Code of Practice

Where reference is made in this Annex to specific sections of the above documents, the title is abbreviated and version stated, e.g. 'NEMS Water Level v4.1.0'.

2 Quality Control

2.1 Additional metadata required

General requirements for site metadata are set out in Section 6.1. The following additional metadata, as applicable to the site and deployment, are required to be available when verifying water level data:

- surveyed information, including:
  - checks of datum continuity over time
  - cross-sections at key locations (e.g. recorder, control, standard gauging section, top and bottom of slope–area reach)
  - reduced levels of the sensor (e.g. orifice or intake pipe(s)) and key parts of the installation (e.g. recorder floor level, base of tower, top of bore casing, dip measurement initial point)
  - elevation and angle of section, if any, of any permanent structure used for gauging (e.g. a bridge)
  - bankfull level
  - cease-to-flow level, if possible
  - bathymetry, where available
- depth below surface of sensors suspended from buoys or platforms
- details of all structures, including:
  - design
  - as-built plan
  - photographs

    - records of any certification requirements
- photographs of controls and the environs of wellheads, buoys, and platforms etc., and any changes to these.

These metadata must be verified and permanently archived with all other metadata as described in Section 6.

2.2 Plots and comparisons

- Check around the time of each site visit for anomalies introduced by inspection and maintenance activities, and to identify steps in the data introduced by cleaning, or replacing or reconfiguring the sensor, data logger, and/or the installation.
- Check continuity of cycles in the data, e.g. tide or abstraction.

2.2.1 Comparisons

- Criteria for deciding a suitable comparison site are similar to those for selecting a suitable infill record donor site. See Appendix A.1 Section 3.
- Rainfall is often more informative if over-plotted as a cumulative trace.
- Use flow for comparisons if bed-shifts may confuse interpretation; however, the required ratings for both sites must be available and reliable.

  Note: A between-station flow comparison can help identify where a rating shift is needed.

  Note: Double mass plots are useful for assessing long-term stationarity of the flow data but not very helpful for day-to-day quality control of a water level record (a large but short-duration error may have very little overall effect on the mass curve).

In addition to cross-checking specific features in the data, look for disruption of:

- shape and pattern in the hydrographs
- lag times, and
- relative scaling of events.

Do not discount the possibility that problems may be transient and occur (and resolve) between site visits.

2.3 Reliability of reference values

When using primary (and other) reference values to verify or to adjust recorded water levels the following should be assessed and considered:

- range-dependent variations in accuracy of staff gauge readings, arising, for example, from:
    - high stage boards that are some distance from the sensor

    - wave lap and surging
    - difficulty reading due to accumulation of debris, staining, reflection, or distance
    - penetration (of distance meters)
- the uncertainty of the reference reading(s)
- timing of the reading in relation to the rate of change of level
- stability of staff gauges and initial points.

The accuracy tolerances for water level data are small and can be overwhelmed by uncertainty in the reference reading, in which case:

- instrumentation and data should not be adjusted to reference values in these circumstances unless there is other corroborating evidence of faulty recording
- if adjusted, the adjustment(s) should be reviewed when reliable reference readings resume
- if reference reading uncertainty exceeds tolerance, or a reference reading is discarded as unreliable, the period of record that would be verified by that information shall be quality coded no higher than QC 500.

At stilling well sites, if there is no EPB installed, maximum quality code that can be assigned to the data is QC 500 because the required primary reference instrument is absent. The impact on data quality arises from:

- there being no independent means available to verify that recorded measurements of well water level are accurate
- inability to independently demonstrate hydraulic connection between the water body and the stilling well is functioning uninhibited by silt or lag, and
- verification being reliant on reference readings from a staff gauge or similar external device that are generally less accurate than readings obtained from an EPB.

Investigate datum continuity if there is persistent bias, regardless of tolerance.

2.3.1 Datum continuity

Measurements of stage are defined as water levels above a known datum. Maintaining site datum and gauge zero is therefore a critical aspect of water level measurement.

A change of datum or gauge zero must be commented and may be compensated by an offset correction to the water level data, or if stage is being measured as a surrogate for flow, by a shift in the stage–discharge rating.

Identification of movement in any benchmark or reference level is easier if the datum continuity analysis over time is carried out using the differences in elevation rather than the actual elevations. Differences in elevation between at least three survey marks are required to be analysed to identify which mark is moving.

Refer to NEMS Water Level (Water Level Field Measurement Standard) for the site reference requirements for various site types, and to NEMS Site Surveys (Code of Practice) for how to survey and track the site datum, reference levels and gauge zero, and maintain those records in a Station History.

2.4 Deviation tests

NEMS Water Level (Water Level Field Measurement Standard) tolerance is expressed as absolute or percent deviation depending on stage. The performance criteria can be combined into a single control or run chart by using a secondary axis on the one chart (Figure A 1) or stacking the charts (Figure A 2).

Use a deviation with range test to monitor range-dependant issues such as reference reading uncertainty, reference reading bias if using multiple gauge boards, and sensor calibration drift.

At stilling well sites where the primary reference is the plumb-bob, incorporate the external readings as a second set of reference values.

For water levels that range over an order of magnitude or more, such as at river sites and some groundwater sites, scatter-plotting logged values versus corresponding reference readings is of limited use. It is best to work with the differences.

Where reliability of reference readings varies, account for their uncertainties (e.g. use error bars on plots).

Radar and other 'down-looking' sensors operate upside down and have better accuracy closer to the sensor. The tolerances must still be applied in the conventional sense of a greater expected accuracy at low stage and low flows.

Tests may be configured to update automatically with new data from the field.

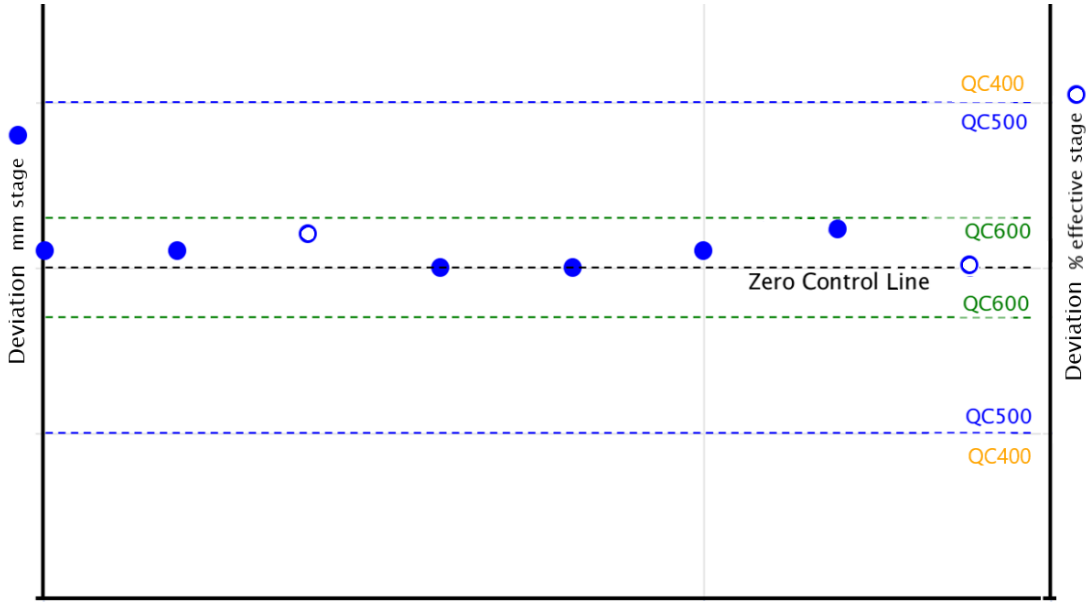


Figure A 1 – An example of a control chart with secondary axis where data are plotted in sequence using the axis applicable for the tolerance test, scaled to align the limits.

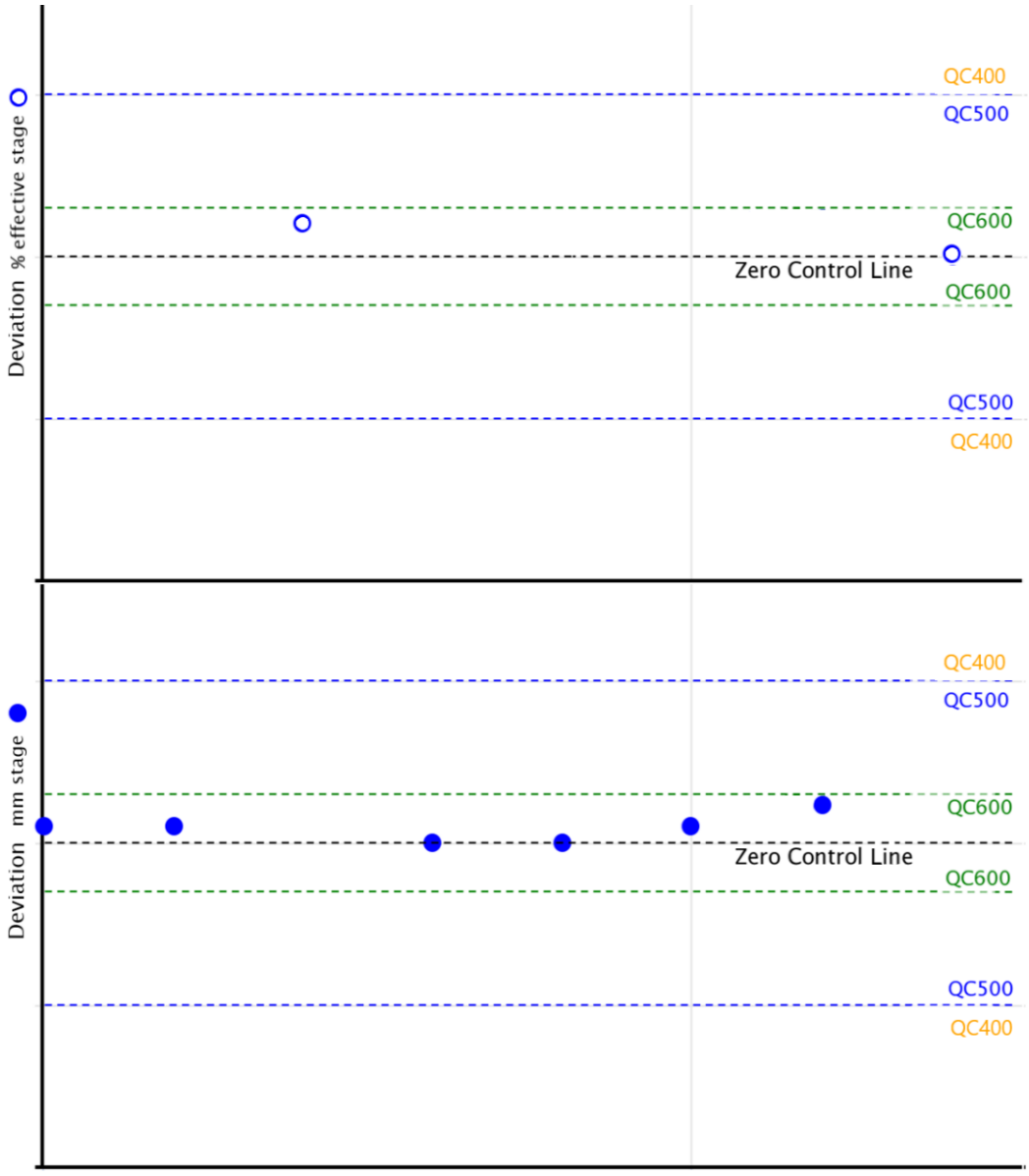


Figure A 2 – An example of a stacked control chart where data are plotted in sequence, but on the top or bottom chart depending on the applicable tolerance test.

3 Potential Errors and Recommended Editing

This section describes common problems specific to water level data, and guides selection of an appropriate method for data repair, including what metadata are then required to be applied and filed.

3.1 Sources of errors

- The water environment (e.g. flow variability, groundwater aeration, stratification, tidal influence).
- Site factors (see NEMS Water Level v4.1.0: Section 1.3 'River stations', 1.4 'Lake and reservoir stations', 1.5 'Groundwater stations', or 1.6 'Sea level stations').
- Interference, deterioration, and damage (e.g. human, biofouling, hydraulic conditions etc.) (see NEMS Water Level v4.1.0: Sections 1.3, 2.7, and 3.1 to 3.3 incl.).
- Maintenance of recording datum (see NEMS Water Level v4.1.0 Section 2.8).
- Dependence on supplementary measurements (e.g. barometric compensation of unvented pressure transducer record) (see NEMS Water Level v4.1.0 Sections 1.6.2 and 7.2.7).
- Instrument and installation function and operation, and conditions that adversely affect them (see NEMS Water Level v4.1.0 Section 2).

3.2 Unintended offset or incorrect change of offset

The recording of water level requires a known and fixed datum be maintained.

Installation or instrument instability, or a device reset after power interruption, may cause a shift in recording zero that creates an unintended offset, biasing subsequent data by a constant or near-constant amount.

Some sensors must be installed at a different level to the recording zero, which then requires an offset be applied to obtain stage in terms of the gauge datum. This offset is usually programmed into the logger. If a mistake is made calculating or entering the offset, the data collected is biased by the amount of error in the programmed offset.

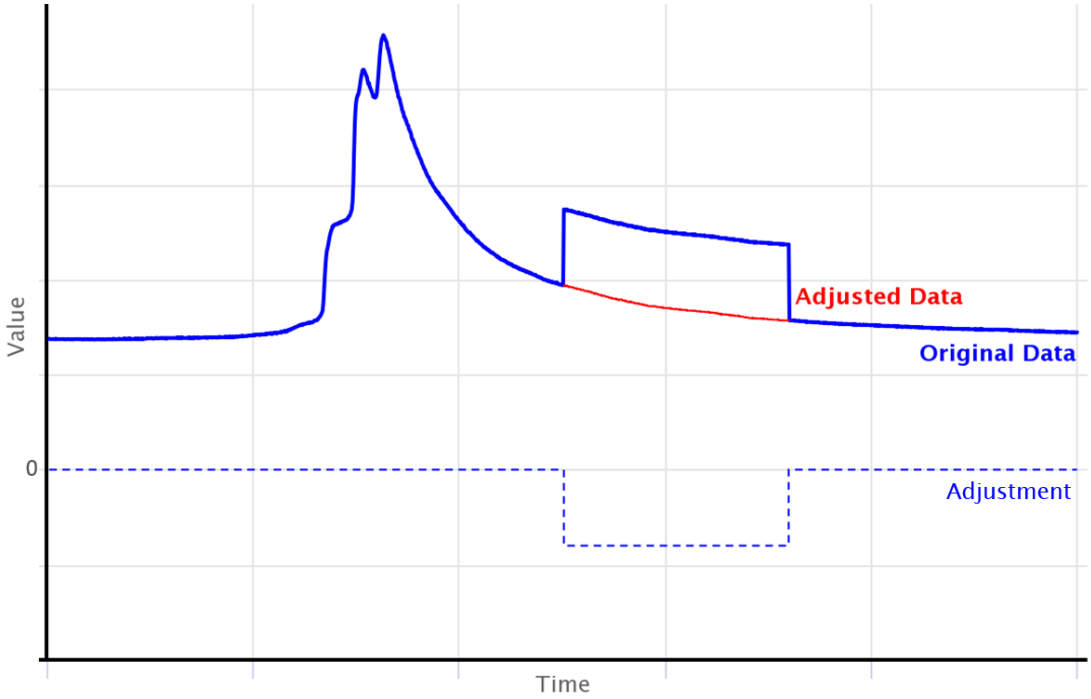


Figure A 3 – An example of part of a hydrograph offset by a constant or near-constant amount (blue line) with the adjusted data (red line) and showing the adjustment applied (blue dotted line).

Table A 1 – Guidance for resolving an unintended offset or incorrect change of offset

Guidance for resolving an unintended offset or incorrect change of offset		see Section(s)
Issue(s)	A period of data is biased by a constant or near-constant amount.	A 3.2
Evidence	Pairs of opposing steps in the data. Period between is 'offset' from surrounding data by a constant or near-constant amount; observable in a data plot and/or deviation track, e.g. control chart. Physical cause may be identifiable, observable, and traceable at site by levelling and/or checking the logger program.	Fig. A 3 A 2 3.6
Solution(s)	Apply an offset shift to the biased period.	4.2
Metadata	If the correction required is fully traceable, quality code is unaffected, but a Transformation Comment is required. Otherwise, 'minor' (QC 500) or 'significant' (QC 400) modification criteria apply and a Data Processing Comment explaining identified cause and details of the amount and period of adjustment is required.	A 4.2.6 6.2.4.8 6.2.3 A 4.2.5 6.2.4.7

3.3 Steps in the data

Steps in the data may result from instrument resets, or from interference or fouling affecting the sensing system or the flow control(s). Cause of the step dictates how the preceding data should be repaired.

3.3.1 Instrument resets

If the step is due to an instrument reset:

- ensure it is not one half of a needed offset correction (see Section A 3.2)
- some form of drift leading up to the reset must be assumed to have occurred if the step is not a result of a change of datum and/or offset.

If the instrument is reset to implement a permanent datum shift:

- all prior stage data can be adjusted by the difference in datum, or
- the step can remain in the data, but with:
  - a filed comment alerting and explaining its presence, and
  - a new rating applied from the time of the shift, in which all stage values are adjusted by the difference in datum, if the water level record is intended as a surrogate for flow.

3.3.2 Interference

Steps in the data due to interference may be transient and self-correct, or persist until rectified during a site visit, or may result from an event that initiated a step-change in all subsequent data. Its source may be:

- mechanical, such as a float or counterweight catching on a valve, ladder, or other equipment in the well

  Note: Levels of potentially interfering items in a well should be known and recorded in the site file.

- environmental conditions such as temperature (freezing or heating), high sediment loads, or hydraulic effects such as backwater
- a combination of mechanical and environmental such as barometric pressure effects in a record from a pressure transducer with a blocked vent
- activities such as engineering works in the vicinity of the recorder.
- Steps in the data due to interference may be compensated, as applicable, using:
- relationships with secondary measurements (e.g. temperature and/or barometric pressure compensation) (see Section 4.9)
- stage–discharge ratings if stage is being recorded as a surrogate for flow (refer to NEMS Rating Curves) and the interference directly affects the flow control(s)
- stage adjustment methods for fouling (see Section A 3.3.3), sticking or jamming (see Section A 3.3.4), silting (see Section A 3.4) or drift (see Section A 3.5).

Compensation for a repetitive problem should be applied consistently through a record by way of stage–discharge rating changes or stage adjustment. It is not good practice within a record to arbitrarily swap between methods for the same problem. Applying both methods to the same period should also be avoided.

3.3.3 Fouling

Fouling may be due to the accumulation of weed, debris, or sediment at, in or over the sensor, or to the ingress of animals or moisture into the workings of the sensing system.

Accumulation may be gradual or episodic and may self-clear naturally, or via some form of automated purging system, or persist until cleared during a site visit. Duration of any adjustment applied to the data must reflect the assumptions made about the nature, timing and extent of the fouling and its subsequent clearance. In most cases the appropriate adjustment is a simple special case of drift correction often referred to as a one-tailed ramp correction, where the adjustment is an offset that increases linearly with time from zero at the start of the affected period to a non-zero value specified at the end of the period of adjustment (see Figure A 4).

Some forms of fouling may also cause noisy data, which should be smoothed or resampled before any adjustment is applied to eliminate a step (see Section A 3.7).

Fouling of the flow control(s) by debris or sediment is usually addressed by rating shifts (refer to NEMS Rating Curves). Fouling of a flow control due to weed growth may be addressed by stage adjustment or by rating shift but not both. Stage adjustment is generally preferable if the weed can be cleared at each site visit, the rating is otherwise stable, and the necessary adjustment is relatively small. Rating shifts are preferable if the weed is more prolific and persistent and becomes the dominant control feature for lengthy periods.

Stage adjustment may not be able to be guided by reference readings if the reference is also affected by whatever is fouling the sensor. Reference readings set aside due to fouling must be identified and explained in an Operational Comment.

Minor silting of stilling well intakes may be adequately compensated by a simple linear drift adjustment as for other forms of fouling but for blocked intakes and silting of the stilling well (see Section A 3.4).

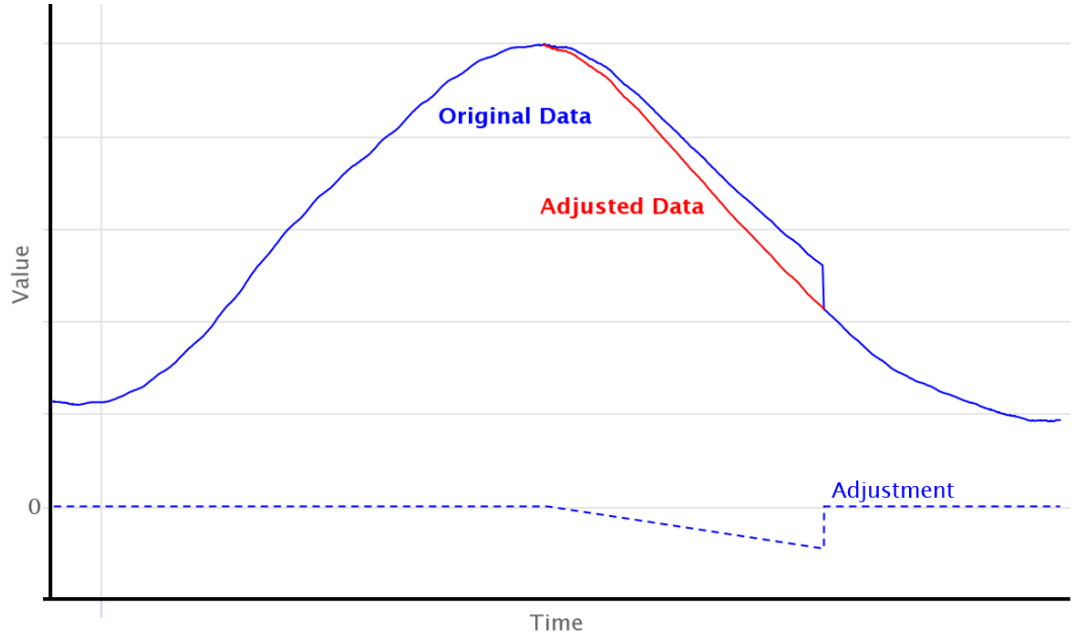


Figure A 4 – An example of an uncharacteristic step in the hydrograph (blue line) with the adjusted data (red line) and showing the gradual linear drift adjustment applied (blue dotted line) that is often referred to as a one-tailed ramp correction.

3.3.4 Instrument sticking or jamming

Instruments that incorporate pulleys or balance beams can record in steps if the pulleys are not free of friction or the balance beam electrical contacts are dirty. Response to changing water level is delayed, followed by a sudden 'catch up' that creates a sequence of steps in the data. 'True' water levels are the top of each step on the rising side of a hydrograph but bottom of each step when stage is falling.

A sticking encoder on a rising stage also has a high risk of the float-tape or beaded-wire slipping. The tape or wire may re-engage in another position and create an unintended offset (see Section A 3.2), or it may not re-engage and 'ride' the pulley.

A pulley with axis of rotation that is not horizontal may also cause the float-tape or beaded-wire to 'ride' the pulley. In situations of riding the pulley, the data are unreliable because the recording zero is no longer fixed. Verification of this situation is a combination of observation of pulley condition and comparison plots, and the affected data may need to be replaced with backup or synthetic data.

Surface followers use pulleys and electrical contact with the water surface. A poor electrical contact from a dirty probe would result in greater immersion of the probe and therefore levels consistently biased low, as well as the possibility of stepping.

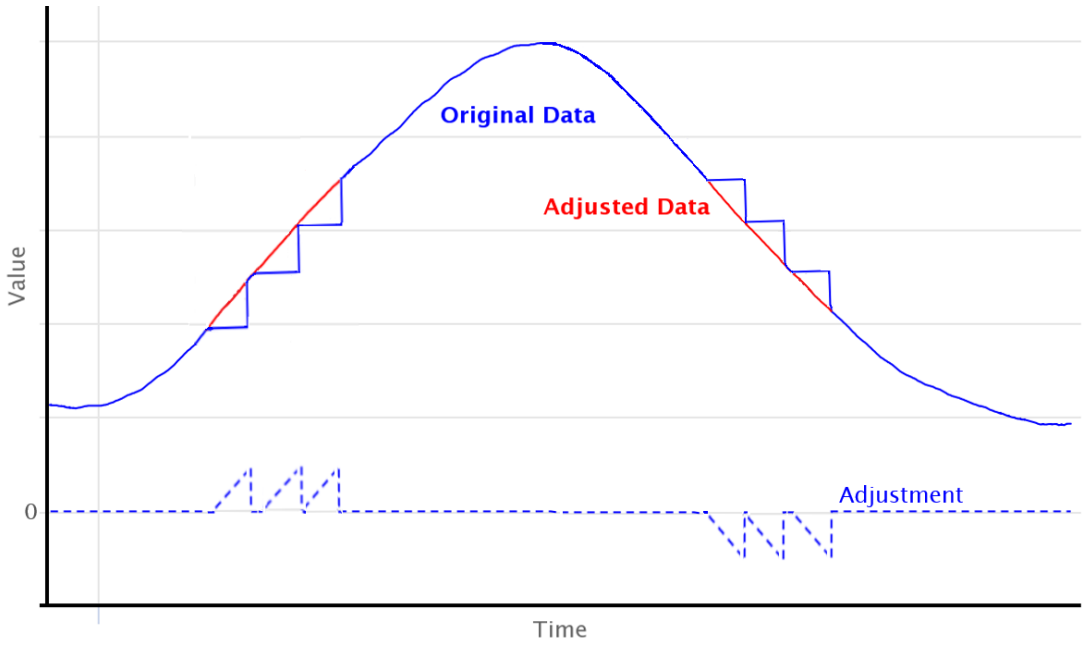


Figure A 5 – An example of uncharacteristic steps in the hydrograph (blue trace) with the adjusted data (red trace) and showing the successive linear drift adjustments applied to eliminate each step (blue dotted line).

Table A 2 – Guidance for resolving steps in the data

Guidance for resolving steps in the data		see Section(s)
Issue(s)	Instrument is not following the change in water level for a time then suddenly 'catches up'. May be repetitive. The surrogate stage record contains a step that translates to a sudden change in flow that cannot have occurred.	A 3.3
Evidence	Physical cause is identified (observed or verified at site, or consequence of an event known to have occurred). Trace of data when plotted steps suddenly up (or down) and may flatline or appear 'held' down (or up) before the step.	Fig. A 4 Fig. A 5 A 2 3.6
Solution(s)	Linear drift adjustment with no (i.e. zero) adjustment at onset of problem and maximum adjustment at the step in the trace, OR stage–discharge rating(s) formulated and applied that eliminate any discontinuity in the derived flow record. Avoid applying drift adjustments over significant events.	4.4 OR NEMS Rating Curves
Metadata	QC 500 or QC 400 depending on matrices and 'minor' or 'significant' change and Data Processing Comment required explaining identified cause and details of each stage adjustment applied (amount and period of adjustment), OR no change to stage quality code and rating(s) quality coded and commented. Flow series acquires lesser of the applicable stage or rating quality codes.	6.2.3 A 4.2.5 6.2.4.7 OR NEMS Rating Curves

3.4 Silting

Stilling wells and their intakes are prone to filling with silt and fines, usually occurring during a flood because floods transport most of the suspended sediment load. Accumulation of sediment in the intake(s) delays filling and emptying of the well causing lag (hysteresis). At site, the lag will be evident as a difference between internal and external water levels read from the plumb bob (EPB) and staff gauge, respectively.

Data affected by minor accumulations cleared promptly by flushing the intake(s) can be treated as fouling using a one-tailed linear drift adjustment applied from the peak of the causative event (zero adjustment) and ending with an adjustment equivalent to the step in the data, usually evident at conclusion of the flush when the intakes are again clear (see Section A 3.3.3). Any atypical 'lumpiness' in the hydrograph indicates a more severe problem requiring additional editing or replacement of the data to achieve a more representative hydrograph.

Intake blockages can become so severe that dampening occurs, minor events may be 'lost', and the shape of the recorded hydrographs is affected (see Figures A 6 and A 7). In such cases the faulty data must be removed and, if possible, replaced with an unaffected backup or a synthetic record.

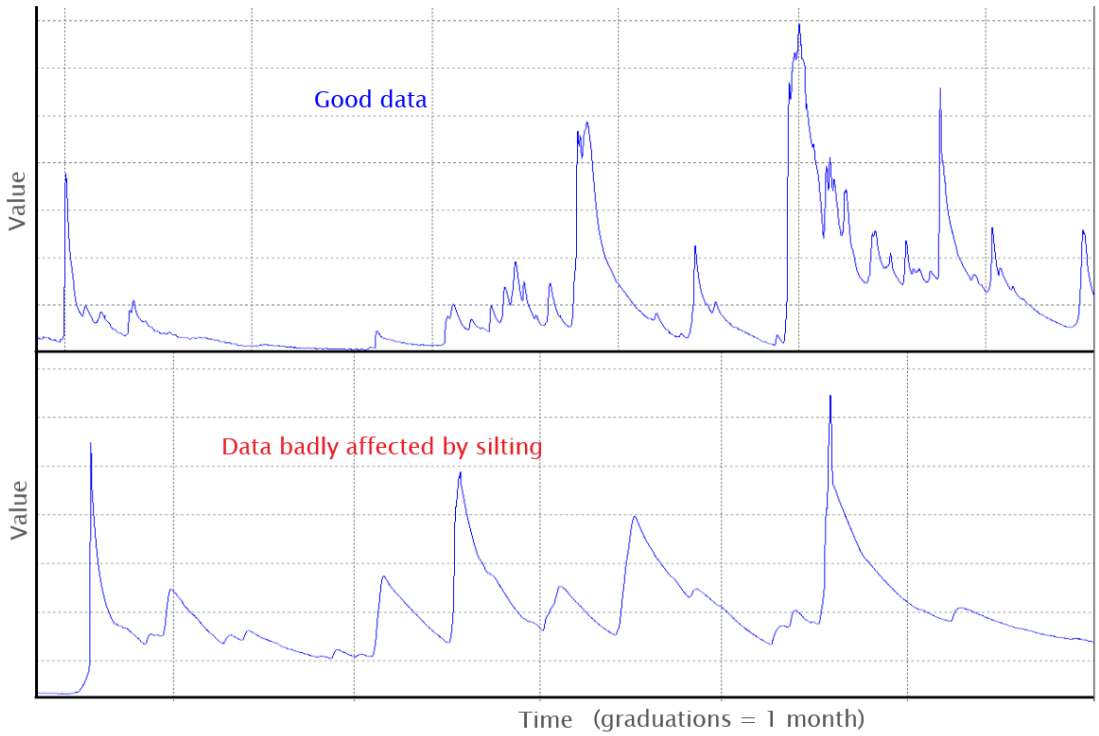


Figure A 6 – Comparison between good data (top) and data badly affected by silting of the stilling well intake(s) (bottom). Data are from the same site and instrument, for the same months, but in different years.

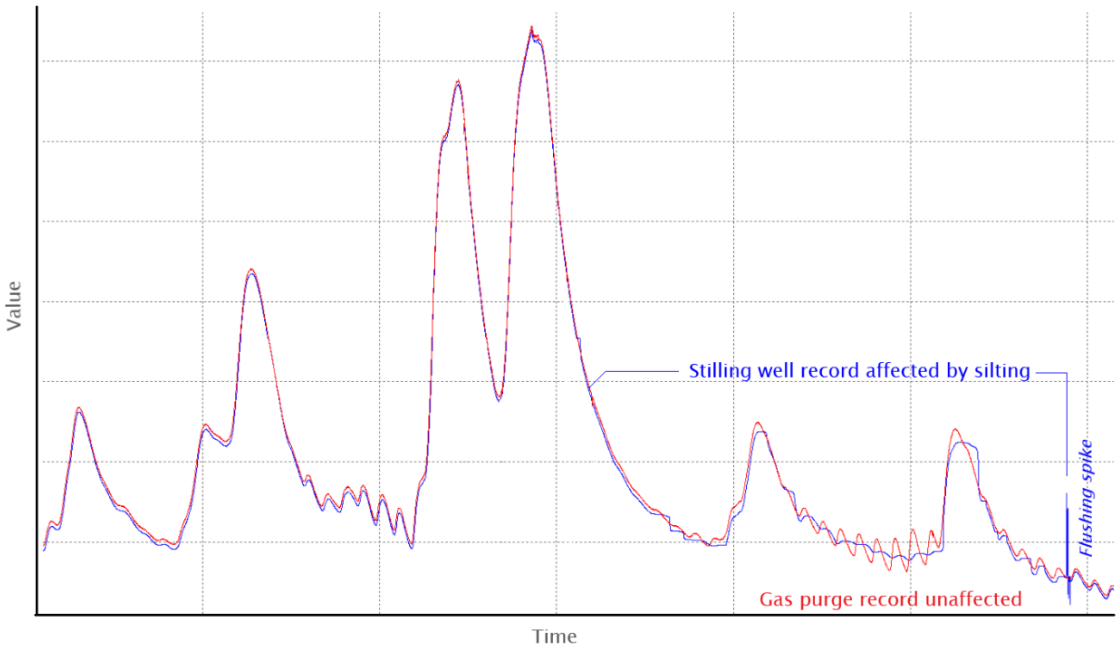


Figure A 7 – Comparison between good data (red trace) and data badly affected by silting of the stilling well intake(s) (blue trace). Data are from the same site and period but from different instruments. The gas purge record is unaffected by silting because its orifice is directly in the river and clear of sediment.

If the well itself fills with silt the full operating range of the float and counterweight may become compromised, or either may become stuck in the mud or an intake may cease to operate if its invert at the well connection is below the silt level. These situations may lead to some truncation of the hydrographs (see Section A 3.8) in addition to the usual silting problems.

Note: Reduced levels of the base of the well and the intake inverts at their connection to the well should be known and available from the station file for reference.

Table A 3 – Guidance for resolving silting effects in the data

Guidance for resolving silting effects in the data		see Section(s)
Issue(s)	Accumulation of sediment in a stilling well and/or its intake(s) results in hysteresis that affects hydrograph shape and may dampen or eliminate the recording of minor events.	A 3.4
Evidence	Differences between internal (well) and external (river) water levels. Results of additional observations and actions such as sounding of silt level, the 'float test', and intake/tower flushing. Trace of data when plotted lags comparison data, exhibits 'lumpiness' and atypical shape, and lacks minor events.	Fig. A 6 Fig. A 7 A 2 3.6

Solution(s)	If minor effect, a linear drift correction with zero adjustment at the peak of the preceding flood and maximum adjustment at the flushing step will suffice. More severe effects may need to be edited (if brief period), or replaced with unaffected backup or synthesised record, or deleted and marked as a gap.	4.4 5 or 4.16 4.20 A 3.11
Metadata	QC 500 or QC 400 depending on matrices and 'minor' or 'significant' change and Data Processing Comment required explaining identified cause and details of each stage adjustment applied (amount and period of adjustment), OR Quality code applicable to the replacement backup record or QC 300 if synthetic, or QC 100 if left missing, and Data Comment required explaining identified issues and details of record substitution.	6.2.3 A 4.2.5 6.2.4.7 or 6.2.3 A 4.2.4 6.2.4.6

3.5 Drift

Other than fouling (see Section A 3.3.3), drift correction is usually needed to compensate for calibration drift. Submersible transducers are most prone. Ultrasonic sensors may also appear to drift but this may have more to do with temperature variations in the air or water column. Immersed ultrasonics normally also sense water temperature and self-compensate, which may be a source of faulty record if that compensation fails.

Calibration drift may be linear or non-linear. Which is applicable must be determined, if possible, by analysis of deviations from reference with time, and/or successive instrument validations. Non-linear drift adjustment may be approximated by a sequence of small linear drift adjustments, but these must be applied carefully to avoid distortion of the record, especially the shape of recessions.

Drift may occur for some time before detection and confirmation. Verification data normally used to control an adjustment may therefore include reference readings that encompass a wide range of water levels, some with large uncertainties. Avoid invalid adjustments by being selective about the reference values used to assess and control adjustment for drift.

3.5.1 Example invalid drift adjustment

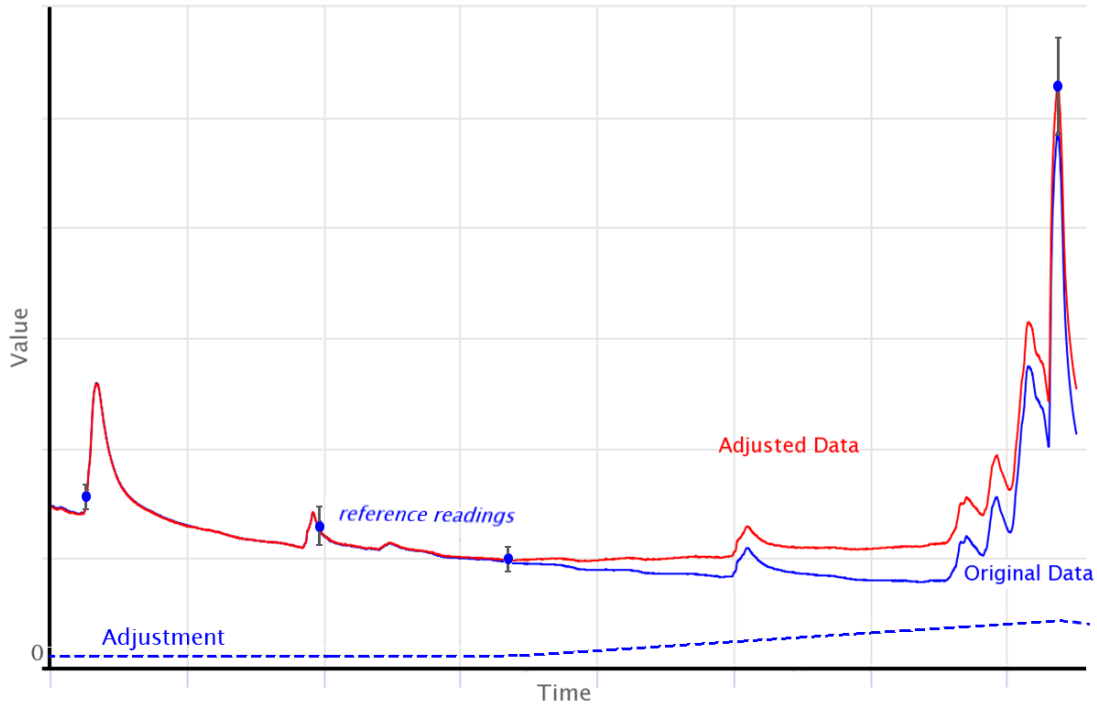


Figure A 8 – An example of a wrongly applied linear drift adjustment where the recession is unrealistically pulled upward by adjustment to a high stage reference value with large uncertainty (as indicated by the vertical error bars).

Table A 4 – Guidance for resolving drift

Guidance for resolving drift		see Section(s)
Issue(s)	Recorded values are biased by an increasing amount over time.	A 3.5
Evidence	Absolute differences between recorded and reference water levels increase with time. Physical cause may be identifiable such as biofouling, silting, or sensor validation results. When plotted, recessions appear uncharacteristically steep or flat.	Fig. 12 Fig. A 8 A 2 3.6
Solution(s)	Apply a linear or non-linear (percent) drift adjustment as applicable depending on whether the drift is determined to be linear or non-linear with time. A non-linear drift adjustment can be approximated by a series of small, short-duration linear drift adjustments, with care.	4.4 or 4.5
Metadata	QC 500 or QC 400 depending on matrices and 'minor' or 'significant' change, and Data Processing Comment required explaining identified cause of drift and details of each adjustment applied (type, amount, and period of adjustment).	6.2.3 A 4.2.5 6.2.4.7

3.6 Spikes

Power supply faults and electromagnetic interference are a common cause of isolated or intermittent spikes.

Isolated spikes in continuous water level data may be deleted or replaced. If deleted, the interpolation engine can be left to interpolate between the remaining adjacent values unless regular interval data are required.

Intermittent spikes may be deleted manually or using a threshold filter. If only one or two successive values are removed at each occurrence the interpolation engine can be left to interpolate between the remaining adjacent values unless regular interval data are required. If more than a few successive values are removed, gap processes are required (see Section A 3.11).

If spiking is frequent, persistent, and affecting consecutive values, treatment as noise is necessary (see Section A 3.7).

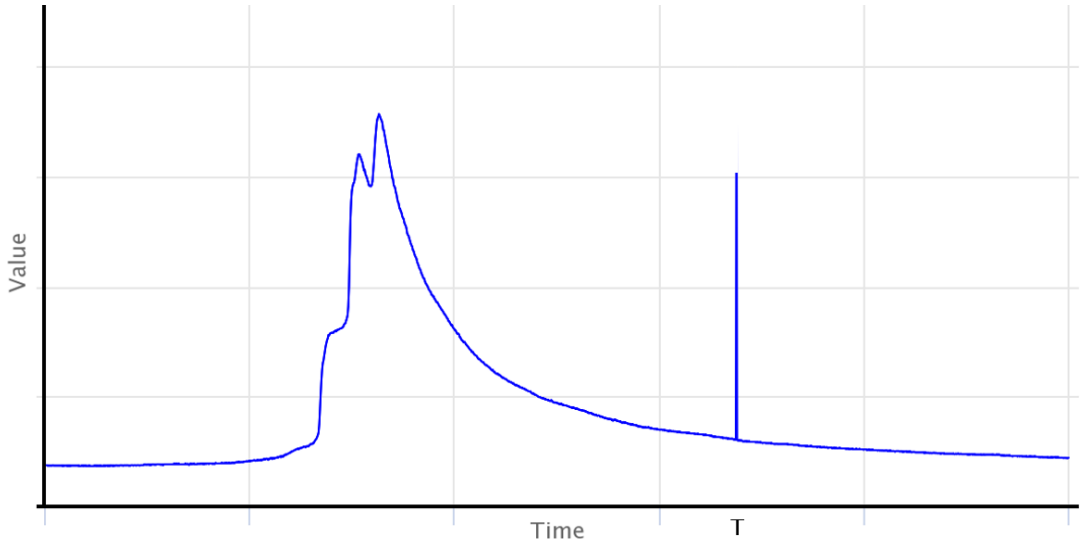


Figure A 9 – An example of a spike at time T that may be deleted or replaced.

Table A 5 – Guidance for resolving spikes in the data

Guidance for resolving spikes in the data		see Section(s)
Issue(s)	Spurious values recorded.	A 3.6
Evidence	Value significantly different from adjacent values. Observable in a plot of the data. Confirmation by field investigation, and elimination of cause if possible.	Fig. A 9 A 2 3.6
Solution(s)	Delete or replace spurious values. If more than a few consecutive values are removed, missing data processes are also then required. If spiking is frequent, persistent, and affecting consecutive values, treatment as noise is necessary.	4.11 or A 3.11 or A 3.7

Metadata	QC 500 unless matrices result is lower and Data Processing Comment required explaining identified cause and whether values are deleted or replaced, OR Refer to missing data or noise treatment guidance as applicable. Comments may be aggregated if frequent and repetitive.	6.2.3 A 4.2.5 6.2.4.7 or A 3.11 or A 3.7

3.7 Noisy data

To select the appropriate filter, cause of the noise must be understood. The type of instrument and how it is installed are key factors.

A moving mean or median filter is appropriate when the noise is random about the representative value. Examples are record from a surface sensor (e.g. radar, laser or down-looking ultrasonic) affected by wave lap or vibration of the mounting structure. The filter output must be centred on the averaging interval but even so, induced hysteresis is possible such that if too large an averaging interval is used the resulting hydrographs show significant lag and may appear to 'tip' forward.

Tracking minima is more appropriate for noise resulting from over-reading, e.g. orifice burial or pressure fluctuations on an upstream facing pressure sensor (diaphragm or orifice).

Tracking maxima is more appropriate for noise resulting from under-reading, e.g. venturi effects on a downstream facing orifice, a current (i.e. mA) output sensor with dwindling power supply, or a surface follower or laser penetrating the water surface.

Pressure transducers often produce noisy data when they have been stressed and are close to failing. The noise may be random or biased depending on the individual instrument. Use of comparison plots is helpful in this case and some experimentation with various filters may be required to achieve the optimum result.

Table A 6 – Guidance for resolving noisy data

Guidance for resolving noisy data		see Section(s)
Issue(s)	Noise obscures representative signal. Range of fluctuations is outside tolerance. Range of fluctuations compromises accurate determination of flow.	A 3.7
Evidence	Noise not seen in independent observations. Trace when data are plotted is 'fuzzy'. Variation between adjacent values is larger than is normal or expected from resolution of the instrument. Noise is absent after cause is addressed.	Fig. 7 Fig. 33 A 2 3.6
Solution(s)	'Smooth' with a statistical filter (e.g. moving mean) or resample (e.g. track maxima or minima). Method choice is determined by instrument type and identified cause. Some cautions apply.	4.12 Fig. 33

Metadata	QC 400 and Data Processing Comment explaining identified cause and method applied.	6.2.3 A 4.2.5 6.2.4.7

3.8 Truncation of hydrograph

Truncation occurs when the measurement system cannot record the full range of the variable of interest. For continuously recorded water levels any limit on the range of recording is almost always unintentional and undesirable, i.e. it is not the intention to collect censored data.

Truncation may be due to limits imposed by:

- the sensor or logger specification and/or programmed configuration, e.g. the electronic output range of a sensor or input range of a logger
- physical aspects of the installation, e.g. the possible range of float travel as governed by the level of the underside of the recorder housing floor, or the level of a sensor in relation to the range of levels that may occur in the water body
- a change in location, behaviour, or use of the water body, e.g. drawdown due to pumping or migration of a river channel away from the sensor.

Regardless of cause, the affected period must be replaced with backup data or treated as missing, i.e. either replaced with synthetic data or deleted, gapped, and documented as verified missing data.

In the case of data with a regular cycle (e.g. sea level or groundwater drawdown and recovery) it may not be appropriate to synthesise a replacement record (see Section A 3.11), but frequent gaps may compromise presentation and analysis of the data. Treating the record as censored in these cases may be a better option, but if so, must be quality coded QC 400 (i.e. 'compromised') and explicitly identified and explained by Data Comments.

Flatlining of a recession, as shown in Figure A 11, may be correct if consistent with the cease-to-flow level at the site. In this case the water level data need no adjustment, and the rating should associate zero flow with that cease-to-flow level.

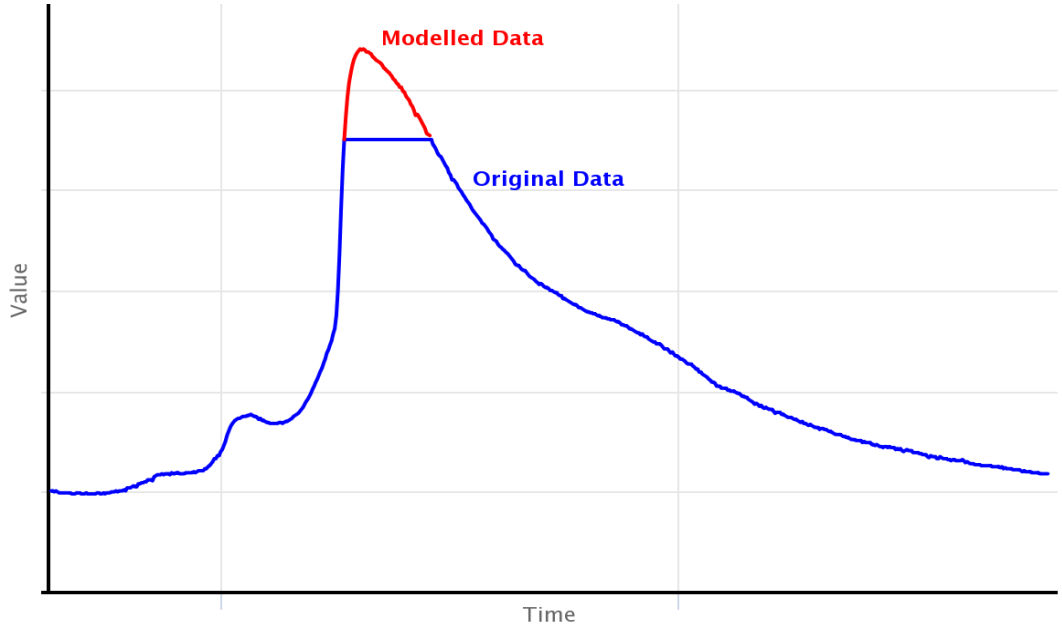


Figure A 10 – An example of a truncated flood peak (blue line) with the faulty data replaced by modelled data (red line). Peak level should be confirmed by survey.

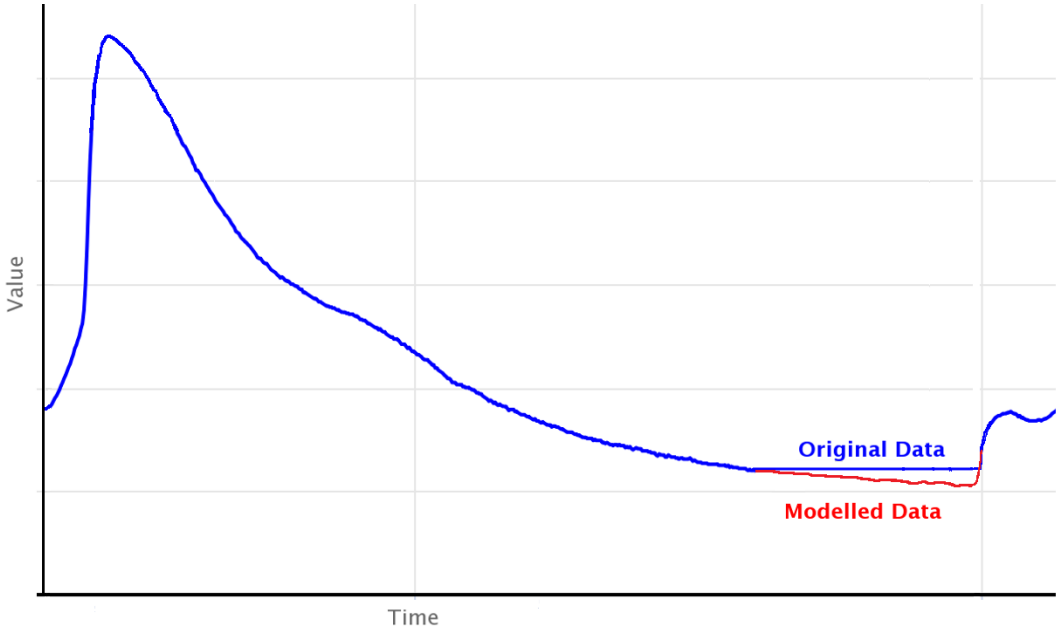


Figure A 11 – An example of a truncated recession (blue line) with the faulty data replaced by modelled data (red line). If the site is rated, minimum level should be checked against the rating to ensure derived flow is not less than zero.

Table A 7 – Guidance for resolving truncation of hydrograph

Guidance for resolving truncation of hydrograph		see Section(s)
Issue(s)	Full range of water levels is not recorded.	A 3.8
Evidence	Peak(s) or trough(s) flatline at a level consistent with cause identified by observation, field validations, and/or site surveys. Difference from actual peak level indicated by flood marks.	Fig. A 10 Fig. A 11 A 2 3.6
Solution(s)	Replace with backup data, or remove and treat as missing, or in limited circumstances accept as censored data. If removed, the gap created may be infilled with synthetic data if appropriate. Method choice is determined by site purpose, identified cause, and available supporting data. Some cautions apply.	4.16 to 4.20 incl. 1.1.5 A 3.11
Metadata	Quality code applicable to the replacement backup record, or QC 300 if replaced with synthetic infill, or QC 100 if left missing, or QC 400 if stored as censored. Data Comments are required explaining identified cause and providing details of decisions made and methods applied.	6.2.3 A 4.2.4 6.2.4.6

3.9 Incorrect scaling

Incorrect scaling means the range of the data is either wrongly reduced or expanded by some factor. The problem may arise from:

- wrong measurement units, e.g. imperial instead of metric, or
- incorrect sensor/logger configuration, e.g. wrong pulley size or wrong multiplier (and usually also then a wrong offset).

Because the recorder zero is usually set from the difference between reference and logged values at the time of configuration, a scaling error shows as differences in subsequent checks that vary in proportion with the difference between current water level and the water level at the time of configuration. If current water level is near the same as at the time of configuration, the verification difference between reference and logged value will be small and the scaling error may not be detected.

The error is most obvious when the extremes of recorded data are compared with independent observations such as flood levels, records from an adjacent site, previous data from the same site, or modelling results.

To correct the data, remove any offset applied, then divide by the incorrect scaling multiplier to obtain raw signal, then multiply the raw signal by the correct scaling multiplier, then apply an appropriate revised offset (i.e. recalculated using the raw signal and its correct multiplier).

If the necessary transformations are fully traceable there is no effect on quality code.

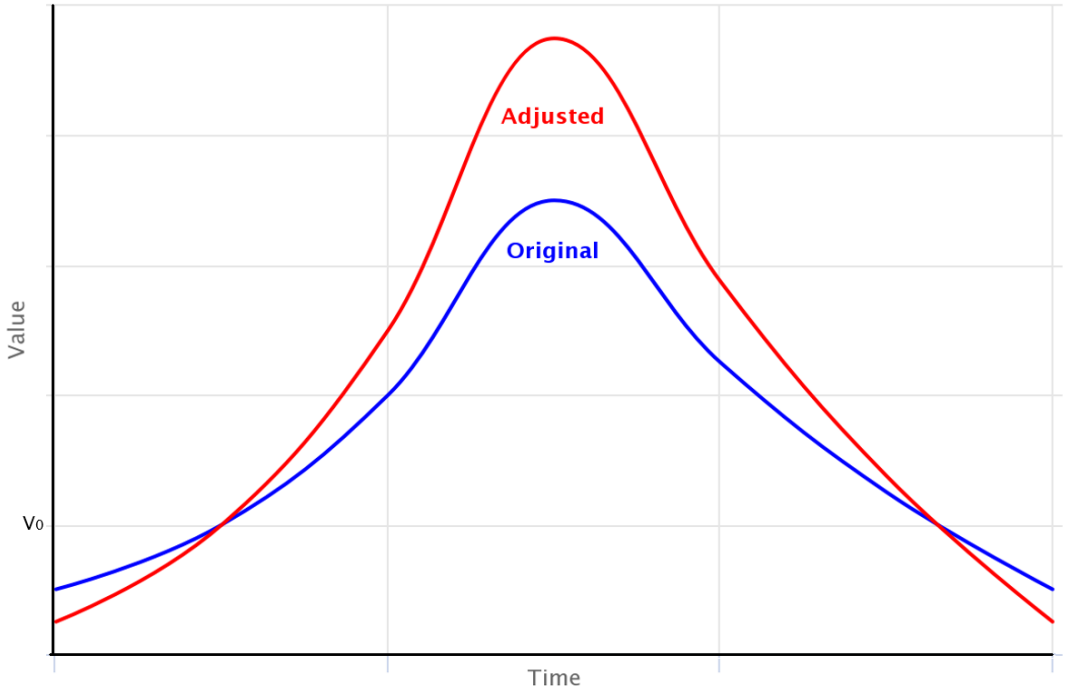


Figure A 12 – Example of the result of linear transformations to correct the scale of the data. V_0 is the value used to originally derive the instrument's configuration parameters.

Table A 8 – Guidance for resolving incorrect scaling

Guidance for resolving incorrect scaling		see Section(s)
Issue(s)	Scale of the data is wrong.	A 3.9
Evidence	Recorded extremes do not agree with those independently observed. Differences between reference and logged values are highly variable and often large. Comparison plots indicate range of the data is wrong.	Fig. 28 Fig. A 12 A 2 3.6
Solution(s)	Apply linear transformations reversing the applied instrument configuration parameters to obtain raw signal, then apply the correct configuration parameters to the recovered raw signal.	4.7
Metadata	If the correction required is fully traceable, quality code is unaffected, but a Transformation Comment is required. Otherwise, matrices and 'minor' or 'significant' modification criteria apply and a Data Processing Comment explaining identified cause and details of the amount and period of adjustment is required.	A 4.2.6 6.2.4.8 6.2.3 A 4.2.5 6.2.4.7

3.10 Time faults

A time shift may be needed to obtain data in NZST or to correct for an incorrectly configured or defaulted logger (see Section 4.3).

If the time fault caused existing data to be overwritten or conflicting new data elements to be discarded, some missing record at period start if shifted forward, or period end if shifted back, is also a consequence that must be addressed (see Section A 3.11).

Time drift adjustment is rarely needed with modern electronic loggers (see Section 4.6). If logger date/time does not agree with actual date/time it is more likely the logger has stopped and there is a gap in the record, possibly unmarked, needing to be identified and addressed.

Historically, mechanical recorder clocks frequently ran slow or fast, so most time-series management software has the ability to make time adjustments simultaneously with value adjustments. There is risk when using drift adjustment tools that time is unintentionally adjusted and time faults are introduced into the processed data. This is relatively easy to detect in fixed interval data by analysing the timesteps or inspecting the timestamps.

Table A 9 – Guidance for resolving time faults

Guidance for resolving time faults		see Section(s)
Issue(s)	Event timing and/or temporal distribution of recorded data is wrong and/or data are missing.	A 3.10
Evidence	Logger date/time is different from actual at inspection. Investigation finds configuration error or reset, and/or event timing and/or temporal distribution anomalies are apparent when compared with nearby sites.	Fig. 18 Fig. 26 A 2 3.6
Solution(s)	If wrong time zone, apply time shift then address any missing record created at the start (or end) by the shift. If a clock fault, replace with reliable backup if independently logged and available, OR if clock is slow or fast, apply time drift adjustment, OR if clock stopped, treat period until restart as missing record.	4.3 or 4.6 Fig. 19 Fig. 27 and/or A 3.11
Metadata	If the time shift is fully traceable, quality code is unaffected, but a Data Processing Comment is required explaining identified cause and details of the shift applied. QC 100 if missing or QC 300 if infilled, and a Data Comment. Otherwise, matrices and 'minor' or 'significant' modification criteria apply and a Data Processing Comment explaining identified cause and details of the amount and period of adjustment is required.	A 4.2.5 6.2.4.7 6.2.3 A 4.2.4 6.2.4.6

3.11 Missing data

When considering the treatment and associated metadata requirements for missing water level data the following broad descriptions of duration are helpful:

- a brief period is a few recording intervals up to an hour
- a short duration is within a cycle or event up to a day
- a longer period may be up to 2 weeks
- an extended period is more than 2 weeks.

A maximum duration of one month for any period of infill is recommended for a river site, although this is dependent on:

- the typical and expected variation in levels at the site
- the possibility of a significant event having occurred, and
- reliability of the relationship(s) used to generate the synthetic record.

Data exhibiting a significant cycle such as tide or other frequent fluctuation (e.g. due to hydro-power generation) shall not be filled over a peak or a trough unless reliably modelled and/or the maximum and/or minimum levels of each cycle are known. Synthetic data other than interpolation are therefore not usually possible for a lake level site affected by seiche or wind tilt, or a sea level site.

3.11.1 Methods for infilling gaps

For details on specific methods for infilling gaps in water level series, see Appendix A.1 to this Annex.

Table A 10 – Guidance for resolving missing data

Guidance for resolving missing data		see Section(s)
Issue(s)	Data are missing.	A 3.11
Evidence	Expected timestamps are not present in the original data. A gap marker may or may not be present depending on data collection method. Comparison plot shows parts of hydrographs or entire events are missing. Investigation confirms data were not logged and/or not collected.	4.16 Fig. 9 Fig. 39 A 2 3.6
Solution(s)	Use backup data and manual observations where available, OR if brief with stable conditions, interpolate across gap if short with stable conditions, infill with a curve if longer period or unstable conditions, apply methods to infill with synthetic data, or mark the gap	App. A.1 4.16 to 4.20 incl. 5.4 & 5.5 A 3.11

	if an extended period, apply methods to infill with synthetic data if within recommended maximum duration, or mark the gap, or note a temporary site closure.	
Metadata	No effect on quality code if brief and interpolated. Otherwise, quality code as applicable to the backup record and manual observations, or QC 300 if infilled, or QC 100 if left as missing. Data Comments are required explaining identified cause and providing details of decisions made and methods applied, including expected reliability of any synthesised infill.	6.2.3 A 4.2.4 6.2.4.6

4 Metadata

4.1 Quality coding

Quality code for water level data is set by four different but related sets of criteria:

- the quality coding flowchart
- the quality coding matrices (Site Matrix and Visit Matrix)
- blanket provisions, and
- data editing actions and adjustments.

The quality coding flowchart and quality coding matrices may be found in NEMS Water Level v4.1.0.

4.1.1 The quality coding matrices

The quality coding matrices use information about the site, instruments, records, and results of each verification to assign an initial quality code to the data. The intention of the matrices is to differentiate between QC 400, QC 500 and QC 600 for the data collected between each inspection. If the outcome of the matrices is either QC 400, QC 500 or QC 600 this is then the maximum final quality code that the data can achieve.

The matrices assign QC 200 (no quality) as an initial quality code if performance fails to achieve any one QC 400 requirement, indicating further assessment and action is required during data processing. Data processing cannot elevate an initial code of QC 400, QC 500 or QC 600 but may elevate or lower an initial code of QC 200.

4.1.2 Blanket provisions

The following provisions apply to water level data in addition to the generic application of quality codes as set out in the quality coding flowchart descriptions:

- Data collected from a stilling well site not equipped with an EPB cannot be assigned a quality code higher than QC 500 (see Section A 2.3).

4.1.3 Data editing actions and adjustments

The quality code of any data collected may be affected by subsequent editing actions and adjustments made to the data. Minor modifications reduce quality code to QC 500. Significant modifications reduce quality code further to QC 400. Refer to Section 6.2.3 for definitions of 'minor' and 'significant'. Guidance on how and when quality code must change as a consequence of data processing is provided in Section A 3 of this Annex.

4.2 Example water level comments

The following are templated examples of comments for water level stations.

Every comment must be assigned a fully specified timestamp and be associated with the relevant data (the time series of water levels) via some form of 'Site' and 'Measurement' database key combination. The database keys are usually specified in some form of record header not shown here.

4.2.1 Site/Initial Comments

River station

Type: Site
Measurement: Water Level
Initial comment for <river name> River water level at *<site name>*
Site number *<network number, ID or code>* on river *<river number>*[1]
The site is situated *<distance to coast>* km from the mouth at grid reference *<map co-ordinates and type*[2]*>*
Drains *<catchment area to site>* km^2 and control is by *<flow control features>*
Additional information: *<site purpose, anything relevant to general interpretation of the record, persistent adverse conditions at site (e.g. weed growth, abstraction, high sediment load), adjacent site(s)> <Some (or All) quality control (and/or data editing) is automated; refer to the relevant Data Processing Comments>*.
The following is also measured at this site: *<list variables, including any backup recorder>; <This site is rated to provide a record of Flow.>*
The local recording authority is: *<name of recording/archiving agency>*

1 from Catchments of New Zealand (SCRCC, 1956).

2 state the co-ordinate system: NZTopo50 or NZGD 2000 preferred (latitude/longitude to 6 decimal places)

Lake station

Type: Site
Measurement: Water Level
Initial comment for *<name of water body>* water level at *<site name>*
Site number *<network number, ID or code>* on river *<river number>*3
The site is situated *<distance to outlet>* km from the outlet at grid reference *<map co-ordinates and type4>*
Drains *<catchment area>*km2 of *<river name>* River catchment
Lake area is *<surface area>*km2 and level is controlled by *<describe features e.g. natural outlet, dam, weir etc.>*
Additional information: *<site purpose, anything relevant to general interpretation of the record, persistent adverse conditions at site (e.g. weed growth, exposure to wind and waves, periodic drying up), adjacent site(s)> <Some (or All) quality control (and/or data editing) is automated; refer to the relevant Data Processing Comments>*.
The following is also measured at this site: *<list variables, including any backup recorder>*
The local recording authority is: *<name of recording/archiving agency>*

Sea level station

Type: Site
Measurement: Water Level
Initial comment for *<name of water body>* Sea Level at *<site name>*
Site number *<network number, ID or code>* at grid reference *<map co-ordinates and type5>*
Situated *<brief location description>*
Additional information: *<site purpose, anything relevant to general interpretation of the record, persistent adverse conditions at site (e.g. biofouling, exposure (to wind and waves), means of calibration and reference, adjacent site(s)> <Some (or All) quality control (and/or data editing) is automated; refer to the relevant Data Processing Comments>*.
The following is also measured at this site: *<list variables, including any backup recorder>*
The local recording authority is: *<name of recording/archiving agency>*

3 from Catchments of New Zealand (SCRCC, 1956).

4 state the co-ordinate system: NZTopo50 or NZGD 2000 preferred (latitude/longitude to 6 decimal places)

[5] state the co-ordinate system: NZTopo50 or NZGD 2000 preferred (latitude/longitude to 6 decimal places)

Groundwater level station

Type: Site
Measurement: Water Level
Initial comment for *<name, ID, or bore number>* Groundwater Station
Located at *<map co-ordinates and type6>* drilled on *<date>* to depth of *<depth of well>*m
Well construction: from *<depth>* to *<depth>*m diameter *<bore dia.>*mm and is *<cased, uncased, or screened>*
Well type *<type>*7 for *<purpose>*8 Aquifer type *<type>*9 depth *<depth>*m
Aquifer lithology *<brief description>*
Log available from *<name and contact details>* Consent *<number or permitted use>*
Ground elevation *<level and datum>*m, Static water level *<level and datum>*m
Additional information: *<site purpose, anything relevant to general interpretation of the record, additional bore location information if more than one bore in vicinity, aquifer properties, water quality grade, level of top of casing or tap used as reference, manual measurement frequency, adjacent bore(s)> <Some (or All) quality control (and/or data editing) is automated; refer to the relevant Data Processing Comments>*.
The following is also measured at this site: *<list variables, including any backup recorder>*
The local recording authority is: *<name of recording/archiving agency>*

4.2.2 Equipment Comment examples

Type: Equipment
Measurement: Water Level
Recorder installed on *<dd-mm-yyyy hhmmss>* is a *<describe main logger features e.g. how powered, compact (or otherwise e.g. PLC), multi- or single input, programmable etc.>* data logger, recording *<describe logging and sampling regime e.g. instantaneous readings at fixed intervals of x-minutes>*. The level sensor is a *<type and output e.g. 0-20mA submersible pressure transducer, gas bubbler and 0-5V dry pressure transducer, down-looking 4-20mA radar, SDI-12 shaft encoder with float and counterweight and 100mm pulley, etc.>* installed in (on) *<brief description e.g. 6m concrete tower, road bridge handrail, weighted cable down well, conduit attached to pier, steel box section secured on piles etc.>*. Sensor range is *<range and units>* with resolution of *<resolution>*mm and nominal accuracy of *<accuracy specification>*. Sensor output is converted to mm stage by *<details of any transformations applied at the time of data capture or collection e.g. scaling multiplier and/or offset>*. Sensor calibration is valid for *<calibration period>* and field checked every *<validation frequency>*. Data are collected by *<method e.g. telemetry and occasional manual download>*.

[6] state the co-ordinate system: NZTopo50 or NZGD 2000 preferred (latitude/longitude to 6 decimal places)

[7] drilled, driven, bored or augured, dug, pit, infiltration gallery, or spring

[8] water supply (domestic, industrial, or public), waste disposal, irrigation, stock, recharge, observation, or disused

[9] confined, unconfined, perched, or fissure

Similarly, for any backup sensor comment as above, as a separate comment if logged independently or added to the above from "The backup level sensor is a *<type and output …" if using the same data logger.*

Type: Equipment
Measurement: Water Level
Staff gauges installed on *<dd-mm-yyyy hhmmss>* surveyed from benchmark *<name of BM used as origin>*, level book *<reference and page>*. Adopted gauge zero is *<reduced level of gauge zero and datum>*. The *<number>* boards are *<describe range and location of each e.g. range 0.3m to 1.7m vertical board on left bank beside sensor, range 1.5m to 2.5m 30 degree sloping board on left bank opposite shed etc.>* The staff gauges are *<primary, or additional to the electric plumb bob primary>* reference at this site, read at every *<visit frequency>* site visit, and resurveyed *<site survey frequency>*. *<Add other relevant information such as prone to damage, silting or subsidence>*.

4.2.3 Operational Comment examples

Type: Operational
Measurement: Water Level
Gas bubbler outlet moved on *<dd-mm-yyyy hhmmss>* from true left bank bridge pier to true right bank bridge pier. New orifice level is *<reduced level and datum, or equivalent stage>* and new offset applied from *<dd-mm-yyyy hhmmss>* is *<new offset>*. Trees on bank sides were trimmed back the same day to maintain access to the river channel.

The following are example comments about maintaining a known datum and reliable references for data verification, both essential to reliable measurement of stage. Information provided in such comments, for water level data, should include:

- details of placement and reduced levels of benchmarks
- changes to recorder zero
- vertical datum used
- type, number, placement, condition, and gauge zero of all reference gauges, including EPBs and external and internal staff gauges, and read points for dipping probes and pressure readings
- which reference gauge is primary
- instances of damage events, and
- reliability of reference readings.

Type: Operational
Measurement: Water Level
Gauge datum changed on *<dd-mm-yyyy hhmmss>* from *<old datum>* to *<new datum>*, refer level book *<reference and page>*. Gauge zero was *<reduced level of gauge zero and old datum>* and is now *<reduced level of gauge zero and new datum>*.

Type: Operational
Measurement: Water Level
Benchmark *<name>* installed on *<dd-mm-yyyy hhmmss>* lost on *<dd-mm-yyyy hhmmss>* as result of *<cause of loss e.g. being washed away or run over>*. Benchmark *<new name>* installed as replacement on *<dd-mm-yyyy hhmmss>*, located at *<co-ordinates and/or location description>* with reduced level *<reduced level and datum>*, refer level book *<reference and page>*.

Type: Operational
Measurement: Water Level
Staff gauge reading on *<dd-mm-yyyy hhmmss>* is unreliable because *<describe problem e.g. the board has been knocked over>* and is not used to verify the logged data. It was *<describe repair>* and resurveyed on *<dd-mm-yyyy hhmmss>*, refer level book *<reference and page>*.

4.2.4 Data Comment examples

Type: Data
Measurement: Water Level
Missing record from *<dd-mm-yyyy hhmmss>* to *<dd-mm-yyyy hhmmss>* due to *<identified cause of recording failure>*. *<Add any other relevant information such as why the gap has not been filled>*.

Type: Data
Measurement: Water Level
Backup record used from *<dd-mm-yyyy hhmmss>* to *<dd-mm-yyyy hhmmss>* due to *<identified cause of primary recording failure>*.

Type: Data
Measurement: Water Level
Change of datalogging interval on *<dd-mm-yyyy hhmmss>* from *<previous interval>* to *<new interval>*.

Type: Data
Measurement: Water Level
Synthetic record from *<dd-mm-yyyy hhmmss>* to *<dd-mm-yyyy hhmmss>* due to *<identified cause of recording failure>*. Record generated from *<provide or describe the relation e.g. state the regression equation>* obtained by *<method e.g. least square regression or hydrological model, etc.>* with input data *<list sites, variables, and periods used>*. *<Add indication of reliability e.g. regression coefficient or standard error and analysis sample size, or some other assessment of uncertainty etc.>*, *<Add limitations on usefulness e.g. hourly or daily values only, or not recommended for model calibration etc.>*

Type: Data
Measurement: Water Level
Data may be compromised from *<dd-mm-yyyy hhmmss>* to *<dd-mm-yyyy hhmmss>*. Cause is unknown but may be due to (or affected by) *<describe suspected cause>*. *<Add other relevant information e.g. comparison records not available, possible reasons for data being correct, etc.>*

4.2.5 Data Processing Comment examples

Type: Data Processing
Measurement: Water Level
Values deleted and record interpolates from *<dd-mm-yyyy hhmmss>* to *<dd-mm-yyyy hhmmss>* to remove spikes caused by *<identified cause>*. Edited by *<name>* on *<date of processing>*.

Type: Data Processing
Measurement: Water Level
Values replaced from *<dd-mm-yyyy hhmmss>* to *<dd-mm-yyyy hhmmss>* to remove spikes caused by *<identified cause>*. Edited by *<name>* on *<date of processing>*.

Type: Data Processing
Measurement: Water Level
Data adjusted from *<dd-mm-yyyy hhmmss>* to *<dd-mm-yyyy hhmmss>* by *<method and parameters e.g. offset shift of C mm, linear drift adjustment of C0mm to C1mm etc.>* to compensate for *<identified cause>*. Edited by *<name>* on *<date of processing>*.

Type: Data Processing
Measurement: Water Level
From *<dd-mm-yyyy hhmmss>* (to *<dd-mm-yyyy hhmmss>*) automated quality control (and/or editing) is applied to this data. Actions include: *<briefly describe each action in specific terms e.g. Range Test: values < x mm or > x'* mm not accepted (or, removed (and gapped)); Flat Line Test: error flagged if n consecutive values are same; etc.> (or Actions are documented in *<provide reference to processing system documentation that contains specific detail of the tests applied to this data e.g. the site file, quality management system etc.>*), applied *<describe where in the process, with respect to what is original data, e.g. on the data logger (or telemetry system, etc.) prior to archiving as original data, or, after original data have been preserved but before near real-time web publication etc.>*, using *<provide name(s) of software and version and briefly describe how the actions are specified and/or configured in the system, and/or provide reference to where the code is permanently preserved, configuration files or screenshots are retained or similar>*.

Similar 'automation' comments must be provided each time any relevant detail changes, from change to an action threshold through to a change of organisational procedure and/or software. Cross-reference relevant Equipment and Operational Comments as required to avoid unnecessary duplication. File a corresponding Stationarity Comment if change of methods potentially disrupts stationarity of the data.

The level of detail required in 'automation' comments depends on the extent to which the comments are necessary to ensure traceability of changes made to the raw measurements (see Sections 3.1.1 and 8.2).

4.2.6 Transformation Comment examples

Transformations applied to a water level record prior to its archiving must be included in the water level metadata. Transformations to convert water level records intended as surrogate to the variable of interest are outside scope of the water level metadata (see Section 6.2.4.8).

Type: Transformation Measurement: Water Level Barometric compensation is applied to this record by *<describe method, including equations>* using *<frequency e.g. hourly or daily or simultaneous etc.>* atmospheric pressure readings from *<source of data e.g. a second pressure transducer at the top of the well, or name of nearby climate station, assumed constant value etc.>*.

Type: Transformation Measurement: Water Level Data from *<dd-mm-yyyy hhmmss>* to *<dd-mm-yyyy hhmmss>* is transformed by Y' = [(Y – *<C>*) x (*<m'/m>*)] + *<C'>* to correct a scaling error. Logger parameters applied from *<dd-mm-yyyy hhmmss>* were multiplier *<m>* and offset *<C>*. Correct logger parameters are multiplier *<m'>* and offset *<C'>* applied on the logger from *<dd-mm-yyyy hhmmss>*. Edited by *<name>* on *<date of processing>*.

Type: Transformation Measurement: Water Level Water levels are archived in metres head of water transformed from sensor readings in millibars using the relation 1 mbar = 0.010215 mH2O at 20C.

4.2.7 Stationarity Comment examples

Type: Stationarity

Measurement: Water Level New *<type e.g. farm or public water supply, hydro-electricity storage, flood detention etc.>* dam commissioned on *<dd-mm-yyyy hhmmss>* at *<location description e.g. x-km upstream of recorder>* on *<name of stream, or unnamed tributary>* that will affect future runoff from *<dam catchment area>* of this recorder's catchment. Data from *<dd-mm-yyyy hhmmss>* to *<dd-mm-yyyy hhmmss>* is affected by dam construction.

Stationarity Comments can be used to capture and collate information about historical methods and data. A real example is provided below.

Type: Stationarity
Measurement: Water Level
The following is applicable from 01-06-1882. Flood levels prior to installation of the painted gauge(s) on the Rail bridge pier were obtained from reports of levels either surveyed or sounded below bridge decks. Relative level of the 1897 bridge deck has been deduced from descriptions provided in letters to the Board from NZ Railways and levels of the 1899 bridge surveyed in 1970, just prior to its demolition. The original bridge was washed away in the Easter 1897 flood. The 1899 road/rail bridge was on the same alignment, which was between the Rail bridge (built 1941) and the highway bridge (opened 1970). Painted gauges were installed and maintained on the Rail bridge from 1941. Readings from the Rail bridge painted gauge have had 6.7 feet (2.042m) added to adjust heights to current recorder datum. Readings from the original Kay Sand and Gravel (KSG) gauge are filed as read with discharge ratings compiled from gaugings filed to KSG stage. Best expected resolution from the old imperial gauges is 1-inch (25mm) with surges of 2 feet (0.61m) or more possible during high flows against the bridge pier. Between
1968 and 1971 gaugings' stage at low flows were pegged and surveyed because water levels fell below the Rail bridge gauge zero.

5 Quality Assurance

5.1 Datum continuity

Further to the requirements of Section 7 of this Standard, datum of water level records must be periodically reviewed for consistency.

Review should precede any change to references at the site, including changes to benchmarks and gauge and recording zeros.

Review must follow every update of the Station History with results from each Biennial Station Inspection (see Annex D of NEMS *Water Level*).

Outcome(s) of the review must be added to the Station History. Any follow-up work required must be added to the tasks identified during the latest site visit.

A datum verification summary shall be included in any audit of water level data.

6 Preservation of Record

Refer to Section 8 of this Standard.

7 References

Soil Conservation and Rivers Control Council (SCRCC). 1956. *Catchments of New Zealand.* SCRCC, Wellington.

Appendix A.1 Methods for Infilling Gaps

1 Information Requirements

The method chosen to infill a gap (i.e. a period of missing record) will depend on:

- the type of water body (e.g. river, lake, sea, or groundwater level)
- the duration requiring infilling
- the likelihood of stable conditions during the period missing
- the nature and availability of neighbouring donor sites
- prior existence of rainfall-runoff or other models
- availability of supporting observations and other evidence such as:
  - peak flood heights
  - manual gauge readings
  - rainfall record
  - surveyed levels
  - photographs.

2 Recommended Methods

The following methods are candidates for infilling gaps in water level records:

- inserting at-site observations of the primary reference gauge
- inserting other at-site manual observations such as surveyed levels, marks, and debris lines
- synthesising a record.

Synthetic infill can be created using one or more of the following methods:

- manual entry of intuitive estimates for short periods
- mathematical means such as calculating a curve, e.g. a river recession, groundwater drawdown/recovery, or tidal sine curve
- methods utilising a donor site or sites, such as:
  - copying a reference trace (from the same or another site)
  - linear or curvilinear regression equations
  - routing flows
  - using equivalent quantiles (percentiles) from flow duration curves
  - ratio of areas (i.e. transfer of specific discharge)
  - a combination of these methods, using multiple donor sites
- water budget
- rainfall-runoff model predictions, and

- outputs from other, possibly more complex hydrological, tidal, and/or hydraulic models.

Supplementary evidence, such as primary reference gauge observations of water level, suitably relevant rainfall records, photos, and flood debris levels, can be incorporated into all the methods detailed above to improve confidence in synthesised data.

Manual entry of intuitive estimates should be limited to gaps of no more than one day.

Infilling a recession by calculation, or by copying a reference trace, should be limited to the recession period in question.

If the synthetic data for a river site are derived from a fully calibrated routing, hydrological, or hydraulic model, gaps of up to two months duration might be reliably filled but the feasibility of infilling any gap longer than one month should be carefully assessed.

The other methods listed should not be used to infill a gap of more than one to two weeks duration, taking into account expected variability and the possibility of significant events having occurred within the period of the gap.

2.1 Infilling with observations

If a logger and/or sensor is disconnected for a period during a site visit, manual observations should be collected so they may be inserted into the record to avoid missing data. Most often the manual observations will be staff gauge readings and their uncertainty should be noted in a filed comment and their quality appropriately quality coded by following the schema.

Large floods can damage equipment, or water level can exceed the range of an instrument or drop below it. Thus, missing record often incorporates a period during which an extreme event has occurred. Every effort must be made to measure the extent of the event when subsequently visiting the site.

The following evidence can be incorporated as one or more points through which any synthetic infill must pass:

- a flood level represented by debris marks
- a low flow level indicated by lines of dried algae
- level indications from photos and/or video
- other evidence, such as an indication from the adjacent land occupier
- operating range of the installation, which should be known and noted in the station history file.

If evidence provides the timing of the extreme event, then this should be used to assign it a time; otherwise, it can be derived from the method of creating the synthetic record.

2.2 Infilling by manual entry

Unless a more sophisticated method is readily to hand, often the most efficient way to fill a short (typically less than one day) gap in a water level record is to intuitively 'draw it by hand', i.e. manually insert values to complete a straightforward rise or recession curve. A straight line should only be used for brief periods, as there is no hydrological basis for that shape.

2.3 Infilling a recession

This method can be used if a longer gap (typically greater than one day) occurs over a period of known recession, i.e. no rain has fallen and neighbouring or upstream stations show a steady recession.

It may be sufficient to copy the recession of the neighbouring or upstream station, or a previous recession at the same site.

An unbroken flow recession can be estimated by connecting the adjacent periods of good flow record with a straight line or smooth curve on a semi-logarithmic plot.

Otherwise, the recession may be calculated from a master recession curve for the site, developed from the flow record. Derivation of a master recession curve is covered in many hydrological texts.

Note: Seasonal variation in recession behaviour may need to be taken into account.

If the infill has been derived as a flow recession it must then be transformed to stage using the inverted applicable stage–discharge rating(s). The stage–discharge ratings applied must cover the full range of the predicted data, which may require the ratings to be extended first.

2.4 Infilling by regression analysis

The method is described in Appendix 2 to the main document.

For river sites, regression analysis is usually more successful if performed using flow rather than water level because the problem of bed shift in one or both sets of input data is eliminated. If the infill is derived from regression of flows, it must then be transformed to stage at the recipient site using the inverted applicable stage–discharge rating(s). The stage–discharge ratings applied must cover the full range of the predicted data, which may require the ratings to be extended first. It may also be necessary to adjust the infill stage to fit seamlessly into the existing record, in which case the end result must be plausible, for example, not introduce a rising recession.

Do not use equations forced to zero for regression of stage or flow. If negative flows are predicted, their significance, and the likelihood of periods of no flow at the recipient site, must be assessed. If periods of no flow are not plausible the analysis should be discarded.

Ensure the summary statistics from the regression are documented in the associated comment, including period used for analysis, interval and type of the regressed data, sample size, equation(s) used to generate the infill, and the regression coefficient (R^2).

2.5 Infilling flow by routing upstream flows

If a gap exists in a record of river flow, and an upstream site or sites exist, it may be possible to route these downstream to create a flow record at the downstream site. This flow record can then be converted to stage using an inverted stage–discharge rating. Requirements for rating coverage and subsequent adjustment of the infill are the same as those described in the above Section 2.4 of this Appendix A.1. Hydraulic routing is preferred, but if there is little attenuation of the hydrograph between the two locations a simple time shift and catchment area ratio adjustment may suffice.

There are several common routing techniques ranging from hydraulic, or distributed, routing that require data about river geometry and a lot of computing power, to hydrologic, or lumped, routing that solves a relatively simple continuity equation. Choice of technique will depend on length of the required period of infill, available input data and resources, and desired accuracy of the synthetic record.

2.6 Infilling flow using equivalent quantiles from flow duration curves

This method is described in McKerchar et al (2010) as the preferred means of creating a synthetic flow record. In concept, it is a form of regression. The relationship between donor and recipient sites is created by deriving a flow duration curve for each site from a period of concurrent record of five or more years, then associating flow values for equivalent percentiles into pairs of rating curve points. The 'rating' is then applied to the donor site flow record to transform it to a synthetic flow record at the recipient site, with a time lag if needed. The derived synthetic flow record at the recipient site is then converted to stage using applicable inverted stage–discharge rating(s). Requirements for rating coverage and subsequent adjustment of the infill are the same as those described in the above Section 2.4 of this Appendix A.1.

The method provides a convenient means of comparing the sites' flow regimes, checking for seasonal bias, and assessing non-linearity while developing the relation.

Test goodness of fit by applying the relation over the concurrent period of record then plotting deviation of the synthetic from actual and calculating the standard error.

The method is not suitable for estimating flood flows because a storm producing a notable flood will almost certainly have variations in rainfall totals across two catchments. Simulation of flood flows requires detailed rainfall records and a suitable rainfall–runoff catchment model (McKerchar et al, 2010).

2.7 Infilling flow records by ratio of areas (specific discharge)

A simple but often effective method of creating flow data from a donor site is to transform flows at the donor site to specific discharge then multiply by the catchment area at the recipient site. If the gap is short and no large floods occurred, this is a useful technique. The derived infill flow record must be converted to stage using inverted stage–discharge ratings for the recipient site. Requirements for rating coverage and subsequent adjustment of the infill are the same as those described in the above Section 2.4 of this Appendix A.1.

Note: Flow divided by catchment area is known as specific discharge or specific yield, although specific yield is more usually associated with aquifers. A modification of this method is to use more than one donor site and/or weight the yield(s) e.g. recipient site yield is half the donor site yield.

2.8 Infilling flow record using a water budget

Records missing for a station that measures inflow to a reservoir can be estimated using the water budget method if accurate records are available of the reservoir outflow and the change in storage contained within the reservoir.

Mean daily inflow to the reservoir is equal to mean daily outflow plus or minus the change in reservoir volume over the day.

Where flow at the inflow station is not the total inflow to the reservoir, an adjustment may be required. The adjustment can be a drainage area ratio or some other assessed scaling factor. The scaling factor can be estimated by applying the water budget equation during periods when inflow, outflow and storage records are all available.

The water budget equation is: $Q\text{i} = K(Q\text{o} + \Delta C)$

where Qi = flow at inflow gauge; Qo = outflow from reservoir; K = inflow scaling factor and ΔC = change in reservoir storage, computed as midnight content at end of current day minus midnight content at end of previous day (start of current day).

The derived infill flow record must be converted to stage using inverted stage–discharge ratings for the recipient site. Requirements for rating coverage and subsequent adjustment of the infill are the same as those described in the above Section 2.4 of this Appendix A.1.

The same principle can be used to estimate missing outflow records for gauging stations located just downstream from a reservoir. The equation is rearranged to solve for outflow, Qo (WMO, 2010).

2.9 Infilling flow record using rainfall–runoff models

Rainfall–runoff models are time consuming to set up, and therefore should only be considered for infilling flow record if one already exists for the location. They also have

the disadvantage that their output can be difficult to replicate. Rainfall–runoff models should only be considered when options to utilise a donor site have been rejected.

The derived infill flow record must be converted to stage using inverted stage–discharge ratings for the recipient site. Requirements for rating coverage and subsequent adjustment of the infill are the same as those described in the above Section 2.4 of this Appendix A.1.

3 Selecting a Suitable Donor Site

One or more adjacent, nearby, upstream and/or downstream hydrological stations may be suitable as donor site(s) to infill a gap in a recipient site record.

For flow stations, catchment characteristics such as area, topography, geology, rainfall distribution, and storage are critical factors to consider when assessing similarity.

In some parts of New Zealand, such as volcanic areas, abandoned river channels, and areas with extensive modified drainage, hydrological regime can vary significantly between adjacent catchments, being strongly influenced by, respectively, the variability in volcanic and alluvial deposits, and by intervention to control the direction of drainage and discharge.

The influence of activities such as abstractions or diversions must be carefully assessed, as must weather patterns prevailing at the time of the periods of data analysed and predicted. There may be large variation between rivers assessed to be hydrologically similar due to events occurring in one that did not occur in the other (McKerchar et al, 2010).

Compare an extended period of record from all candidate sites. However, depending on activities and weather patterns, it may be prudent to limit the analysis to two to three weeks of data either side of the gap. If stage is used rather than flow, a shorter period may avoid the derived relation being affected by bed shift.

Use overplots to compare timing and shape of hydrographs.

Use X-Y (scatter) plots to explore:

- the relationship between the sites, both visually and statistically (e.g. by correlation co-efficient, (r))
- potential non-linearity and seasonal bias, and
- the most suitable interval at which to generate the infill record. For example, a poor fit might only justify daily means, while an excellent fit might reasonably provide hourly values.

Note: Some software allows lag times to be assessed using scatter plots or other correlation tools; otherwise, these may be assessed using data overplots.

4 Other Considerations

4.1 Time resolution of infill data

The time resolution of infill data should be sufficient to convey realistic hydrograph shape and ensure that points of inflection, such as onset of rise and peaks, are sensibly represented; however, the time resolution should also reflect how the infill data were derived, for example, from hourly observations or synthesis of daily mean flows.

Use of longer interval means to synthesise infill poses a particular problem when incorporating the infill into the recipient record because most time-series managers do not allow the mixing of average in interval and instantaneous data in the same time series. Some judgment is required, and the filed comment(s) must make clear how the infill was derived and then incorporated into the record.

4.2 Seasonality of relationships

The effect of seasonality on the relationship used to derive a synthetic record should be explored. Seasonal variations may arise from climate differences between donor and recipient sites, irrigation activity, cycles of different land use or cover, or water allocation rules such as minimum flow periods. If significant, a relationship may be required for each season or part thereof.

4.3 Non-linear relationships

Any non-linear relationship derived between hydrological stations should be consistent with the differences in physical characteristics of their contributing catchments; for example, those arising from differences in storage, by way of geology, ice/snow cover, or the presence of reservoirs and lakes, that may lead to delayed or attenuated runoff or differing rates of baseflow depletion.

4.4 Using multiple donor sites

If more than one suitable donor site is available, multiple regression can be used. The regression analysis determines the relative contribution of each donor site.

Multiple donor sites are also useful to test for and minimise bias from and/or dependence on a single donor source (Joenssen and Bankhofer, 2012).

5 References

Joenssen D, Bankhofer U. 2012. *Hot Deck Methods for Imputing Missing Data*. In: International Workshop on Machine Learning and Data Mining in Pattern Recognition (pp. 63-75). Springer Berlin Heidelberg. Retrieved from http://link.springer.com/chapter/10.1007/978-3-642-31537-4_6 (14 July 2020).

McKerchar A, Henderson R, Horrell G. 2010. *Standard procedures for creating and describing synthetic hydrological record.* NIWA Client Report No. CHC2010-002 prepared for Tasman District Council under an Envirolink project.

World Meteorological Organization (WMO). 2010. *Manual on stream gauging (vol. II) – Computation of discharge.* WMO Publication No. 1044. Retrieved from www.wmo.int/pages/prog/hwrp/publications/stream_gauging/1044_Vol_II_en.pdf (25 August 2020)

Annex B Rainfall Data Processing

1 General Overview

1.1. Normative references

This Annex shall be read in conjunction with the following references:

NEMS Rainfall Recording – Measurement of Rainfall Data for Hydrological Purposes

Where reference is made from this Annex to specific sections of the above document, its title is abbreviated and version stated, i.e. 'NEMS *Rainfall Recording* v2.1'.

1.2. Scope of this annex

While the NEMS *Rainfall Recording (Measurement of Rainfall Data for Hydrological Purposes)* does not specifically exclude other methods of automatic rainfall recording, virtually all rainfall intensity data collected in New Zealand is via tipping bucket gauges.

This Annex is therefore also focused on the processing of rainfall data captured using tipping bucket gauges. The methods and tools are generally applicable to most other available and emerging means of digitally recording rainfall. However, this Annex and its normative reference will require revision to incorporate techniques specific to other instrumentation and methods that may be deployed in future or have been used in the past (e.g. digitised chart records or manually entered daily readings).

1.3. Effect of data type

Rainfall data may be captured and stored as totals in fixed intervals with regular timestep, or totals in intervals with irregular timestep, or tip-by-tip timestamped as they occur (now known as event data; see Appendix B.2 for more information about event rainfall data).

The data in all cases are incremental, i.e. values are totalled in any period, but they may be stored as a total in the preceding interval with interpolation or as discrete totals with no interpolation between adjacent values.

The difference in interpretation is essentially what is implied to have happened between timestamps and this affects how rainfall is totalled in any nominated period. This in turn has some bearing on how the data are verified and processed, especially if filed data elements are deleted.

For an interpolating data type, each value stored represents accumulation at a constant rate in the interval between adjacent timestamps that can be apportioned to any part-interval between the timestamps. Each timestamp also sets the start of the next value's accumulation. Rainfall is only considered to have ceased when a zero value is encountered; however, because the data are totals in the preceding interval the period of no rain is the duration of the timestep up to the timestamp of the zero value.

The Hilltop Software data types intended for tip data ('Six minute Rainfall' and 'Thirty minute Rainfall') are an interpolating hybrid whereby the data are stored timestamped as each tip occurred but when analysed, if there is no value stored in the six (or thirty) minutes prior, Hilltop inserts a zero value 'on the fly', i.e. it is not written to the data file. The interpretation is that each bucket took no more than six (or thirty) minutes to fill before tipping.

With a discrete data type, the value stored is instantaneous, i.e. all water tipped from a gauge bucket is assumed to have arrived in the bucket at the time of the tip. Totals are aggregated up to and including any value that coincides with the end of a requested totalling interval. Between timestamps no rain is deemed to have occurred, such that requesting a total for a period between adjacent timestamps will return a value of zero.

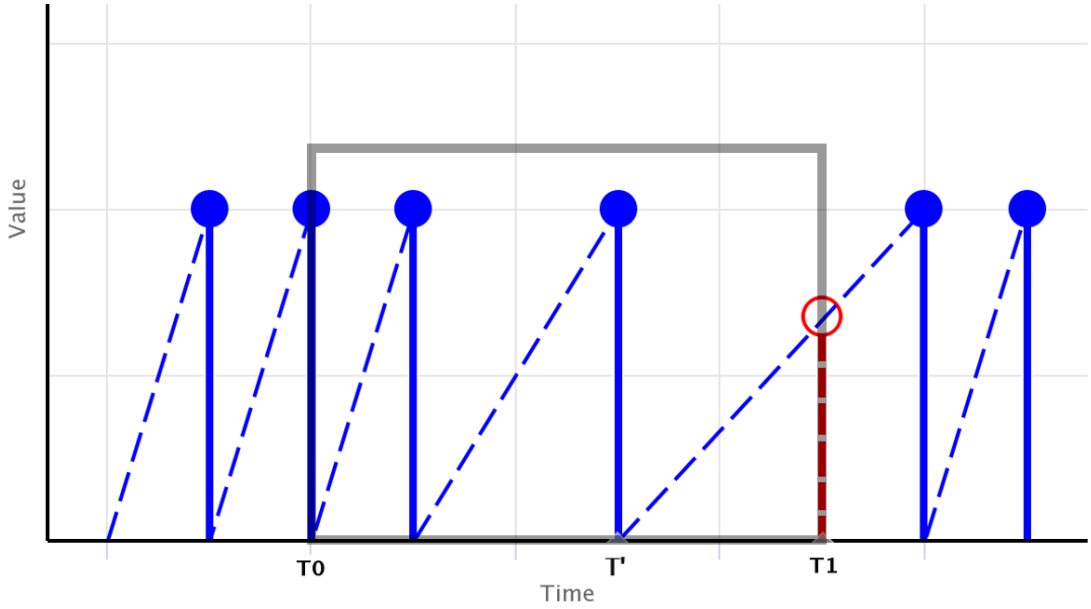


Figure B 1 - An example of the difference between interpolating and discrete incremental tip data. If the data type is discrete the dashed lines do not exist. If interpolating, the total from T0 to T1 (grey box) is the sum of the two blue dot values within the box plus the interpolated value at T1 (red circle). If discrete, only the two blue dot values within the box are summed. If totalling up to T0 there is no difference; each data type sums the two blue dot values up to and including T0. If totalling from T1 to the end, two blue dot values are summed if discrete, but if interpolating, only the part accumulation from T1 to the next blue dot is added to the last blue dot value. If totalling from T' to T1 a discrete data type returns zero while an interpolating data type returns the value interpolated at T1.

2 Quality Control

2.1 Rainfall Data Quality Matrix

The Rainfall Data Quality Matrix should be completed while on site at each visit. If not, it should be completed as the first quality control task of data processing (see also Section B 5.1.2).

2.2 Additional metadata required

General requirements for metadata are set out in Section 6.1. The following additional metadata, as applicable to the site and deployment, are required to be available when verifying rainfall data:

- details of all gauges present, including any reference or backup gauges beyond the immediate enclosure:
  - location
  - type, including whether fitted with an inlet siphon
  - dimensions, including storage capacity in terms of rainfall depth where relevant
  - orifice height, including whether installed with a splash grid if at ground level
  - method of measurement, including any other agencies involved
  - accuracy
  - resolution
  - recording interval
  - recording method, e.g. to data logger, electronic field sheet, paper logbook, direct transmission to base etc.
- details of any changes to the enclosure, instrumentation, or ancillary equipment during the record period
- relevant completed Rainfall Site Matrix assessments
- relevant completed Rainfall Data Quality matrix assessments
- observations of any change to exposure, aspect, or obstructions (see Section 2 of NEMS *Rainfall Recording* v2.1)
- results of gauge verification inspections (see Sections 3.3.1 and 3.4.1 of NEMS *Rainfall Recording* v2.1)
- details of relevant gauge validations (see Section 5.2 of NEMS *Rainfall Recording* v2.1) including:
  - date and time of the validation
  - method and equipment
  - required range of theoretical tip value(s)
  - reason for the validation, and
  - outcome of the validation
- photographs of the enclosure and environs, and any changes to these.

Where a rainfall intensity recording site is installed at a location where records exist from an earlier daily manual rainfall recording site, the daily manual records shall be assigned a different variable name. These two datasets can be combined, when necessary, to provide a single contiguous record when required by users.

These metadata must be verified and permanently archived with all other metadata as described in Section 6.

2.3 Plots and comparisons

2.3.1 Fixed interval totals

- Use five-minute totals, or totals at the recording interval if greater than five minutes, to check for anomalies such as:
  - spuriously high values indicative of interference (see Section B 3.2.2),
  - frequent occurrence of the same maximum value suggesting a range limit (see Section B 3.2.6 and Figure B 2)
  - prolonged periods of the same non-zero value that may be due to a partially blocked collector (see Section B 3.2.3 and Figure B 2).

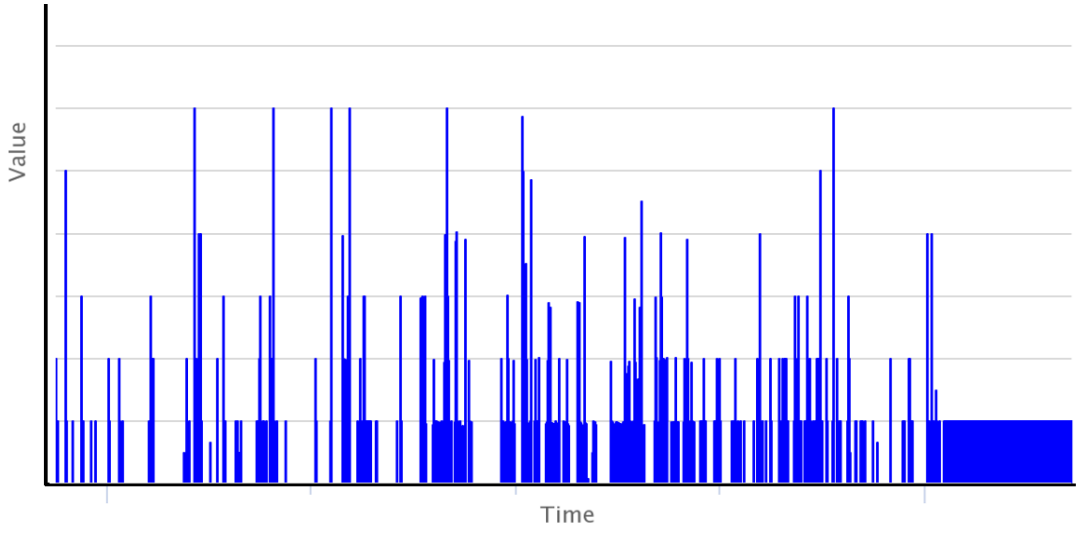


Figure B 2 – An example of a five-minute interval bar plot showing suspiciously repetitive maxima and a period of likely blockage at the end.

- Use hourly totals to confirm storm intensities. Twenty-five millimetres per hour is heavy rain and a useful threshold to apply at most gauges in New Zealand.
- Use daily totals to confirm magnitude and timing of events such as:
  - storms
  - dry spells
  - prolonged wet periods.

  Note: Forecast heavy rain warnings are useful to sanity check storm event daily totals. 100 mm or more in 24 hours over a wide area is 'severe'.

2.3.2 Cumulative totals

For short periods of record, such as between successive site visits, cumulative totals are most useful when used in comparisons (see Sections B 2.3.3 and B 2.3.4).

Over longer periods, cumulative plots are useful to check for stationarity issues. In this context they are sometimes referred to as mass plots and are recommended to be included in any rainfall data audit.

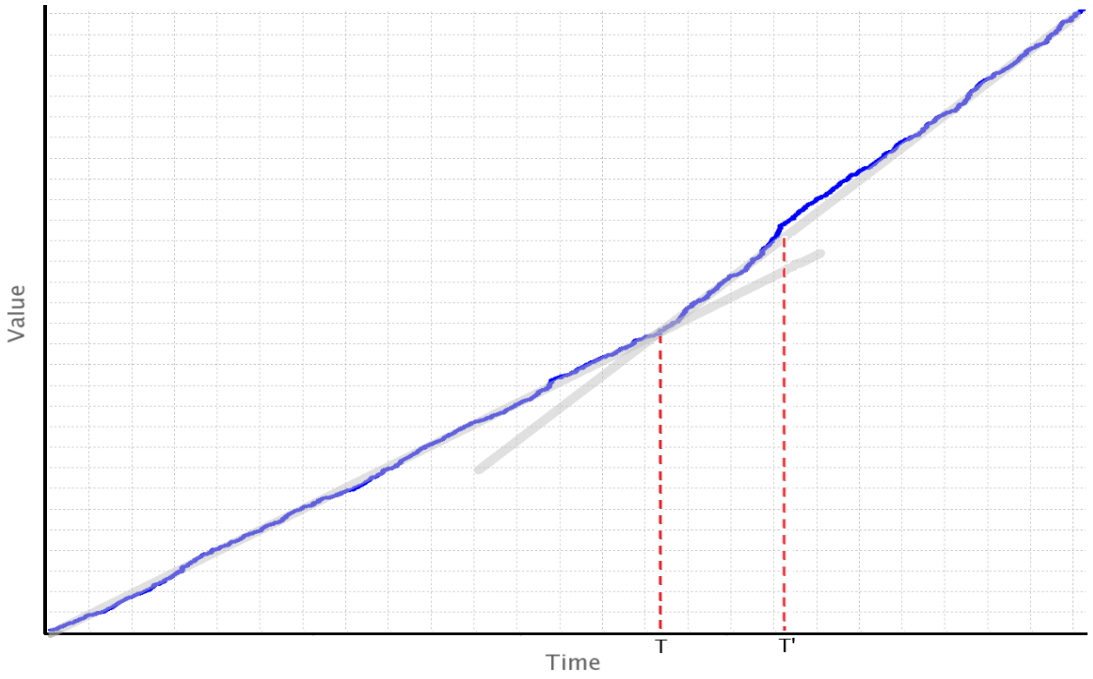


Figure B 3 – An example of a cumulative plot of a long period of record showing change in slope of the trace (indicated by grey lines) suggesting something changed from time T to compromise stationarity. The 'hump' around time T' should also be investigated.

2.3.3 Comparisons

- Use comparisons to:
  - cross-check the data for anomalies, and
  - confirm editing and adjustments have been properly carried out.
- Use fixed interval and cumulative totals to check for anomalies. Compare the recorded intensity data with:
  - a reliable and representative record from another site (see Section B 2.3.4), or
  - a backup instrument at the same site, provided it is not affected by the same data quality issue(s), e.g. an overgrown enclosure, interference, or snow.
- Use a common totalling interval that is at least as long as the longest recording interval of the data to be compared.

  For example, if comparing an event record with record from a standard daily gauge use a totalling interval of 24 hours from 9 a.m. or the daily data will be apportioned and thus misrepresented.

- If using a backup record for comparison, there should be no difference in scale or event timing other than due to resolution (bucket size and/or recording interval) differences.

- When comparing with another site, proportions, patterns, and timing of events should be similar and consistent, although allowance must be made for the passage of storms and fronts. Reference to weather situation maps may be needed.
- Use cumulative plots or period totals to confirm editing and adjustments. Compare intensity gauge records and primary reference gauge totals:
  - before and after any editing of data (Figure B 4), and
  - before and after adjusting the verified clean record to the corresponding primary reference gauge total(s) (Figure B 5).

2.3.4 Between-station comparisons

- Criteria for selecting a suitable rainfall comparison site are similar to those for selecting a suitable infill record donor site (see Appendix B.1 Section 2.5).
- Use between-station comparisons to:
  - check for transient problems that may occur and resolve between site visits, such as a temporary blockage or interference
  - identify when a problem detected during a site visit arose, e.g. loss of pulses to the data logger
  - investigate problems that develop gradually and may not be apparent from a single inspection, such as corrosion of moving parts.
- In the absence of a suitable comparison rainfall site, a record of water levels or flows resulting from the rainfall at or near the site can be used.
  - If plotting, use a log scale for flow if data range is a problem
  - Use cumulative totals, or a fixed totalling interval of near the time of concentration of the catchment, to investigate rainfall rates and event timings and proportions.

2.4 Gauge verification and validation

2.4.1 Tipping bucket (intensity) gauge

Verification and validation requirements are set out in NEMS Rainfall Recording (Measurement of Rainfall Data for Hydrological Purposes).

Verification assesses condition of the gauge at each site visit and requires successful timely validation of the gauge. Failure to validate when required, or an unsatisfactory validation result, means the gauge does not pass its verification check and the data affected must be quality coded QC 400. The period of affected data is from the last successful validation or acceptable condition check, up to the next successful validation or acceptable condition check, whichever is longer.

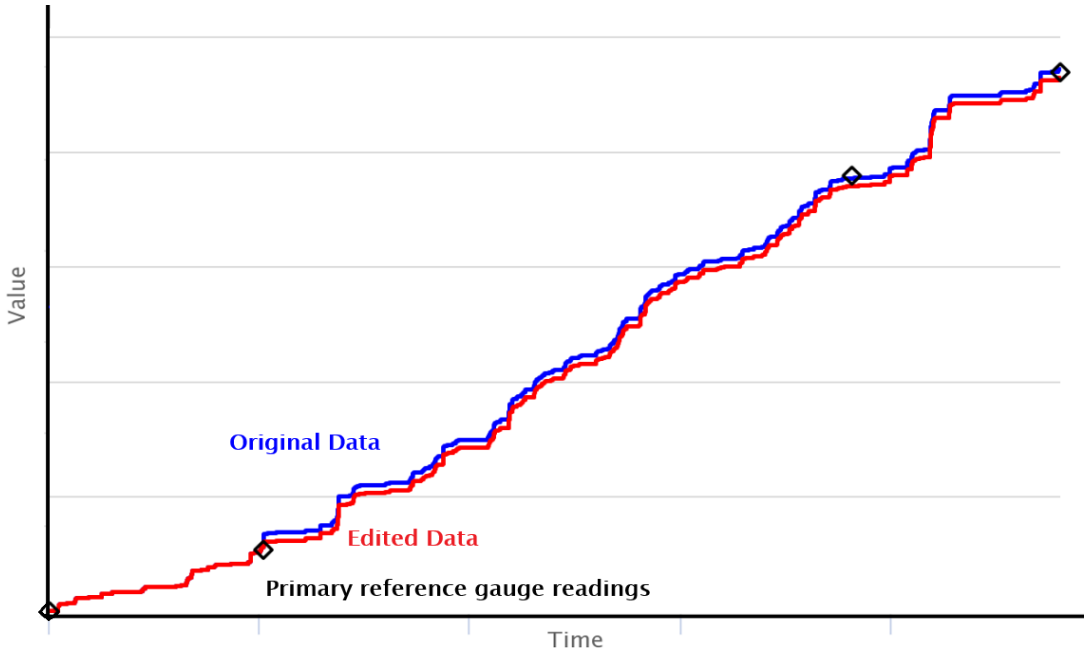


Figure B 4 – An example of a comparison plot of cumulative intensity and reference gauge totals before and after editing to remove validation test tips.

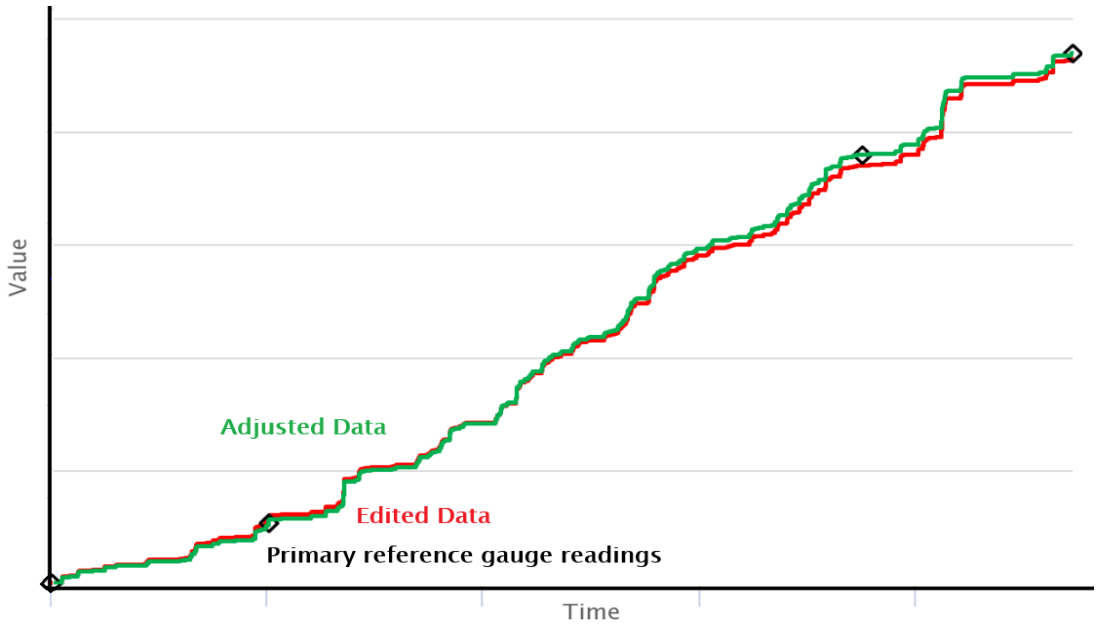


Figure B 5 – Comparison plot of the edited cumulative intensity and reference gauge totals from Figure B 4, before and after adjusting to the reference gauge totals.

Use the Rainfall Data Quality Matrix in NEMS *Rainfall Recording (Measurement of Rainfall Data for Hydrological Purposes)* to determine quality code for other outcome combinations of the verification and validation criteria.

Gauges fitted with siphons are calibrated to tip at a lower volume per bucket than gauges without. If a siphon is removed, unless the gauge is recalibrated it will over-read

by a nominal 9%. The normal process of adjusting the record to primary reference gauge totals will compensate, but the clean unadjusted record will remain biased unless it too is adjusted for the difference in calibration by reducing the nominal tip value, e.g. from 0.5 mm to 0.455 mm.

2.4.2 Primary reference gauge

Verification requirements are set out in NEMS *Rainfall Recording (Measurement of Rainfall Data for Hydrological Purposes)*. There are no validation requirements for primary reference gauges.

Verification assesses condition of the gauge at each site visit. A primary reference gauge reading is deemed unreliable if any one of the verification criteria is not met when the gauge is inspected and its contents measured. Intensity data collected in the corresponding period between the preceding acceptable inspection and the 'failed' inspection cannot be quality coded higher than QC 400.

Primary reference gauge readings regarded as unreliable, for whatever reason, must be identified in any relevant quality control checks, e.g. control charts and deviation tests (see Section B 2.5). An unreliable or missing primary reference gauge reading may be replaced by an assessed or estimated reading (see Appendix B.1 Sections 2.2 and 2.3).

2.4.3 Test tips

Bucket function is tested by tipping them manually. Validation with a field calibration device puts water through the gauge that is not rainfall. If these additional tips are logged, they must be removed from the record. How this is best done depends on the data type used to store the data.

If the data are stored as discrete totals the entire data element for each test tip (i.e. the value and its timestamp) may be deleted because there is no interpolation, so no effect on apparent rate of accumulation of the next actual tip logged.

If the data are stored as an interpolating data type, edit each test tip value to zero to retain the timestamps and therefore capture in the time series that the buckets were known to have been left empty at that time.

Allowance should be made for any part-full bucket or siphon disturbed by gauge testing or cleaning.

Total the recorded data before and after removing the test tips and reconcile the totals with the number of test tips intended to be removed. Quality code is unchanged by the editing of test tips, and a comment is not required, but the reconciliation must be stored permanently with the processing records.

2.4.4 Status checks

Because there may be a long time between rain events, systems that record tip by tip (event data) are often set up to log and/or send a zero value and timestamp at regular intervals independent of the gauge, to indicate the site is still operating.

If the rainfall data are stored as discrete totals, these extra data elements in the record that do not originate from the rain gauge do not matter and can remain in the series.

If the rainfall data are stored as an interpolating data type, these extra data elements alter the apparent start and rate of accumulation of the next actual tip, influencing how the rainfall record is interpreted, and may alter reported rainfall intensities. Ideally, the extra data elements should be filtered from the record, but this may not be practical.

A Data Comment must be filed that describes the frequency of status data generated, its effect with respect to data type, and whether the status data elements remain in the processed record or have been filtered out. If filtered, reconcile the data before and after. The total amount of rainfall recorded in the period should be unchanged. Filtering to remove status data elements has no effect on quality code.

2.5 Deviation tests

NEMS *Rainfall Recording (Measurement of Rainfall Data for Hydrological Purposes)* expresses tolerance as absolute or percent deviation depending on catch. Use the primary reference gauge reading to determine catch unless that is unreliable (see Section B 2.4.2). Test tips must be deducted from the intensity gauge total before calculating the deviation from reference (see Section B 2.4.3).

The performance criteria can be combined into a single control or run chart by using a secondary axis on the one chart (Figure B 6) or stacking the charts (Figure B 7).

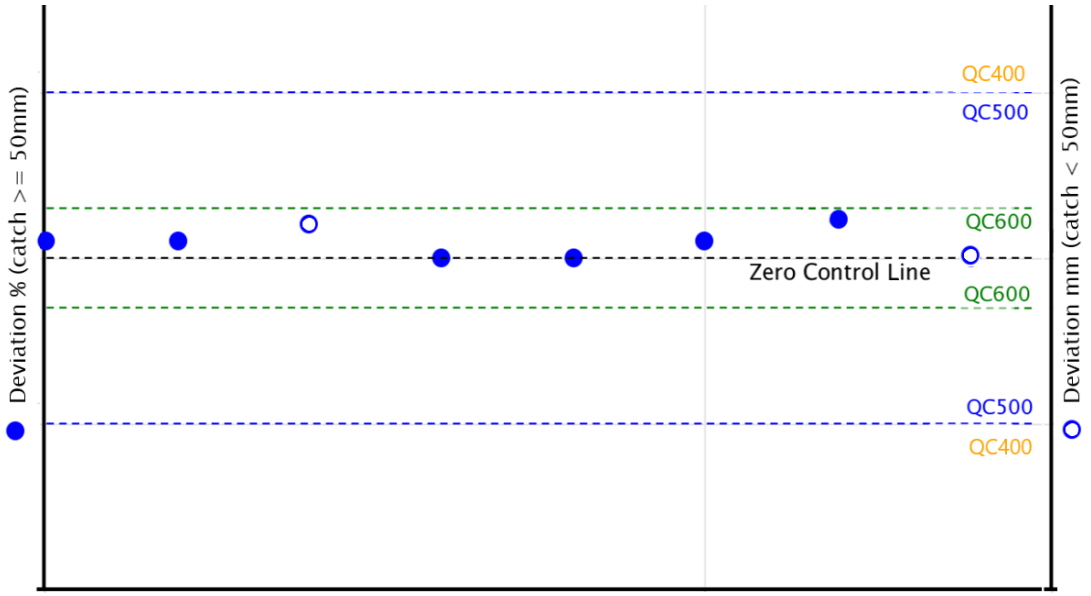


Figure B 6 – An example of a control chart with secondary axis where data are plotted in sequence using the axis applicable for the tolerance test, scaled to align the limits.

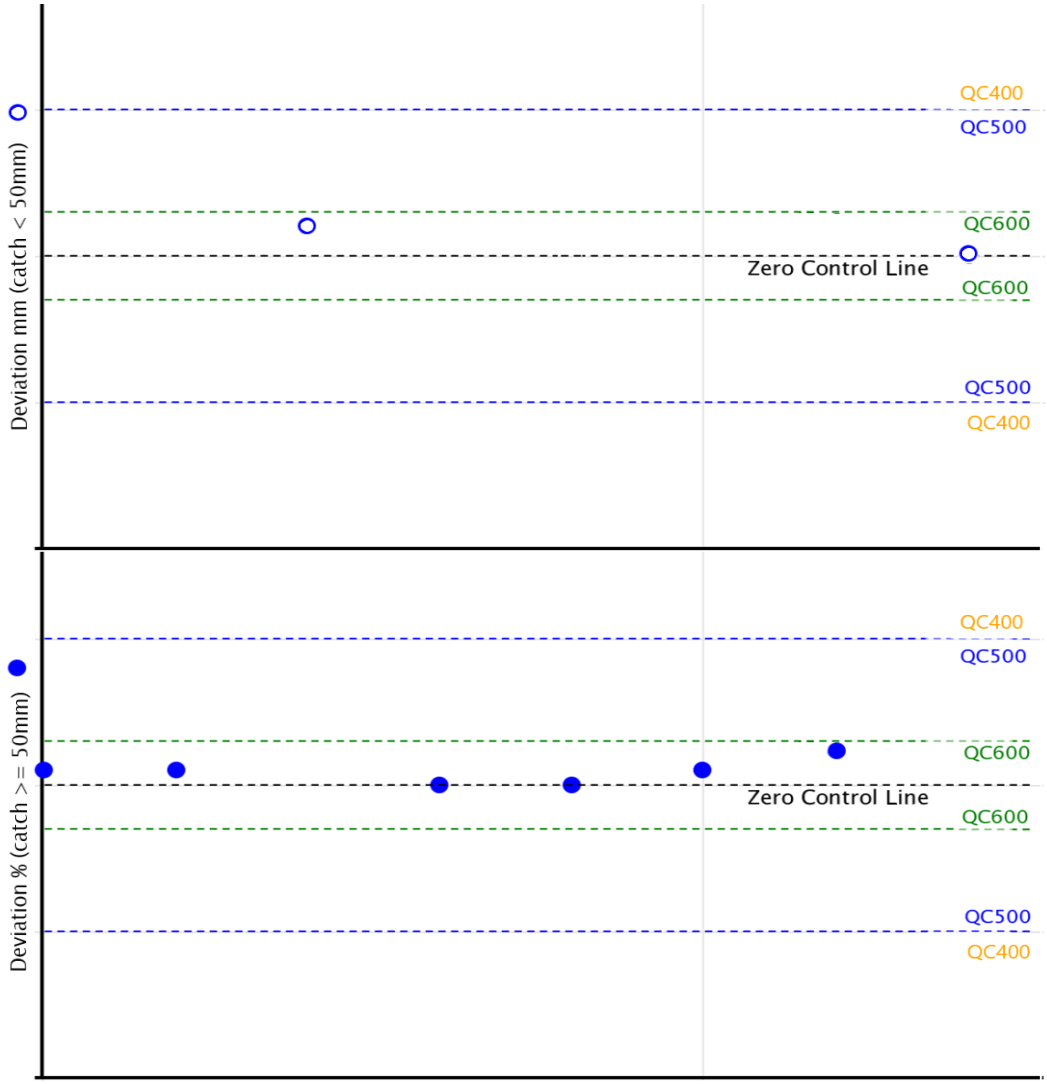


Figure B 7 – An example of a stacked control chart where data are plotted in sequence, but on the top or bottom chart depending on the applicable tolerance test.

Use a deviation with time test to investigate time-dependent issues such as leakage and/or evaporation from the primary reference gauge, or seasonal differences such as when snowfall affects the intensity gauge but not a standpipe reference gauge.

Account for uncertainty in primary reference gauge readings (e.g. use error bars if plotting). Identify any readings that are deemed unreliable but do not exclude them from the tests; the definition of unreliable encompasses a wide range of factors (see Section B 2.4.2).

A scatterplot of reference readings versus corresponding logger totals (net of test tips) can be useful to investigate calibration issues and intermittent problems with intensity gauge function, such as a faulty reed switch or partially blocked drain, that may not be identified during an inspection.

Tests may be configured to update automatically with new data from the field.

3 Potential Errors and Recommended Editing

This section describes common problems specific to rainfall intensity data and guides selection of an appropriate method for data repair, including what metadata are then required to be applied and filed.

3.1 Sources of errors

- Site factors (see Section 2 of NEMS *Rainfall Recording* v2.1)
- Instrument installation, physical condition, and function (e.g. relative orifice heights; failure to generate and/or log a pulse; damage or deterioration resulting in leaks, restriction of bucket movement, and poor surface condition leading to additional evaporation or wetting losses) (see Section 3 of NEMS *Rainfall Recording* v2.1)
- Environmental conditions that adversely affect catch (e.g. evaporation of gauge contents, exposure to high winds, debris or solid precipitation accumulating in the collector) (see NEMS *Rainfall Recording* v2.1: Sections 2.2, 3.3.4 and 4.1.4)
- Primary reference gauge overflows and spills (see Section 4.1 of NEMS *Rainfall Recording* v2.1)
- Issues of calibration (see Section 5 of NEMS *Rainfall Recording* v2.1).

Issues with captured data are not always identifiable from the site visit verification alone. Some problems such as blockages, restriction of buckets, or failure to generate a pulse may be transient and occur and resolve between visits. Issues such as a leaking primary reference gauge may not be apparent from a single visit. Interpretation of plots and comparisons (see Section B 2.3) and deviation tests (see Section B 2.5) are necessary for these cases.

3.1.1 Systematic error

The components of systematic error in precipitation measurement are listed in Table B 1, adapted from Sevruk (1982). These sources of error are minimised in New Zealand by good site selection, design, and maintenance. Sevruk's correction techniques are not employed in the normal processing of rainfall data collected in New Zealand.

In NEMS Rainfall Recording (Measurement of Rainfall Data for Hydrological Purposes):

- the likely effect of wind on rainfall data quality is assessed by the Rainfall Site Matrix
- evaporation prevention is included in the verification requirements of a primary reference gauge (see Section 3.3.1 of NEMS *Rainfall Recording* v2.1)
- snowfall is treated very broadly, and only as an adverse environmental condition, via the Rainfall Data Quality Matrix

- wetting losses are not discussed or assessed.

Quality code does not compensate for bias in the data due to these effects and the quality code assigned is not specific to these sources of bias. It is therefore essential that data users are made aware of potential bias in the data from these sources via adequate comments.

Table B 1 – Main components of systematic error in precipitation measurement and their meteorological and instrumental factors, in order of general importance (Sevruk, 1982)

Error component	Magnitude	Meteorological factors	Instrumental factors
Loss due to wind-field deformation above gauge orifice	2–10% or 10–50% if snow	Wind speed at gauge rim during precipitation, and structure of precipitation	Shape, orifice area and depth of rim and collector
Wetting losses: internal walls of collector and in container when emptied	2–10%	Frequency, type, and amount of precipitation, drying time of gauge, and frequency of emptying container	As above plus material, colour, and age of collector and container
Evaporation loss from container	0–4%	Precipitation type, saturation deficit and wind speed at rim during time from precipitation end to measurement	Orifice area, isolation of container, colour and age of collector, or type of funnel
Splash (out and in)	1–2%	Rainfall intensity and wind speed	Shape and depth of collector and kind of installation
Blowing and drifting snow		Intensity and duration of snowstorm, wind speed, and state of snow cover	Shape, orifice area and depth of rim and collector

3.2 False intensities

3.2.1 Rainfall rate

When intensity is determined by dividing each tip value by its preceding timestep, false intensities can result. Causes are:

- siphon gauges tipping multiple times in a short interval if the bucket was near full prior to the siphon emptying and/or bucket capacity is less than that of the siphon
- additional zero value data elements written to an interpolating record by sources unrelated to the gauge, e.g. status checks (see Section B 2.4.4) and some CSV imports
- fixed interval data logging too frequent with respect to bucket capacity, e.g. 0.5 mm in a 1-minute timestep is an effective rate of 30 mm/hour,

- siphons and/or buckets storing more than one light rainfall event before emptying
- no mechanism or algorithm to identify periods of no rainfall.

The issue is more one of how the data are collected, stored, and interpreted than errors in the data per se. Solutions are one or more of the following, as applicable:

- aggregate tips into a reasonable fixed interval before dividing by that interval to determine rainfall rate

  For example, to avoid over-representing the rate of light rain (< 2.5 mm/hour) when using a 0.5 mm bucket, data should be aggregated into fixed intervals no shorter than 12 minutes.

- *remove from the record any additional zero value data elements arising from status checks or importing of data (see Section B 2.4.4)*
- *implement documented assumptions about when a rain event begins, e.g. Hilltop Software's Six (or Thirty) minute Rainfall data type (see Section B 1.3)*
- *install equipment more suited to determining onset of rain and rainfall rate, e.g. drop counters and/or smaller capacity buckets.*

3.2.2 Interference

Interference may result in over or under catch, may affect the intensity, backup, and/or primary reference gauge and may be transient or persist until rectified during a site visit. Causes may be:

- *the deliberate acts of people, such as adding contents to or emptying a gauge; striking or shaking a tipping bucket to cause additional tips; or removing, damaging, or blocking the rim and/or collector*
- *animals striking, shaking, or rubbing a tipping bucket causing additional tips; chewing or pecking the cable between gauge and data logger causing additional pulses or loss of signal; or pulling over, or drowning in, standpipes*
- *site aspects in combination with environmental conditions that allow additional water to enter a gauge, e.g. installation of an overhead cable and/or nearby pole, aerial spraying or irrigation etc.*
- *electrical interference if cable is not sufficiently shielded, causing induced pulses to be logged, e.g. from communications equipment or a nearby electric fence, or insufficient debounce to resolve fluttering reed-switch closures into one pulse per bucket tip.*

If significant, but transient and not obvious when the site is visited, and depending on which gauges are affected, interference can be detected as:

- *unexpected or unusually high intensities apparent in bar plots*
- *larger than expected deviation of recorded rainfall from corresponding reference reading*

- *anomalies of timing and magnitude when compared with the backup gauge, or other intensity gauges at a nearby sites.*

Brief or regular instances of identified interference can be edited from the record. Longer affected periods may need to be deleted and treated as missing record.

Interference may result in no data, which must also be treated as missing record (see Section B 3.5).

If the primary reference gauge is affected, its reading is unreliable and may need to be replaced with an assessed or estimated reading (see Appendix B.1 Sections 2.2 and 2.3).

3.2.3 Fouling

The collector, funnel or siphon may become blocked by windblown debris, bird droppings, spiderwebs, or solid precipitation. Fouling may result in under catch and/or unusually prolonged apparent rain events often with a relatively constant rainfall rate. Effects may be transient and resolve between site visits or persist until rectified during a site visit.

Fouling, if transient and not obvious when the site is visited, can be detected as:

- *a gradual or 'rounded' rather than 'stepped' cumulative plot trace (see Figure B 8)*
- *unusually constant and prolonged intensities apparent in bar plots (see Figure B 9)*
- *larger than expected deviation of recorded rainfall from corresponding reference reading, especially if catch has spilled, splashed, evaporated, or been blown from the blocked collector*
- *anomalies in rain event timing and magnitude when compared with the backup gauge or other intensity gauges at one or more nearby sites.*

Periods of identified fouling must be deleted and treated as missing record (see Section B 3.5).

If the primary reference gauge is affected, its reading is unreliable and may need to be replaced with an assessed or estimated reading (see Appendix B.1 Sections 2.2 and 2.3).

Another form of fouling is when the orifice or buckets become encrusted with airborne particles such as fine dust or pollen. If the orifice rim is affected, the result is similar to rim damage (see Section B 3.2.2). If the collector surface is affected, evaporation may be enhanced (see Section B 3.1). If the buckets are affected, it upsets their calibration (see Section B 3.2.5.).

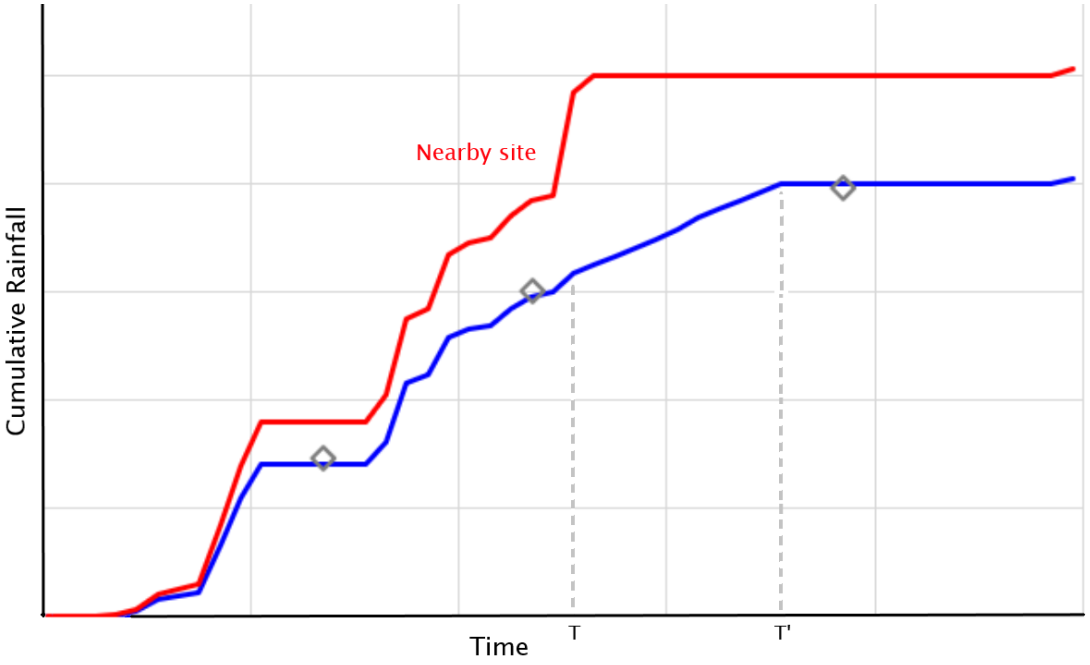


Figure B 8 – An example of a cumulative between-site comparative plot, with primary reference gauge readings, showing a period of fouling (blockage) between time T and T'.

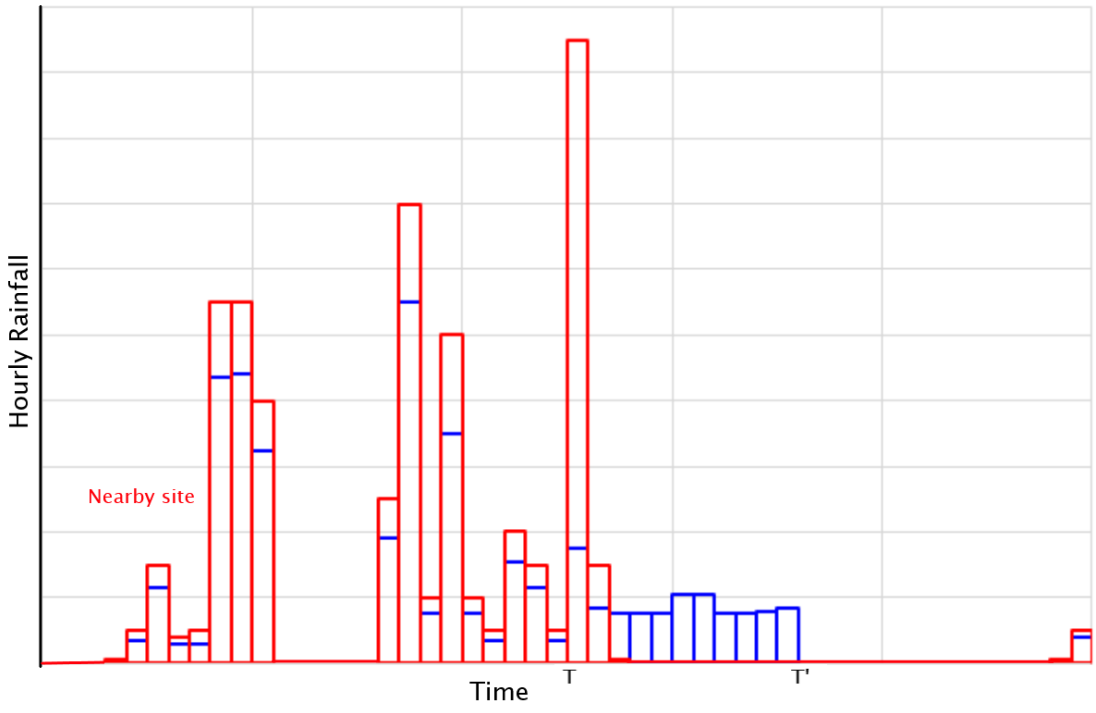


Figure B 9 – An example of a between-site comparative bar plot showing the same period of fouling (blockage) between time T and T' as in Figure B 8.

3.2.4 Restricted bucket movement

The tipping mechanism may partially or fully seize or jam due to:

- ingress of dust, dirt, pollen, or vegetation
- general deterioration due to age and/or corrosion (marine and geothermal environments are especially harsh)
- parts, such as the magnet, dislodging
- the base, if plastic, warping if too hot.

The above will usually cause the buckets to tip later and/or more slowly, and possibly spill/splash more or overflow, effectively upsetting gauge calibration. Recorded rainfall is biased low. Adjusting affected record to corresponding primary reference gauge total(s) is an acceptable solution for the bias; however, this only rescales each recorded tip value and does not alter timesteps or apply compensation gradually.

If the intensity gauge drain blocks, buckets can come to rest on water trapped in the base rather than on their calibration screws, and tip increasingly frequently as water level in the base rises until they are unable to tip at all. Recorded data are increasingly biased high until tipping ceases.

Adjusting the prior recorded data to the relevant assessed primary reference gauge total(s) is an acceptable solution to the bias; however, this only rescales each recorded tip value and does not alter timesteps or apply compensation gradually.

If the buckets can no longer tip:

- decide when that occurred, and
- assess the relevant reference gauge total(s), i.e. decide what proportion of the reference total(s) relate to each of the periods before and after tipping ceased, and
- substitute reliable backup data if available, or
- treat the period after as missing data (see Section B 3.5).

Note: The light plastic 'spoon' in cheaper tipping gauges that are often used as a backup intensity gauge can become bound by spiders' webs sufficient to stop them tipping. It is important to monitor and maintain gauge condition so the backup record can be used with confidence when required.

3.2.5 Loss of calibration

The intensity gauge must be level for the buckets to tip evenly and perform to calibration. A gauge that is not level is effectively out of calibration.

Quality code is determined from the Rainfall Data Quality Matrix. Any resulting bias in the data contributes to the deviation of intensity gauge (recorded rainfall) from reference catch and is compensated by adjusting the record to primary reference gauge totals. The clean intensity record remains biased if not adjusted. An Operational Comment is required to identify the period affected (see Section B 5.2.3).

Intensity gauges fitted with siphons are calibrated with a lesser bucket capacity. If a siphon is subsequently removed or installed, the gauge must be recalibrated as appropriate, or the data collected adjusted for bias (see Section B 2.4.1).

3.2.6 Range limits

Rainfall recording range limits may be encountered if the data logger is unable to keep up with the intensity gauge tip frequency or the input memory is too small to store each possible value in the desired form.

3.2.6.1 Switch closure input (tip frequency)

The data logger employed must be able to scan its inputs quickly enough to keep up with the maximum possible tip frequency of the intensity gauge or it will not count all the pulses sent to it. This frequency will depend on the maximum expected rainfall intensity and the size of the buckets. Inability to keep up means the most intense rainfalls will be under recorded while lesser events are unaffected.

This problem is easily detected if validation checks are carried out using an equivalent or higher rate of water delivery than the maximum expected rainfall intensity and consequent tips are logged to the same logger port or an alternate port with identical specification and configuration.

Detecting this problem in the data is otherwise difficult unless a backup gauge of bigger bucket capacity and/or an independent pulse counter that can keep up is available on site to compare with. To repair affected data, the most reliable available option from the following may be used:

- replace with reliable backup data
- use validation results to identify the intensity at which recording becomes compromised and pro-rata rescaling the data accordingly
- adjust all data to primary reference gauge readings, recognising that this rescales all the values and therefore the result should be checked by between-site comparison(s), or
- delete the affected period and treat as missing record.

Input memory (number of bits)

Loggers may have insufficient bits available for the data input depending on how the pulses are being logged. Logger port selection and configuration, frequency of logging, and size of the number to be stored influence likelihood of the problem.

For example, 10 bits can store a maximum unsigned value of 1023, which means if the data are logged every minute in 500 micrometre increments, the maximum intensity able to be stored is 1 mm/min or 60 mm/hr.

Figure B 2 illustrates the problem. Recorded values are clipped at a common maximum. Affected record is best replaced with reliable unaffected backup data, if available, or treated as missing (see Section B 3.5).

Storing the date and time of each tip uses much more storage and requires the logger to have adequate time resolution to ensure tips are not under-registered because they 'blur' together. The effect of insufficient time resolution is similar to the tip frequency problem (see Switch Closure Input (Tip Frequency)).

Table B 2 – Guidance for resolving false intensities

Guidance for resolving false intensities		see Section(s)
Issue(s)	Apparent rainfall intensities are inaccurate and/or incorrect.	B 3.2
Evidence	Implausible rainfall rates. Unexpectedly high or unusually constant or prolonged intensities. Larger than expected deviation between recording and reference gauges. Timing and magnitude anomalies when compared with other sites.	Figs. B 2 & B 8 & B 9 B 2 3.6
Solution(s)	If due to calculation method, modify method, OR Remove test tips, and zero values inserted as system checks or by import routines, OR If rain event timing is unaffected, rescale the data, e.g. adjust to primary reference or to the usual ratio of recorded to reference, or replace with backup data if available, OR If rain event timing is affected, e.g. by blockage of the collector, or maxima are clipped, replace with reliable backup data if available or delete the affected data then treat as missing.	B 3.2.1 or B 2.4.3 or B 4 & 4.8 or B 3.5 & 5.4 & 5.5
Metadata	Quality code is unaffected by removing test and status check values or adjusting to primary reference. Otherwise, quality code is as applicable to the backup data, or QC 300 if data are replaced by synthetic infill, or QC 100 if deleted and left missing, Data Comments are required explaining identified issue and cause and providing details of decisions made and methods applied.	B 5 6.2.3 6.2.4.6

3.3 Catch discrepancies

Calculation of the deviation of total recorded rainfall from the corresponding primary reference gauge reading will reveal unacceptable catch discrepancies as defined in NEMS Rainfall Recording (Measurement of Rainfall Data for Hydrological Purposes). Deviations are monitored over time using quality charts (see Section B 2.5).

3.3.1 Site and environment factors

There will always be some difference in catch between gauges in the same enclosure due to their different size and/or position and possibly condition. Differences may also have a seasonal component.

Causative factors are:

- relative under or over exposure
- wind effects
- gauge size
- orifice height and diameter
- aspect
- obstructions to airflow, if any, past each gauge
- evaporation (which poor gauge condition or lack of prevention may exacerbate)
- blockage of the collector by airborne debris or solid precipitation.

Factors are often interrelated; for example, a taller or physically larger gauge is more prone to wind effects while a gauge at ground level may be buried by snow, if snowfall occurs in the area.

Discrepancies due to these factors are minimised by good site design, operation, and maintenance. The impact on data quality of the various factors is assessed via the combination of the Rainfall Site Matrix and Rainfall Data Quality Matrix. Clean recorded data are routinely adjusted to the primary reference, being the gauge least likely to change type and position over time, and thus this processing step compensates for variability in the impact of these factors through the record.

At some sites, a persistent bias may be evident over a relatively long time despite best practice installation and operation. If identified, describe the magnitude and direction of the bias in the Site/Initial Comment Additional Information.

3.3.2 Intensity gauge and recording faults

Catch discrepancies due to instrument and recording faults, other than those also associated with false intensities (see Section B 3.2), usually arise from failure to log pulses because of:

- a data logging fault, e.g. loss of logger power or a storage overrun
- loss of signal between the gauge and logger due to a break or disconnect in the cabling, or communication fail if logged remotely, or
- failure of the gauge to generate a pulse, e.g. a faulty reed switch, missing magnet, bound or floating buckets, or seized tipping mechanism.

If due to a data logging fault there may or may not also be a time fault (see Section B 3.4) depending on cause and how data capture has been configured.

In the other cases, data logging continues but no tips are recorded. The fault is usually identified by failure to record test tips during on-site verification of the gauge but may be transient and not apparent at the time of the site visit.

Comparison with reliable record from backup or nearby gauges is needed in any case to identify when the fault arose and the consequent period of missing record.

Sometimes buckets will only generate a pulse on one side. Rainfall recorded in the affected period will be about half what is expected. Either:

- replace the affected period with reliable backup data, assign quality code according to Section 3.5 of NEMS Rainfall Recording v2.1, and supply a Data Comment (see Sections 6.2.4.6 and B 5.2.4), or
- rescale the data to twice its nominal bucket size, e.g. 0.5 mm tips become 1 mm tips, or
- delete the affected period and treat as missing (see Section B 3.5).

Rescaling to twice the bucket size effectively halves the recording resolution. The result should be compared with a nearby site to assess the effect on timing of rainfall events. If there is little effect the quality code can be reassessed against the Rainfall Site Matrix and Rainfall Data Quality Matrix with the revised apparent resolution. If the data are still reasonably representative but event timing is affected, the quality code can be no more than QC 400. In either case, a Transformation Comment is required (see Sections 6.2.4.8 and B 5.2.6).

Otherwise, the affected period must be replaced with reliable backup data or treated as missing (see Section B 3.5).

3.3.3 Primary reference gauge catch loss and measurement errors

Catch discrepancies may arise from primary reference gauge readings affected by catch loss or measurement errors.

Catch loss

Catch loss may be caused by evaporation, leaks, or overflow.

A primary reference gauge without evaporation prevention, or that is leaking, is deemed unreliable and the intensity data collected in the corresponding period cannot be assigned a quality code of more than QC 400 (see Section 3.3.1 of NEMS Rainfall Recording v2.1).

A primary reference gauge that has overflowed is regarded as compromised and therefore the associated intensity record cannot be assigned a quality code of more than QC 400 (see Section 4.1.1 of NEMS Rainfall Recording v2.1 and the quality coding flowchart).

However, it is also possible and desirable to reduce resulting bias in the final adjusted series by doing one of the following, in order of preference:

- measure catch leaked from an inner can (usually recoverable from the outer can unless that is leaking too) and include in the reference reading

- replace the unreliable reference reading with an estimated reading (see Appendix B.1 Section 2.3), or
- incorporate the corresponding period of clean as-recorded data into the adjusted series without adjustment to reference.

A Data Comment must be filed for any period not adjusted to the primary reference totals, explaining why, and stating the reference gauge and corresponding final filed recorded totals (see Section B 5.2.4). Quality code for the unadjusted period can be no more than QC 500 and is otherwise determined by the Rainfall Data Quality Matrix.

Measurement errors

The most common primary reference gauge measurement errors are:

- spills while tipping gauge contents into a flask to measure
- miscounting the number of fills of the flask, and
- using the wrong dipstick.

A gauge intended to be measured by flask should always be dipped first. If contents are spilled, the dipstick reading can be substituted. If not dipped first, an estimate of the proportion spilled must be noted and incorporated into the reading uncertainty that is then used to assess quality code via the Rainfall Data Quality Matrix.

Possibility of miscounting is minimised if each fill of the flask is written down immediately after reading, then all summed to obtain the total reading. The dipstick reading, done first, provides confidence that every fill has been accounted for.

If the orifice and storage can diameters are known, dipped readings using the wrong dipstick, or measurements made using a conventional steel rule or tape if the graduated dipstick has been left behind, are recoverable by calculation.

For example, if the depth of catch in a can by conventional steel tape is X mm, equivalent rainfall depth R = X (A/a), where A is the can cross-section area and a is the orifice cross-section area.

Note: if the gauge is of uniform diameter, i.e. A = a, rainfall depth is directly measurable with a conventional ruler or tape.

A reading may not be possible if gauge contents are frozen. This should be prevented whenever possible, or the contents carefully melted then measured as normal, or measurement and emptying postponed to a subsequent visit when contents are again liquid. If the gauge is a standpipe, it is possible to measure down from the orifice to the ice surface, then subtract the measurement from the gauge capacity, but the reading obtained will be biased high because water expands when frozen.

If obtaining a primary reference reading is postponed it may be necessary to assess the part-total applicable to each visit, for example, if the intensity gauge was replaced during the visit on which the primary reference was not read (see Appendix B.1 Section 2.2).

Applicable quality code is determined by the Rainfall Data Quality Matrix measurement accuracy criteria. An Operational Comment is also required to document relevant calculations and explain a compromised reference (see Sections 6.2.4.5 and B 5.2.3).

Table B 3 – Guidance for resolving catch discrepancies

Guidance for resolving catch discrepancies		see Section(s)
Issue(s)	Unacceptable differences between primary reference gauge catch and total recorded rainfall in the same period.	B 3.3
Evidence	Deviations greater than tolerance. Possible long-term persistent bias. Failure to log test tips. Rain events missing or noticeably short when compared with other sites. Visible evidence of primary reference gauge leaks or overflows. Known and documented primary reference gauge measurement errors.	B 2 3.6
Solution(s)	Adjust recorded data to reliable primary reference readings. If error source is the primary reference, use dipped readings to confirm or as substitute, and/or assess or estimate catch as applicable to the nature of, and period affected by the error. If error source is the intensity gauge and tips are being logged, rescale the data. Either adjust to primary reference or to the usual ratio of recorded to reference if adjusting the as-recorded series. If logging of tips has stopped, e.g. pulses are not being generated or registered, use comparison plots to identify from when, then substitute reliable backup data if available or treat the affected period as missing data.	B 4 4.8 App. B.1 B 4 4.8 B 2 3.6 B 3.5 5.4 & 5.5
Metadata	Document any long-term persistent bias in otherwise good data in the Site/Initial Comment. Applicable quality code is the least of that determined by the Rainfall Site Matrix and Rainfall Data Quality Matrix and the quality coding flowchart, or QC 300 if replaced with synthetic infill, or QC 100 if left missing. Various combinations of Data, Transformation, Equipment, Operational and Stationarity Comments are required depending on error source(s) and method(s) used to resolve.	B 3.3.1 B 5.2.1 6.2.4.3 B 5.1 B 5.2 6.2.4

3.4 Time faults

A time shift may be needed to obtain data in NZST or to correct for an incorrectly configured or defaulted logger (see Section 4.3).

If the time fault caused existing data to be overwritten or conflicting new data elements to be discarded, some missing record at period start (if shifted forward) or period end (if shifted back) is also a consequence that must be addressed (see Section B 3.5).

If the data are stored as an interpolating data type, a time drift adjustment alters the apparent rate of accumulation of each increment of rainfall and may affect reporting of intensities, especially those of short duration, more than if a discrete data type is used. Determining whether a clock drifted or stopped is therefore important for incremental data (see Figures B 10 to B 13 incl.).

Data logging may also have stopped when the clock stopped, or all subsequent tips may be tallied into a single stored value at clock restart, depending on how data collection is configured. A period of missing intensity record is a consequence of either, but a tip tally captures all rainfall volume since the clock stopped, that can then be apportioned to fill the gap using the same method as for a primary reference gauge total (see Appendix B.1 Section 2.1).

Historically, mechanical recorder clocks frequently ran slow or fast, so most time-series management software has the ability to make time adjustments simultaneously with value adjustments. There is risk when using drift adjustment tools that time is unintentionally adjusted and time faults are introduced into the processed data. This is relatively easy to detect in fixed interval data by analysing the timesteps or inspecting the timestamps but can only be detected in event (tip-by-tip) rainfall intensity data by comparing the processed data with the original, as in Figures B 4 and B 5.

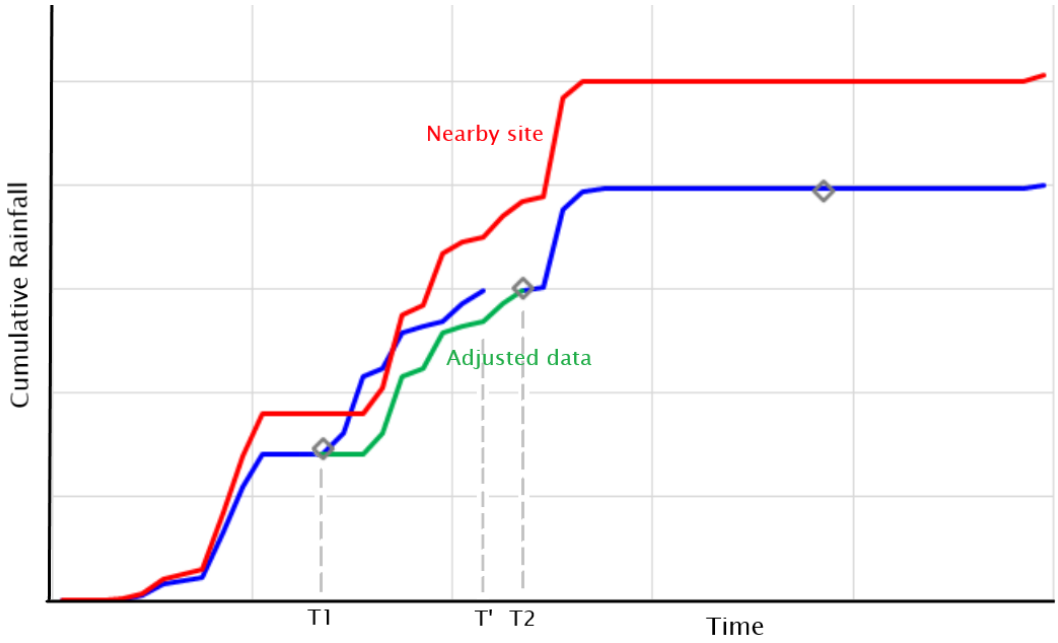


Figure B 10 – An example of a cumulative between-site comparative plot showing a time shift applied to incremental data. Data logged from T1 to T' are moved forward by the time difference between T' (logger time at inspection) and T2 (actual time at inspection). The gap created after T1 has been closed as suggested by the nearby site. All other timesteps are preserved. Rainfall intensity is the same as before but event timing is later.

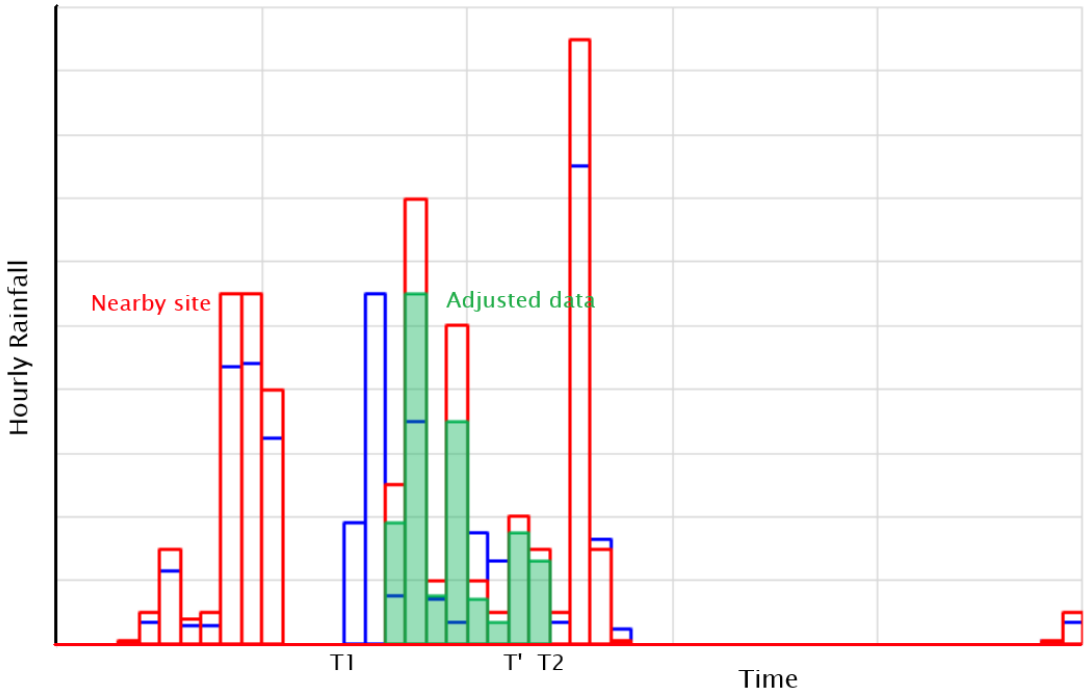


Figure B 11 – An example of a between-site comparative bar plot showing the same time shift as in Figure B 10. Data logged from T1 to T' are moved forward by the time difference between T' (logger time at inspection) and T2 (actual time at inspection). Rainfall intensity is the same as before but event timing is later.

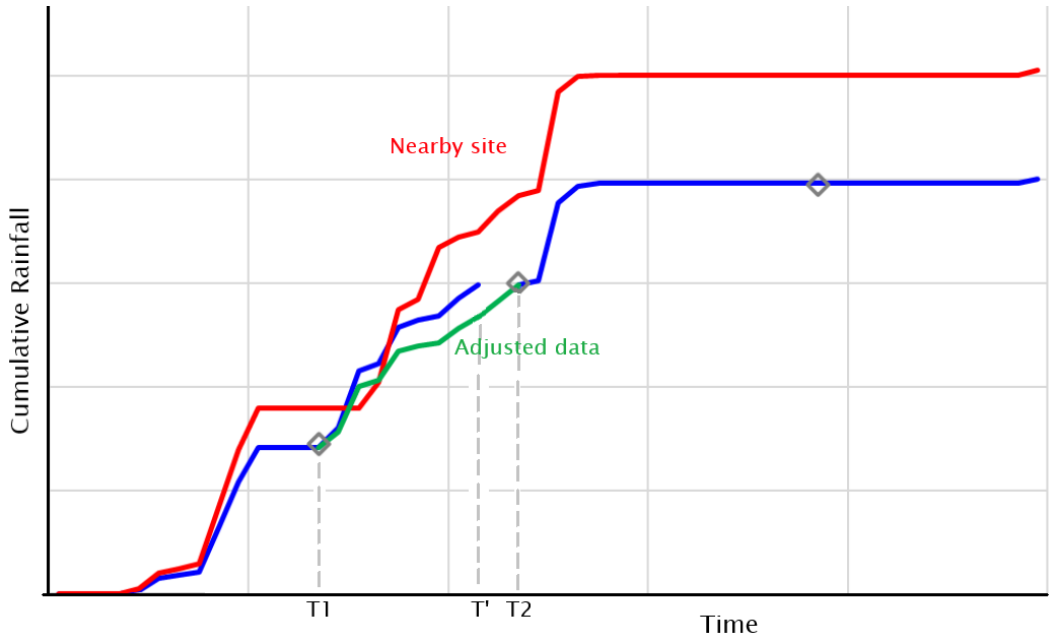


Figure B 12 – An example of a cumulative between-site comparative plot showing a time drift adjustment applied to incremental data. Data logged from T1 to T' are stretched forward by the time difference between T' (logger time at inspection) and T2 (actual time at inspection). Each timestep is stretched by the same proportion as the overall adjustment. Event timing is spread out and apparent rainfall intensity is less.

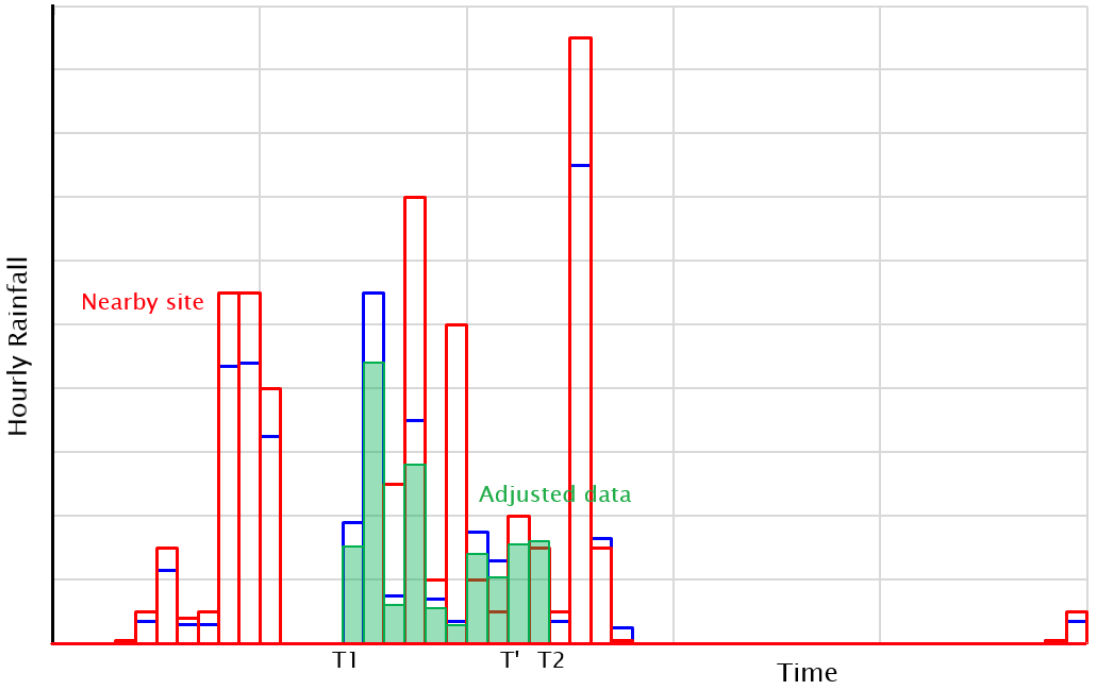


Figure B 13 – An example of a between-site comparative bar plot showing the same time drift adjustment as in Figure B 12. Data logged from T1 to T' are stretched forward by the time difference between T' (logger time at inspection) and T2 (actual time at inspection). Event timing is spread out and apparent rainfall intensity is less.

Table B 4 – Guidance for resolving time faults

Guidance for resolving time faults		see Section(s)
Issue(s)	Event timing and/or temporal distribution of recorded data is wrong and/or data are missing.	B 3.4
Evidence	Logger date/time is different from actual at inspection. Investigation finds configuration error or reset, and/or event timing and/or temporal distribution anomalies are apparent when compared with nearby sites.	Figs. B 10 to B 13 incl. B 2 3.6
Solution(s)	If wrong time zone, apply time shift then address any missing record created at the start (or end) by the shift. If a clock fault, replace with reliable backup if independently logged and available, OR if clock is slow or fast, apply time drift adjustment, OR if clock stopped, treat period until restart as missing record, using apportioning to infill if total rainfall in period is available.	4.3 or 4.6 and/or B 3.5
Metadata	If the time shift is fully traceable, quality code is unaffected, but a Data Processing Comment is required explaining identified cause and details of the shift applied. QC 100 if missing or QC 300 if infilled and a Data Comment. Otherwise, 'minor' or 'significant' modification criteria apply and a Data Processing Comment explaining identified cause and details of the amount and period of adjustment is required.	B 5.2.5 6.2.4.7 B 5.2.4 6.2.4.6 6.2.3

3.5 Missing data

If the data are stored as incremental totals of interpolating data type, a gap created by missing data must either be closed, infilled, or marked to prevent interpolation through the period of the gap.

If the data are stored as incremental discrete totals the concept of interpolation is not present; however, infill is still relevant although the data handling is different.

Gaps in the primary reference gauge adjusted series must be filled wherever possible. This series is more useful for analysis of rainfall volumes over long time periods, for which gaps in the record are problematic.

The clean but unadjusted series must be archived with gaps closed or with backup data substituted as applicable and available, but otherwise gaps may be marked but not infilled. This series may be more acceptable for storm intensity analysis, where the results of infilling gaps with synthetic data may be misleading, or a user of the data may choose to censor the adjusted series by reference to the corresponding unadjusted series.

When considering the treatment and associated metadata requirements for missing rainfall data the following broad descriptions of duration are helpful:

- a brief period is a few recording intervals up to an hour
- a short duration is no more than 48 hours
- a longer period may be two or more days up to one week, and
- an extended period may be a week or more.

Rainfall is a point measure, i.e. the data are specific to the location at which they were measured. New Zealand's geography and topography cause the spatial and temporal distribution of rainfall to be highly variable over relatively short distances. When selecting and applying an appropriate method for resolving missing data, variation in the distribution of rainfall in the vicinity at the time must be taken into account with consideration of the duration of the period missing (see Appendix B.1 Sections 2.5 and 3).

For example, it may not be appropriate to apportion a primary reference gauge total to the temporal distribution of rainfall at an adjacent site if one has experienced a thunderstorm and the other has not, even if the missing period is short and daily primary reference gauge readings are available.

Note: Synthesising a rainfall record is less certain than synthesising stream flow.

A continuous period of a month or more missing shall only be filled with backup data, primary reference gauge totals and/or assessed parts thereof, or synthesised monthly totals.

3.5.1 Closing gaps in incremental data

Closing a gap by removing the gap marker or flag in an incremental interpolating data series results in the next stored total (or the previous, if the data type is 'succeeding interval') being spread at a constant rate through what was the interval of the gap (see Section B 1.3).

Conversely, if the data type is discrete and the next stored total is accumulated, e.g. a tally of multiple tips or a primary reference gauge total, rainfall intensities derived from any interval including the total other than exactly aligned with the original gap will be misrepresented.

Generally, when using a time-series management system to store time-series data, repacking of data is not needed and is effectively redundant (see Section 4.13), but depending on the data type, some manual apportioning and/or repacking of the incremental data may be needed to improve representation of rainfall intensities when actual data are missing and only an accumulated total (including zero) is available to fill the missing period.

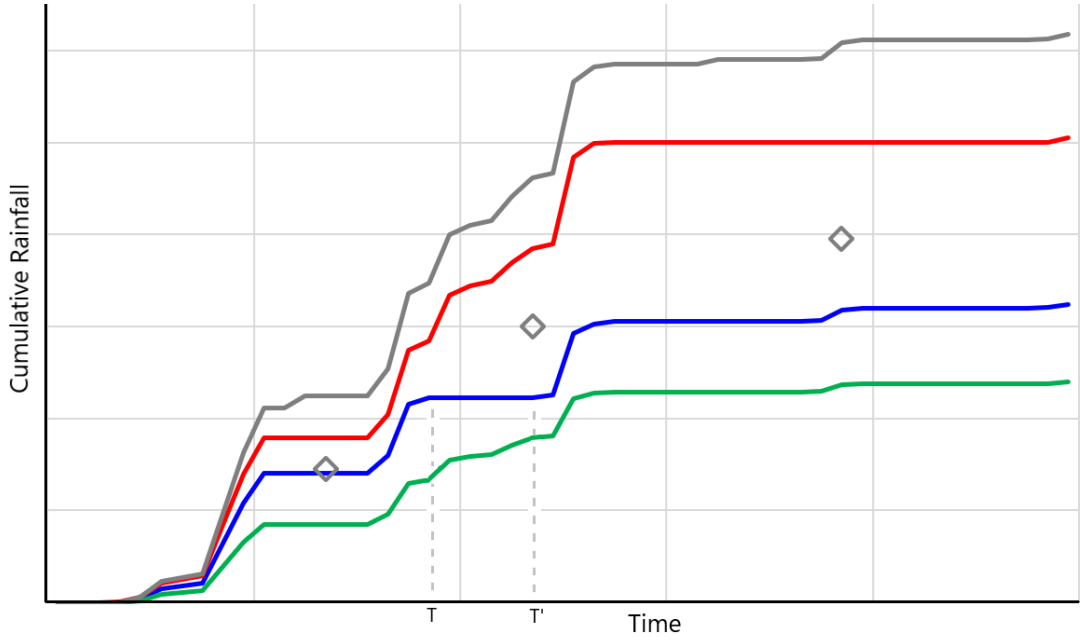


Figure B 14 – An example of a cumulative between-site comparative plot showing a period of rainfall missing in the blue trace between T and T', corroborated by the recorded total at T' being short of the primary reference total (diamond marker).

3.5.2 Methods for infilling gaps

For details on specific methods for infilling gaps in rainfall series, see Appendix B.1 of this Annex.

Table B 5 – Guidance for resolving missing data

Guidance for resolving missing data		see Section(s)
Issue(s)	Data are missing.	B 3.5
Evidence	Expected timestamps are not present in original fixed interval data. A gap marker may or may not be present depending on data collection method. Intensity gauge catch is short compared with reliable primary reference and/or backup gauge. Cumulative plot shows unexpected flat period in the trace. Between-site comparison shows expected event(s) and/or catch are missing. Investigation confirms data were not logged and/or not collected.	4.16 Fig. B 14 B 2 3.6
Solution(s)	Use backup data and/or independent at-site observations if available and reliable, OR if a brief period with no rain event likely to have occurred, close the gap, OR apply one or more methods from Appendix B.1 to infill with synthetic data as appropriate to the available supporting data, OR mark the gap. If a month or more is missing, infill only with monthly values.	B 3.5 App. B.1 4.16 to 4.20 incl. 5.4 & 5.5
Metadata	No effect on quality code if brief and gap closed. Otherwise, quality code as applicable to the backup record and/or manual observations, or QC 300 if infilled with synthetic data or an accumulated total (estimated, assessed, or actual), or QC 100 if left as missing. Data Comments are required explaining identified cause and providing details of decisions made and methods	B 5.1 6.2.3 B 5.2.4 6.2.4.6

	applied, including the expected reliability and resolution of any synthesised infill.	

4 Adjusting Data to Primary Reference

Apart from infilling missing record and creating metadata, adjusting recorded data to the primary reference readings is the final required step when processing a rainfall time series and is intended to help preserve stationarity of the record by adjusting all intensity record to catch recorded by the gauge that is least likely to change type and location (position and height) over the lifetime of a site.

The adjustment is implemented by changing the recorded data increment, which changes apparent resolution of the intensity data, i.e. the size of each gauge bucket tip (see Section 4.8).

4.1 Snow

Snow may block the intensity gauge but be captured by the primary reference gauge. If periods when this has occurred are not identified, and the affected intensity data consequently removed and treated as missing (see Section B 3.5), the additional catch in the primary reference gauge will be spread over the corresponding period of rainfall as recorded, introducing a positive bias error to the adjusted data while retaining false intensities in the period of blockage.

In areas subject to occasional snowfall, possible snowfall events must be carefully investigated for evidence of gauge blockage, and if uncertain and not treated as missing data, a rational and considered decision must be made as to whether adjusting to primary reference gauge readings is appropriate for the corresponding recorded data that might include one or more snowfalls that have compromised rainfall recording.

A Data Comment must be filed for any period not adjusted to the primary reference totals, explaining why, and stating the reference gauge and corresponding final filed recorded totals (see Section B 5.2.4). Quality code for the unadjusted period can be no more than QC 500 and is otherwise determined by the Rainfall Data Quality Matrix.

In areas subject to frequent snowfall, alternate instrumentation, and methods more suited to conditions should be implemented.

5 Metadata

5.1 Quality coding

Quality code for rainfall data is set by three successive assessments:

- the Rainfall Site Matrix
- the Rainfall Data Quality Matrix, and

- data processing actions and final data status assessed against the quality coding flowchart

The quality coding flowchart and quality code assessment matrices can be found in NEMS Rainfall Recording (Measurement of Rainfall Data for Hydrological Purposes). The flowchart is also available in NEMS National Quality Code Schema.

5.1.1 The Rainfall Site Matrix

The Rainfall Site Matrix effectively sets a maximum achievable quality code for any rainfall data collected from a recording site. This assessment should be completed before rainfall data are collected.

The result is unlikely to change frequently so the assessment may be stored in the Station History, but it must be current and known when inspecting the site and during processing of any data collected.

5.1.2 The Rainfall Data Quality Matrix

The Rainfall Data Quality Matrix uses information from each site visit to determine whether quality code for the data collected between visits should be reduced from the maximum achievable for the site. The Data Quality Matrix score is added to the Site Matrix score to decide quality code of data collected. This assessment should, for quality assurance preventive action purposes, be completed before departing the site, but if not, becomes the first step of quality control during data processing.

Nothing in the Data Quality Matrix is triggered by a data processing action. The effect of data processing actions on quality code are addressed in the third assessment against the quality coding flowchart criteria (see Section B 5.1.3).

By applying the Data Quality Matrix at the time of data collection it is possible to assign quality codes higher than QC 200 to unprocessed data, but this may be misleading because processing actions may result in periods of data acquiring a different code.

Note: If the maximum possible quality for the data is QC 400 from the Site Matrix score the Data Quality score is immaterial and the Data Quality Matrix need not be used. However, maintenance and interpretation of quality control deviation tests requires the same information so it useful to complete the Data Quality Matrix in any case as part of the processing documentation.

5.1.3 Data processing actions and adjustments

The quality code of any data collected may be affected by subsequent actions on and adjustments made to the data. Minor modifications reduce quality code to QC 500. Significant modifications reduce quality code further to QC 400. Refer to Section 6.2.3 for definitions of 'minor' and 'significant'.

Adjustment of clean intensity record to reliable relevant primary reference gauge totals is required and has no additional effect on the quality code, i.e. this action is effectively exempt from the quality coding flowchart data modification test.

Further guidance on how and when quality code must change as a consequence of data processing is provided in Section B 3 of this Annex.

5.2 Example rainfall comments

The following are templated examples of comments for rainfall stations.

Every comment must be assigned a fully specified timestamp and be associated with the relevant data (the time series of rainfall) via some form of 'Site' and 'Measurement' key combination. These 'database keys' are usually specified in some form of record header not shown here.

5.2.1 Site/Initial Comments

Rainfall station

Type: Site
Measurement: Rainfall
Initial comment for the rainfall station at *<site name>*
In the catchment of the *<river name>* River, river number *<river number>*[10]
Situated at grid reference *<map co-ordinates and type*[11]*>* at an altitude of *<elevation>*m
Data are recorded as *<x>*mm tips counted as they occur *(or* totals in *<x>* minute intervals*)*
Additional information: *<alternate network number (e.g. Met. number), site purpose, anything relevant to general interpretation of the record, persistent adverse conditions at site (e.g. exposure, obstructions, aspect, snow), adjacent site(s)> <Some (or All) quality control (and/or data editing) is automated; refer to the relevant Data Processing Comments>*.
The following is also measured at this site: *<list variables, including any backup recorder>*
The local recording authority is: *<name of recording/archiving agency>*

5.2.2 Equipment Comment examples

Type: Equipment
Measurement: Rainfall
Recorder installed on *<dd-mm-yyyy hhmmss>* is a *<describe main logger features e.g. how powered, compact (or otherwise e.g. PLC), multi- or single input, programmable etc.>* data logger, recording *<describe logging and sampling regime e.g. each tip as it occurs, or, mm totals at fixed intervals of x-minutes>*. The intensity gauge is a *<type, orifice dimensions and bucket size e.g. 0.5mm tipping bucket with 200mm diameter orifice and inlet siphon>* installed at a height of *<orifice height> (or* at ground level with splash grid*)* in a *<describe enclosure e.g. dimensions, type of security/fencing etc.>.* Gauge calibration is valid for *<calibration period>* and field checked every *<validation frequency>.* The backup intensity gauge is a *<type, orifice dimensions and bucket size e.g. 100x50mm rectangular orifice gauge with 1mm tipping spoon>* installed at a height of *<orifice height> (or* at ground level with splash grid*), <distance>* from the intensity gauge. Gauge calibration is *<give details of validity and checks, if any, e.g. as supplied and not field checked>.* Data are collected by *<method and frequency e.g. twice daily telemetry polling and occasional manual download>*.

If the backup intensity gauge is logged independently to a different logger and/or with a different sampling regime, a separate dedicated comment is preferable.

Type: Equipment
Measurement: Rainfall
Primary reference gauge installed on *<dd-mm-yyyy hhmmss>* is a *<type, orifice dimensions and capacity e.g. non-recording 3m standpipe with 150mm diameter orifice, or, large Octapent storage gauge with 1250mm capacity and 127mm diameter orifice>*, located *<distance>* from the intensity gauge at a height of *<orifice height> (or* at ground level with splash grid*).* The gauge is checked, and contents measured by *<describe method e.g. dipstick, and/or x-mm flask) every <verification (visit) frequency>*, at *<state resolution of readings>* resolution and expected accuracy of *<state achievable accuracy>.* Readings are captured to *<method and frequency e.g. paper (or electronic) field sheets each visit>* and transferred to computer by *<describe method e.g. manual entry to check data, or, import/upload to field station inspections etc.>*.

5.2.3 Operational Comment examples

Type: Operational
Measurement: Rainfall
Intensity gauge repositioned on *<dd-mm-yyyy hhmmss>* to *<describe relative location to previous>* to/because of *<provide reason>.* Gauge is now *<distance>* from the primary reference gauge at a height of *<orifice height> (or* at ground level with splash grid*).*

Type: Operational
Measurement: Rainfall
Gauge exposure changed due to *<provide reason e.g. removal of a tree, changes to enclosure fencing, new obstructions such as a building etc.>* noted on *<dd-mm-yyyy hhmmss>* (and effective from *<dd-mm-yyyy hhmmss>*).

Type: Operational
Measurement: Rainfall
Primary reference gauge dip reading of *<Y>* mm on *<dd-mm-yyyy hhmmss>* is calculated from a measurement of *<X>* mm using *<provide equation(s) and identify the variables e.g. Y = X(A/a) where A is can diameter and a is orifice diameter, or Y = C-X where C is gauge capacity>* because *<provide reason, e.g. wrong dipstick or conventional ruler used, or contents were frozen).*

Type: Operational
Measurement: Rainfall
Primary reference gauge failed verification on *<dd-mm-yyyy hhmmss>* because of *<provide reason>.* Readings from *<dd-mm-yyyy hhmmss>* to *<dd-mm-yyyy hhmmss>* are considered unreliable. Gauge was replaced (*or* repaired) on *<dd-mm-yyyy hhmmss>* with same *(or <describe type, location, and height> if different*).

Type: Operational
Measurement: Rainfall
Intensity gauge failed verification on *<dd-mm-yyyy hhmmss>* because of *<provide reason>.* Calibration is affected from *<dd-mm-yyyy hhmmss>* to *<dd-mm-yyyy hhmmss>*. Gauge was replaced (*or* repaired) on *<dd-mm-yyyy hhmmss>* with same *(or <describe type, location, and height> if different*).

When a gauge is replaced, a corresponding Equipment Comment is required if the type, location, or orifice height of the gauge has changed (see Section B 5.2.2). If it is the primary reference gauge that has changed location and/or orifice height, a Stationarity Comment alerting and explaining the change is also required (see Section B 5.2.7).

Routine comment about verification failures of either gauge is recommended in a rainfall record because quality coding on its own is not sufficient to distinguish between problem-free data collected from an otherwise maximum achievable QC 400 site (according to the Rainfall Site Matrix) and data compromised by gauge condition or performance issues (QC 400 according to the Rainfall Data Quality Matrix) collected from an otherwise QC 600 capable site.

5.2.4 Data Comment examples

Type: Data
Measurement: Rainfall
Missing record from *<dd-mm-yyyy hhmmss>* to *<dd-mm-yyyy hhmmss>* due to *<identified cause of recording failure>*. Sites considered for infilling the gap were *<list of sites and their grid references> (or* No suitable sites are available for infilling the gap*.) <Add any other relevant information such as why the gap has not been filled>.*

Type: Data
Measurement: Rainfall
Gap from *<dd-mm-yyyy hhmmss>* to *<dd-mm-yyyy hhmmss>* due to *<identified cause of recording failure>* closed with no rainfall assumed. Corresponding primary reference gauge catch is (assessed as) zero and no rainfall was recorded at the following nearby sites: *<list sites with grid references>.*

Type: Data
Measurement: Rainfall
Data capture method changed on *<dd-mm-yyyy hhmmss>* to *<describe new method e.g. event data, where each tip is timestamped as it occurs>*. (A zero-value status check is also generated on the logger every *<describe frequency e.g. hour, or day at a certain time>*.) Data was previously logged as *<describe previous method e.g. mm totals in fixed intervals of x-minutes>*.

Type: Data
Measurement: Rainfall
Data may be compromised by snowfall blocking the intensity gauge from *<dd-mm-yyyy hhmmss>* to *<dd-mm-yyyy hhmmss>*. Primary reference gauge total from *<dd-mm-yyyy hhmmss>* to *<dd-mm-yyyy hhmmss>* is *<x>* mm. Corresponding recorded total is *<y>* mm. Recorded rainfall is not adjusted to primary reference gauge for this period.

Type: Data
Measurement: Rainfall
Synthetic record from *<dd-mm-yyyy hhmmss>* to *<dd-mm-yyyy hhmmss>* due to *<identified cause of recording failure>*. Primary reference readings are not available. Record was generated from *<provide or describe the relation e.g. state the regression equation>* obtained by *<method e.g. least squares or multiple regression or rainfall-runoff model algorithm, etc.>* with input data of *<list sites and periods used>. <Add indication of reliability e.g. regression coefficient or standard error and analysis sample size, or some other assessment of uncertainty etc.>, <Add limitations on usefulness e.g. hourly or daily values only, or not recommended for hydrological model calibration, drought analysis etc.>*

Type: Data
Measurement: Rainfall
Backup record used from *<dd-mm-yyyy hhmmss>* to *<dd-mm-yyyy hhmmss>* due to *<identified cause of primary recording failure>*.

Type: Data
Measurement: Rainfall
Synthetic record from *<dd-mm-yyyy hhmmss>* to *<dd-mm-yyyy hhmmss>* due to *<identified cause of recording failure>*. Primary reference total for the infilled period is assessed as *<x>* mm from a gauge reading of *<y>* mm for the period *<dd-mm-yyyy hhmmss>* to *<dd-mm-yyyy hhmmss>*. Record was generated by apportioning the *<x>* mm with respect to *<provide interval e.g. hourly or daily>* values recorded at *<site name and grid reference>. <Add indication of reliability or some other assessment of uncertainty etc.>, <Add limitations on usefulness e.g. not recommended for hydrological model calibration, drought analysis etc.>*

5.2.5 Data Processing Comment examples

Type: Data Processing
Measurement: Rainfall
Values deleted (*or* edited to zero) from *<dd-mm-yyyy hhmmss>* to *<dd-mm-yyyy hhmmss>* to remove false (*or* test) tips due to *<identified cause e.g. interference, verification check, or validation>*. Edited by *<name>* on *<date of processing>*.

Type: Data Processing
Measurement: Rainfall
Data filtered from *<dd-mm-yyyy hhmmss>* to *<dd-mm-yyyy hhmmss>* to remove zero values generated as *<frequency e.g. hourly, or daily (at hhmmss)>* site status checks. Edited by *<name>* on *<date of processing>*.

Type: Data Processing
Measurement: Rainfall
From *<dd-mm-yyyy hhmmss>* (to *<dd-mm-yyyy hhmmss>*) automated quality control (*and/or* editing) is applied to this data. Actions include: *<briefly describe each action in specific terms e.g. Range Test: 1-minute totals > x mm not accepted (or, removed (and gapped)); Gap Test: gap flagged if timestep > 48 hrs; Neighbour Test: error flagged when hourly totals differ from backup by > 2%; etc.> (or* Actions are documented in *<provide reference to processing system documentation that contains specific detail of the tests applied to this data e.g. the site file, quality management system etc.>)*, applied *<describe where in the process, with respect to what is original data, e.g. on the data logger (or telemetry system, etc.) prior to archiving as original data, or, after original data have been preserved but before near real-time web publication etc.>*, using *<provide name(s) of software and version and briefly describe how the actions are specified and/or configured in the system, and/or provide reference to where the code is permanently preserved, configuration files or screenshots are retained or similar>*.

Type: Data Processing
Measurement: Rainfall
Data adjusted from *<dd-mm-yyyy hhmmss>* to *<dd-mm-yyyy hhmmss>* by (*or* for) *<method and parameters e.g. time drift (or shift) of x (hours, minutes etc.)>* to compensate for *<identified cause e.g. clock running slow (or fast), or wrong logger time at setup etc.>*. Edited by *<name>* on *<date of processing>*.

Similar 'automation' comments must be provided each time any relevant detail changes, from change to an action threshold through to a change of organisational procedure and/or software. Cross-reference relevant Equipment and Operational Comments as required to avoid unnecessary duplication. File a corresponding Stationarity Comment if change of methods potentially disrupts stationarity of the data.

The level of detail required in 'automation' comments depends on the extent to which the comments are necessary to ensure traceability of changes made to the raw measurements (see Sections 3.1.1 and 8.2).

5.2.6 Transformation Comment examples

A Transformation Comment is not required for each change in the factor applied to adjust a rainfall record to its primary reference. It is sufficient to file a single Transformation Comment after the Site/Initial Comment, such as:

Type: Transformation
Measurement: Rainfall
All data, except where commented otherwise, is adjusted to primary reference gauge catch, which is independently measured at each recorder inspection. Logged rainfall is multiplied by the ratio of reference gauge total to logged total in each corresponding period. Resolution of filed rainfall therefore varies over time from the nominal rainfall depth represented by each gauge bucket tip.

Type: Transformation
Measurement: Rainfall
Data from *<dd-mm-yyyy hhmmss>* to *<dd-mm-yyyy hhmmss>* is not adjusted to primary reference because the reference reading is unreliable (*or* not available).

An Operational Comment must be filed in association with the above that explains why a reference reading is unreliable or not available.

5.2.7 Stationarity Comment examples

Summarise results of Rainfall Site Matrix assessments into Stationarity Comments as they are completed. Include the determined maximum quality code achievable and the factors causing any downgrade to QC 500 or QC 400.

Stationarity Comments can also be used to capture and collate information about historical methods and data. A common change to be identified in a Stationarity Comment is date and time of each change in 'event' rainfall method (see Appendix B.2 to this Annex).

Type: Stationarity
Measurement: Rainfall
Primary reference gauge replaced by *<new type>* (*and/or* relocated to *<new location> and/or* reinstalled at *<new height>*) on *<dd-mm-yyyy hhmmss>. <Add relevant before and after details and reason for change>. <Add period of overlap if any, and describe the correlation between readings from old and new configurations during period of overlap>.*

In the above example, replacement date and time is when readings from the new setup are adopted as primary reference and applied to the intensity data collected going forward.

Note: NEMS Rainfall Recording (Measurement of Rainfall Data for Hydrological Purposes) requires at least a two-year overlap if a primary reference gauge is to be relocated.

6 Preservation of Record

For rainfall sites, in addition to the requirements of Sections 6 and 8 of this Standard, the recording agency must store and retain indefinitely, and if electronic, back up regularly:

- all primary reference gauge data, including the original field observations
- the original (as defined) intensity gauge data (see Section 3.1.1)
- the verified edited and quality coded intensity gauge time series, i.e. the clean data
- the fully processed time series, i.e. the clean data adjusted to primary reference gauge totals, with any missing record filled wherever possible and quality codes revised as applicable, and
- all required associated metadata for each of the above.

7 References

Sevruk B. 1982. *Methods of correction for systematic error in point precipitation measurement for operational use* (Operational Hydrology Report 21). Geneva, Switzerland: World Meteorological Organization.

Soil Conservation and Rivers Control Council (SCRCC). 1956. *Catchments of New Zealand.* SCRCC, Wellington.

Appendix B.1 Methods for Infilling Gaps

1 Information Requirements

The method chosen to infill a gap (i.e. a period of missing record) will depend on:

- the duration requiring infilling
- the likelihood of no rainfall during the period missing
- the likelihood of heavy rainfall during the period missing
- the nature and availability of neighbouring donor sites
- prior knowledge of spatial and temporal rainfall distribution in the area (e.g. radar coverage, isohyet maps, altitude relationships, correlations between sites)
- prior existence of rainfall forecasts and other predictive rainfall models (as may be used as input to hydrological or hydraulic models)
- availability of supporting observations and other evidence such as:
  - primary reference gauge readings
  - a water level or flow record
  - ad hoc observations by, for example, the land occupier.

2 Recommended Methods

The following methods are candidates for infilling gaps in rainfall records:

- inserting all, or an assessed part, of the primary reference gauge total
- inserting other at-site observations, such as periods of no rain noted while on site or by the land occupier
- obtaining an estimated rainfall record from MetService, extracted from their radar imagery
- synthesising a record.

Synthetic infill can be created using one or more of the following methods:

- methods utilising a donor site or sites, such as:
- apportioning all or part of a primary reference gauge total to the temporal distribution of a suitable reference site
- linear regression equations
- estimates generated by algorithms in a rainfall–runoff model

  Note: Rainfall–runoff models used for near real-time flow prediction often include a step to estimate the model rainfall input for sites that have failed to supply actual data.

- interpolating from one or more isohyet maps of an event
- interpolating or extrapolating from an altitude relationship.

A combination of the above methods, for example, modifying a regression analysis to account for known periods of no rainfall at the recipient site, may improve results.

Infilling of missing data is only required to be attempted for the fully processed rainfall series, i.e. the record that is adjusted to the primary reference gauge totals. If reliable primary reference gauge totals exist, the corresponding record period(s) that include synthetic data generated by any method must sum to the relevant primary reference gauge total(s).

2.1 Infilling using primary reference gauge totals

When the intensity gauge(s) or data logging has failed, a rainfall total may still be available from the primary reference gauge. This total may pertain only to the missing period or to a longer interval, in which case the portion relevant to the missing period must be assessed (see Appendix B.1 Section 2.2).

The rainfall total covering the missing period can be filed as a single value at the end of the period. If the data type is discrete, this will cause errors of representation because the rain is assumed to have all occurred instantaneously at that time. If the data type is interpolating, the interpolation engine spreads the total evenly through the period at a constant rate, except for Hilltop Software's Six (and Thirty) minute Rainfall where the total is spread only through the previous six (or thirty) minutes.

The rainfall total covering the missing period may be apportioned, in order of preference, according to the temporal distribution of:

- rainfall for the same period at a suitable donor site (see Appendix B.1 Section 2.5), or
- values extracted from MetService rain radar for the location, or
- modelled rainfall predictions for the site.

Apportioning is achieved by scaling each value in the donor series by the ratio of the recipient to corresponding donor period totals, such that the infill sums to the recipient total rainfall for the period while acquiring the timestamps of the donor series. Apportioning therefore assumes the same temporal distribution of rainfall at both sites. This assumption should be tested whenever possible by comparing rainfall from several surrounding gauges.

Quality code for the infill using either method is QC 300; the total stored as a single value is 'limited measured data', while the temporal distribution of apportioned infill is synthetic. Comment(s) as for synthetic data are also required (see Sections 5.5.2 and B 5.2.4).

2.2 Assessing the primary reference gauge total

If a primary reference gauge reading relates to a period longer than the period of interest, the portion applicable to the period of interest must be assessed.

If the clean recorded intensity or backup gauge data are reliable up to the period of interest:

- determine the recorded total corresponding to the part period of the reference gauge reading up to the period of interest
- determine the average of all previous reliable deviations for the particular combination of intensity or backup gauge (i.e. same serial number, installation, and calibration period) and reference gauge
- rescale the part-period recorded total by that average, then
- deduct the rescaled part-period recorded total from the reference reading
- the remainder is the assessed portion of the reference reading.

For example:

- *Primary reference gauge reading for period 1-Mar-2020 10:30:00 to 3-May-2020 11:15:00 is 210 mm*
- *Period of interest is 20-Apr-2020 9:30:00 to 3-May-2020 11:15:00*
- *Recorded total for period 1-Mar-2020 10:30:00 to 20-Apr-2020 9:30:00 is 150 mm*
- *Average of previous relevant reliable deviations is -3%*
- *Rescaled recorded total for period 1-Mar-2020 10:30:00 to 20-Apr-2020 9:30:00 is (100-3)/100 x 150 = 145.5 mm*
- *Assessed portion of reference gauge total for period 20-Apr-2020 9:30:00 to 3-May-2020 11:15:00 is 210 – 145.5 = 64.5 mm*

If the primary reference gauge was not read and emptied during a site visit it may be desirable to assess the relevant portions of the subsequent reading and treat the two periods separately. The method of assessment is the same except the periods are bounded by the site visits and the period of interest is the first of the two.

Data adjusted to an assessed primary reference gauge total cannot acquire a quality code higher than QC 400. Most often, an assessed reference reading is required in relation to infill of missing record so the quality code will be QC 300.

If the intensity and backup gauge data at site are unreliable a suitable donor site (see Appendix B.1 Section 2.5) may be used. Quality code is restricted to QC 300 for any application of an assessed reference reading obtained by reference to a donor site.

Comment is required explaining the derivation of an assessed reference, regardless of method.

2.3 Estimating the primary reference gauge total

If a primary reference gauge reading is missing or compromised it may be estimated from the recorded intensity or backup gauge data by scaling the recorded total for the relevant period as for the assessment method described in Appendix B.1 Section 2.2.

If recorded intensity or backup gauge data are also missing or unreliable, a reference total can be estimated using one or more of the following methods:

- interpolation of, or prediction from, some form of relationship with one or more suitable donor sites (see Appendix B.1 Section 2.5):
  - regression analysis (see Appendix B.1 Section 2.6)
  - altitude/orographic relationships
  - mass (cumulative) curve comparisons
- interpolation of an isohyetal or raster (e.g. radar) map of the area for the relevant period.

Regression analysis is preferred because the goodness of fit and consequent uncertainty can be explicitly determined. Regression can be weighted by one or more of the other relationships and/or results sanity checked against maps of the spatial rainfall distribution of the period of interest, or of events within the period, or of rainfall distribution more generally. GIS tools are useful to explore spatial relationships and weightings.

A quality code of QC 300 applies to any application of an estimated primary reference gauge total and comment is required explaining derivation of the estimated rainfall regardless of method.

2.4 Infilling periods of no rain

A gap in a rainfall record may not have missed any rain. The absence of rain may be:

- known from documented observation at site
- inferred from nil reference gauge catch (actual or assessed) and no corresponding rainfall recorded at a nearby gauge, or
- predicted from a relationship with one or more nearby gauges.

Deleting the gap marker is not sufficient on its own to substitute a period of no rainfall. For the discrete data type, gap markers are irrelevant because there is, by definition, no interpolation to prevent. For an interpolating data type, deleting a gap marker allows the system to interpolate between the adjacent values which may be non-zero.

A record of nil rainfall can be created in the time series by deleting the gap marker (if any) and entering zero values at the start and end of the nil rainfall period. However, this is still only partially useful. For a discrete data type the additional zero values are of no consequence and a suitable Data Comment is more useful. For an interpolating data type the effective period of no rainfall begins from the last non-zero value stored prior to the zero value filed at the start of the infill period.

If the period of nil rainfall is known or inferred, quality code may be carried forward from the adjacent series, but a comment is required to explain that there was a gap in the record, no rain occurred, and how this is known or was inferred.

If the period of nil rainfall is predicted from a nearby site it is synthetic data, QC 300 applies, and an appropriate Data Comment explaining method etc. is required (see Section B 5.2.4).

2.5 Selecting a suitable donor site

One or more nearby stations can be used as a donor site to infill a missing record. When selecting suitable donor sites, consider:

- the relative locations of the recipient and donor sites, including altitude and aspect
- topographical influences and orographic effects and therefore likely rainfall gradient in the vicinity
- seasonal differences between the sites
- the weather pattern and type of rainfall at the time of the missing record, e.g. convective or frontal rain (warm or cold), and consequent effect on intensity and temporal and spatial variation.

Compare an extended period of record from recipient and donor site(s) using between-station comparisons and scatterplots. Between-station comparisons allow investigation of the timing and shape of hyetographs. Scatterplots allow exploration of:

- the fit between the two sites visually and by correlation co-efficient (r^2)
- the potential for lag, non-linearity, or seasonal bias, and
- the most suitable timestep for the infill. A poor relationship might only support generating daily values with acceptable uncertainty, while an excellent fit might permit hourly infill values.

In New Zealand rainfall distribution is potentially highly variable over relatively small areas. Similarity cannot be assumed without evidence even over short distances. Multi-site consideration is recommended.

2.6 Infilling by regression analysis

Regression analysis is an alternative to apportioning a primary reference gauge total (see Appendix B.1 Section 2.1) or can be used when no reliable data are available from any of the gauges at site.

- General procedure is described in Appendix 2 to the main document.
- Select one or more suitable donor sites (see Appendix B.1 Section 2.5).
- Analyse the period of the available primary reference gauge total, or if no reference total, a period of the same weather (or seasonal) pattern:
  - generally, about two to three weeks either side of gap, or

    - no more than two to three times the extent of the gap if an extended period (see Section B 3.5).
- Decide a suitable data interval for analysis and acceptable timestep of the infill, determined with reference to the extent of the gap and the quality of the relationship(s) (see Sections B 3.5 and 6.2.5).

Regression analysis is preferred to apportioning because the goodness of fit and consequent uncertainty can be explicitly determined. However, the derived relation may introduce a constant that predicts additional rain days or negative rainfall unless one of the following options is utilised:

- edit predicted infill values to zero when there is zero rainfall at the donor site(s) then redistribute the rainfall removed over the remaining non-zero infill values. This is an extra processing step that may not be warranted over the other options
- calculate the regression equation only when the donor site(s) have rain and apply it only to those times to generate the infill rainfall
- force the regression through the origin (0,0). This tends to inflate the R^2 and may discount topographic and orographic induced differences in the occurrence of light rain between sites.

2.7 Infilling from rainfall–runoff models

Rainfall–runoff models sometimes incorporate algorithms for estimating rainfall at a site from which data collection has temporarily failed. If such a model already exists that includes the recipient site, this is a viable source of infill data, but these models are time consuming to set up and have the disadvantage that their output can be difficult to replicate, so they are difficult to justify for the sole purpose of generating infill record.

Infill from this source is synthetic data, QC 300 applies, and an appropriate Data Comment explaining method etc. is required (see Section B 5.3.2).

3 Other Considerations

3.1 Seasonality of relationships

Seasonal differences tend to exacerbate topographic- and orographic-induced variability in rainfall distribution and may affect the reliability of some donor sites and not others. The effect of seasonality on the relationship(s) used to derive a synthetic rainfall record must be considered, and then accounted for if significant.

Examples are the occurrence of snow at one site and not the other during winter, seasonal differences in the relative strength and direction of the wind, seasonal differences in the influence of obstructions such as deciduous trees, and the relative frequency of summer thunderstorms.

3.2 Using multiple donor sites

Although multi-site consideration is recommended (see Appendix B.1 Section 2.5), multiple regression may not necessarily improve the accuracy of synthetic rainfall data because of the same potential variability that makes multi-site consideration necessary.

The relative usefulness and possible bias can be tested by developing relationships with several combinations of donor sites and comparing what they predict with the actual record. However, in most cases the occurrence and extent of missing record will not justify this level of analytical investment.

4 References

McKerchar A, Henderson R, Horrell G. 2010. *Standard procedures for creating and describing synthetic hydrological record.* NIWA Client Report No. CHC2010-002 prepared for Tasman District Council under an Envirolink project.

Appendix B.2 Changes to Event Rainfall

The definition of event rainfall data and its method of capture via tipping bucket rain gauges has changed in New Zealand since it became possible to record every bucket tip as it occurs and transmit and store data without data compression.

This appendix describes the historic method, what has changed, the consequent effect on selection of an appropriate time-series data type for storing the data, and the effect of data compression as applied to the data before it was permanently stored.

The combination of the method of event rainfall capture, the data type in which it is stored, and any compression applied, may affect how and what data are retrieved for analysis. Any change to any one of these factors without corresponding attention to the others may compromise stationarity of the time series. It is also a significant issue to resolve when migrating legacy data into new time-series management systems or adding data collected a different way to an existing time series.

1 Fixed Interval Recording

1.1 Punch-tape recorders

From the early 1970s until the introduction of Aquitel telemetry in the mid-1980s, rainfall intensity data were digitally recorded in New Zealand on punched paper tape using a recording interval of six minutes (one-tenth of an hour) centred on the hour.

To maximise the length of time a paper tape could be left on a recorder a method was devised of punching only when rainfall occurred, i.e. capturing only the rain events, and thus was known as ‘event rainfall’ data. The recorder punched a coded time when a pulse was received from the bucket gauge. The coded time incremented every six minutes.

When the tape was read the coded times were collated and converted by the processing software to the amount of rainfall in each six-minute interval. To then make most efficient use of the limited computer storage only the intervals containing non-zero values were written.

1.2 Aquitel telemetry

Aquitel remote telemetry units were set to log every 7.5 or 15 minutes and logged a value every interval whether tips had occurred or not. The base telemetry software compressed redundant values out of the time series as it wrote the data to file.

1.3 Data type

The data type used to store these data is incremental and interpolating with timestamp at the end of the interval, i.e. each value filed is the total rainfall in the preceding time interval, and the timestamp of the previous value sets the start of the current time

interval. This means that when there is no rain, it is sufficient to store a zero value one recording interval immediately prior to the first non-zero value of the next rain event. The time-series manager (TSM) interprets all time from the last stored value of the previous rain event up to the time of the zero value as a period of no rain.

1.4 Data compression

All TSMs that are or were in use in New Zealand are capable of applying various forms of data compression. The universally common form that concerns data processing and data retrieval is the lossy process of removing redundant values from an interpolating time series. 'Redundant' is defined differently in the various software and in most systems the user has considerable control over the degree of compression applied.

Where compression has been applied, the period and range should be recorded in the metadata; however, automatic data compression using a range of zero was often a system default and rarely commented.

Fixed interval rainfall data were not usually compressed using a range other than zero, but legacy software TIDEDA implemented this differently to other TSMs and removed not only duplicate values but also those where the rate of rainfall was the same, and therefore removed proportionally more data elements, as shown in Table B 6.

Table B 6 – Fixed interval and event rainfall time series and TIDEDA data compression

Rainfall with recording interval of six minutes				**As filed in TIDEDA compressed to range = 0**	
Fixed interval data		'Traditional' event data			
Date/time	Rain (mm)	Date/time	Rain (mm)	Date/time	Rain (mm)
24/07/2020 12:00	2.5	24/07/2020 12:00	2.5	24/07/2020 12:00	2.5
24/07/2020 12:06	3.0	24/07/2020 12:06	3.0	24/07/2020 12:06	3.0
24/07/2020 12:12	2.0	24/07/2020 12:12	2.0	24/07/2020 12:12	2.0
24/07/2020 12:18	0	24/07/2020 12:42	0	24/07/2020 12:42	0
24/07/2020 12:24	0	24/07/2020 12:48	0.5	24/07/2020 13:00	1.5
24/07/2020 12:30	0	24/07/2020 12:54	0.5		
24/07/2020 12:36	0	24/07/2020 13:00	0.5		
24/07/2020 12:42	0				
24/07/2020 12:48	0.5				
24/07/2020 12:54	0.5				
24/07/2020 13:00	0.5				

The original fixed interval data are recoverable from the compressed time series by resampling (repacking) the compressed data to the recording interval, provided the compression range applied was zero.

2 Tip Recording

This method logs bucket tips as they occur, to a time resolution of one second, and has become known as event recording or event rainfall.

On receipt of each pulse from the tipping bucket gauge a logger may store a value with timestamp (either a rainfall depth or a tip count), or just the timestamp. Processing software converts counts to rainfall depth for filing in the time series.

Time interval between each stored value varies and is not predictable.

Note: One-second time resolution records quite precisely when the bucket tipped but not when the rain collected in the bucket actually fell. Resolution of tipping bucket rainfall data depends more on bucket size.

2.1 Zero values

When there is no rain, no data will be logged from the gauge. Long dry spells become problematic in that it cannot be certain the site is still working unless inspected, so some agencies program their loggers to store a zero value at a regular interval such as once or twice every day at the same time, or on the hour every hour.

For the interpolating data type this practice presents a false interpretation of the data because the rate of rainfall accumulation is determined by the time interval between preceding and current timestamps regardless of the preceding value. The gauge bucket may indeed be filling due to rainfall as the status check value of zero is being logged.

2.2 Data type

These data are incremental because they are intended to be totalled but may be stored in a discrete or interpolating data type.

2.2.1 Discrete totals

If stored in a discrete data type, there is no valid interpolation between data elements and therefore no apportioning of rainfall between timestamps by way of assuming an average rate of accumulation.

Rainfall is taken as having occurred in the instant a bucket tipped and total rainfall in any period is simply tallied on that basis. Zero values inserted in the data have no effect.

2.2.2 Total in preceding interval

If the data are stored in an interpolating data type, interpolation is valid, and apportioning can occur.

Rainfall is taken as having occurred at a constant rate over the interval between successive timestamps. In this way two interpretations are possible depending on whether zeros are added by the logger:

- the rainfall is deemed to have accumulated in the period between the time of the immediately preceding stored zero value and the current tip time, or
- if there are no zero values stored in the data, rainfall is deemed to have accumulated in the period between the time of the immediately preceding tip and the current one, which leads to an interpretation that there is never a period of no rain.

Total rainfall in any period is the sum of values for all intervals wholly within the period, plus amounts apportioned to any part intervals at the start and/or end of the specified period.

A value of zero stored in the data changes the apparent rate of accumulation of the subsequent bucket tip because the timestamp of the zero value sets the start of the next accumulation interval. Zero values inserted into tip data therefore have some effect on statistics calculated from the data, although the effect may not be significant depending on the analysis undertaken.

Hilltop Software does not support discrete totals but offers two data types for tip recording that insert a zero value into the time series 'on the fly' when statistics are calculated from the data, at either 6 minutes or 30 minutes prior to a tip, if no tips are filed in that interval. In this way Hilltop Software establishes that any recorded bucket tip accumulated over no more than the previous 6 (or 30) minutes without altering the stored data.

2.3 Data compression

Lossy compression of tip data stored as discrete totals should not be attempted because technically there is no redundant data to remove.

If tip data are stored as total in preceding interval and zero values have been regularly inserted there is some incentive to compress redundant zero values out of the time series before permanent storage. However, the effect of data compression on the non-zero data is likely to be software dependent and somewhat unpredictable due to the irregular intervals between data elements. Any data compression applied should be a range of zero and restricted to periods of only zero values.

3 Combining Records of Different Type

Rainfall recording at many sites has changed from fixed interval (including 'old-style' event recording) to tip recording ('new-age' event recording). This is a significant change to the method of capturing rainfall data from tipping bucket gauges that affects how the rainfall is subsequently represented and interpreted, to the extent that most TSMs offer different data types for their storage.

Data should be stored in the data type most appropriate to the method of capture. Records of different data type should not be combined in the same time series unless the TSM software supports combining data of different type.

Facilities for combining data of different type vary. Some TSMs support the storing of data of different interpolation method in the same time series. Other TSMs allow two or more time series of different data type to be stored separately but concatenated for analysis.

Annex C Processing of Gauging Results

1 General Overview

This Annex contains further specific guidance for the post-processing, quality review, documentation, and archiving of measurements of open channel flow (i.e. discharge gaugings, hereafter referred to as gauging) after a discharge result has been obtained.

The initial data processing required to obtain a discharge result from the field measurements is included in NEMS *Open Channel Flow Measurement – Measurement of Open Channel Flow v 2.0.0*.

1.1 Normative references

This Annex shall be read in conjunction with the following references:

- NEMS *Open Channel Flow Measurement – Measurement of Open Channel Flow v 2.0.0.*
- (Where reference is made from this Annex to specific sections of the above document, its title is abbreviated and version stated, i.e. 'NEMS Open Channel Flow v2.0.0').
- QRevInt Manual - see Genesis HydroTech LLC website (https://www.genesishydrotech.com/qrevint).

1.2 Documenting the data processing system for gaugings

Discharge measurements that have been registered (see Section C 1.2.1) and reviewed (see Section C 2) shall be archived in a database (also see Section C 6).

Methodologies applied by each agency to process and preserve gauging data shall be documented by the agency. Procedures vary widely depending on the combination of:

- gauging method(s) and instrumentation used
- choice of software to process gaugings, QRevInt being the required method for ADCP gauging, and QRevMS for all mean section acoustic gauging methods
- the time-series manager in which results will be permanently stored.

Some time-series managers store gauging results as a multi-item time series with associated electronic forms and 2-D cross-section data to store the measurement detail. In these systems all fields in the multi-item data must contain values, so a default or flag value is stored if an item is missing (see Appendix C.3 Section 5). Any changes or adjustments to, or deletions of, data must be rolled through to all parts of the gauging,

which may need to be managed manually depending on the system and process. Housekeeping procedures are needed for data stored in these systems.

Some systems store gaugings in relational database tables and use queries to make selected gauging data available to other system tools and applications, such as a Ratings workbench. These systems are better at maintaining integrity of the data but require additional processes to view and manipulate the data as a time series.

Complexity of the gauging information stored varies between systems and gauging methods. Facilities vary and not all gauging methods and formats are handled to the same extent. The archiving system may store one or more of the following:

- raw measurement data, which may be manually input, and may be recalculated each time the measurement is accessed so results can potentially change if the system software changes
- editable summary results as determined and generated by the system software and/or from manual data entry
- proprietary summaries, imported as editable data or as a webform or non-editable image
- data imported from smart devices, which may include the measurement data that may then be recalculated on import, or be the proprietary calculation and/or summary results in an exchange format offered by the device software
- output from QRevInt/QRevMS
- measurement metadata imported from the gauging instrument and/or smart device and/or retrospectively manually entered.

Adequate mechanisms shall be put in place to store all relevant metadata with, or accessible from, or indexed from, the actual discharge measurement.

Procedures must ensure all requirements for control of editing (see Section 3.8), metadata (see Sections C 2.1 and C 4), and preservation of record (see Section C 6) are satisfied for all gaugings stored. Additional housekeeping and/or manual procedures may be needed.

For example, additional procedures may be required for permanent storage of, and access to, the original measurement data outside of the time-series management system, or for controlling and tracing the editing of data to ensure integrity across all related parts if not managed entirely by the system.

1.2.1 Gauging register

Each gauging returned to the office must be entered chronologically into a register with a minimum of the following noted:

- river name
- site name
- gauging method, and

- date and time of the measurement.

A unique identifier for each gauging is obtained from this register to be used for all data and records associated with the gauging.

Note: Identifiers are more helpful for Ratings work, and registration errors are easier to find, if the identifier is sequential. Some time-series management systems only support numeric identifiers.

A discharge measurement subsequently deleted from its site record must not be removed from the register. Deletion of the measurement must be recorded in the register, with the date on which the deletion was actioned and by whom.

The register should also record the following:

- the computed discharge result
- stage assigned to the gauging (if any)
- the gauging party
- the purpose of the gauging

  Note: Purpose dictates what takes priority when gauging. Requirements for some purposes may conflict with others. Examples are: i) gaugings intended to calibrate a rating need a stage measurement whilst gaugings to assess compliance with minimum flow rules may not, and ii) gaugings for habitat assessment may be done at locations unsuited to discharge measurement because measurement of velocities in that habitat type is the objective, and those gaugings would not be used to calibrate a rating.

- date the gauging is input into the time-series management system
- cross-referencing as is helpful to traceability, e.g. to a data import log, accompanying suspended sediment measurement, original data file, electronic field sheet etc.

1.2.2 Original records

The discharge measurement and supplementary data (whether electronic, or paper records) on arrival at the office shall be:

- entered into a register (see Section C 1.2.1), and
- permanently identified with site identifiers, unique measurement number, and relevant date(s) and time(s), and
- moved from field computers, handheld devices, phones, or backup media to permanent storage locations, or
- if paper records, indexed and stored in a fireproof secure location.

All original records shall be retained indefinitely by the recording agency.

Note: The original record may be required at a later date, should the archived processed data be found to be in error, corrupt, or lost.

2 Quality Control

2.1 Additional metadata required

Expanding on the generic metadata requirements described in Section 6, the following metadata (as applicable) shall be collated, verified, and permanently archived, and be accessible as needed when verifying and archiving discharge measurements:

- site and equipment details:
  - location of the measurement cross-section(s) and/or reach
  - proximity to any associated water level reference and identification of any possible undesirable influences (see NEMS *Open Channel Flow* v2.0.0 Section 2.3.) and Section 4.0)
  - stage heights from each water level gauge at site, at start and end of the discharge measurement, and while gauging if stage is changing rapidly (also see Section C 2.3)
  - deployment details, including type of instrument or meter, instrument configuration values, instrument validation tests, method of deployment, and sampling regime (may be coded)
  - measurements related to instrument deployment (e.g. transducer depth, azimuth, meter distance above weight, size of weight, airline length, vertical and horizontal angles, length of reach etc.)
  - observations that support or impact the method, e.g. wind speed and direction at water surface, water temperature, salinity, turbidity and/or water clarity
  - factors affecting suitability of the reach for gauging as identified within the Site Matrix (see NEMS *Open Channel Flow* v2.0.0 _Annex ??)

  Note: statistical uncertainty analysis does not account for the impact of poor measurement conditions or poor practice on the result., such as may be caused by the presence of weed, turbulence, low SNR, soft substrate, or difficulty sounding depths and/or setting the meter.

- station and/or instrument calibration details:
  - serial number(s) of instrument(s) used
  - operating firmware and software versions
  - calibration data, including date of most recent calibration, and calibration parameters and limits (see Section C 2.2)

    - ground-truthing as needed for image velocimetry methods
    - magnetic declination for moving boat ADCP methods
    - results of pre- and post-deployment tests (see Section C 2.2)
- measurement details:
    - gauging number
    - gauging party
    - recording agency
    - calculation method(s), including the software and version used, for the original and archived discharge result(s)
    - uncertainty of the original and archived discharge result(s)
    - coverage factor (confidence level) and calculation method(s), including the software and version used, for the uncertainty of the original and archived discharge result(s)
    - sampling detail (which may be coded), including as applicable:
        - number of verticals and sampling points
        - proportions of measured to unmeasured area
        - sampling time(s)
        - extrapolation method(s)
        - edge assessment(s) and treatment.
    - estimate(s) of alpha, as applied to surface velocities to obtain mean velocity
    - quality code assessment.

2.2 Deployment tests and checks

To achieve a quality code of QC 600, instruments used for discharge measurement must have a current and valid calibration, be used within their calibrated range, and be serviceable when deployed. Calibration history and results of pre- and post-deployment tests must be available to the processor. Quality code can be no more than QC 500 in any of the following circumstances and an Operational Comment must be filed giving the reason(s) for the reduced quality code:

- instrument is overdue for calibration, is damaged, or was used outside its calibrated range (e.g. above or below velocity thresholds), or in a manner that invalidates the calibration (e.g. a meter calibrated without its guard but used with the guard in place, or a Doppler instrument deployed before it had reached equilibrium with water temperature)
- instrument is used without recommended clearances (e.g. from stream bed and/or banks, or transducer blanking and screening distances)
- instrument fails a pre-or post-deployment check, e.g. a beam check, spin test, or compass calibration

- QRevIntMS software not used for acoustic measurements
- OURSIN not used for calculation of measurement uncertainty
- SUNY not used for calculation of measurement uncertainty for salt dilution discharge measurements,

It is possible to request a damaged current meter be recalibrated in its damaged condition before repair, enabling the discharge to be recalculated using the 'as is' calibration to recover the measurement. If this has been done, an Operational Comment must be filed providing details of the 'as is' calibration and reason for it (see Section C 4.2.3).

2.3 Stage height for the gauging

- A stage height for the gauging is required if the gauging is to be used to develop a stage–discharge rating for the site (also see NEMS Open Channel Flow v2.0.0 - Section 2.4).

The stage height assigned is the mean gauge height representative of the discharge measured (see Appendix C.1). It should be obtained in a consistent manner for the site, and the usual source and method(s) be recorded in an Equipment Comment (see Section C 4.2.2).

If there is some distance between the gauging location and the location of the water level reference, lag due to time of travel may need to be accounted for when determining mean stage height for the gauging. Time of travel can be estimated by dividing the distance between the two locations by the mean velocity for the gauging.

Uncertainty of stage can outweigh uncertainty of discharge measurement in situations where stage is changing rapidly, or lacks resolution, or is difficult to determine due to on-site conditions. An Operational Comment is required in any of these situations stating the uncertainty in the stage height assigned to the gauging (either calculated, observed, or estimated) and the reason(s) for it.

Stage height assigned to the gauging must be reconciled with the filed stage record. If significantly different, the difference must be resolved. If the filed stage record is independently edited or adjusted, agreement with stage height(s) assigned to any gauging(s) in the period altered must be re-evaluated.

Note: The stage–discharge rating fitted to gaugings will be applied to the filed recorded stage to derive a record of flow. If the stage assigned to a gauging is different from the filed recorded stage at the file time of the gauging, no matter how well the rating curve is fitted to the gauging the measured and corresponding derived rated flows will not match.

2.4 Calculation of uncertainty

A quantitative uncertainty for the discharge measurement result must be calculated whenever possible and stored and presented with the result in expanded form, to coverage factor 2 (95% level of confidence). The uncertainty is also used to determine quality code for the measurement (see Section C 4.1).

Discharge measurements are composite quantities that depend on several component quantities, so the total error of the measurement is a combination of the errors in all component measurements. Uncertainty for the discharge result is determined using statistical rules for combining the component standard deviations.

QRevInt shall be used for all ADCP moving boat discharge measurements and QRevMS shall be used for all discharge measurements utilising acoustic instruments and the mean section method

Uncertainty analysis is applied after all measurement bias has been corrected (JCGM, 2008, their Section 3.2.4) and measurement protocols have been implemented with rigour (JCGM, 2008, their Section 3.4.8), (Muste and Lee, 2013).

Note: For more information see JCGM (2008) and ISO 5168:2005.

2.4.1 Rotating-element current-meter measurements

Calculate uncertainty using the standard algorithms described in ISO 5168:2005 and ISO 748:2021. ISO methods are in terms of one standard deviation so the uncertainty obtained must be multiplied by 2 for 95% level of confidence.

2.4.2 ADV instruments

QRevMS shall be used for the calculation of all ADV discharge measurements with the uncertainty produced used for quality coding purposes.

2.4.3 ADCP profilers with velocity-area stationary method

The QRevMS software shall be used for the determination the uncertainty of the measurement (see Section C 2.6). This software which was originally developed by Dave Mueller (Genesishydrotech) provides a consistent set of calculation methods for all ADCP equipment. It uses similar principles to ISO 748:2007 and ISO 5168:2005, in that it assigns uncertainty to components of the gauging then combines the component uncertainties to obtain overall uncertainty at the 95% level of confidence.

2.4.4 ADCP profilers with velocity-area moving boat method

OURSIN within the QRevInt software shall be used to calculate the measurement uncertainty (see Section C 2.6). This software was originally developed by the United States Geological Survey (USGS), Dave Mueller (Genesishydrotech) now continues this development, and it provides a consistent set of calculation methods for all ADCP brands. It uses similar principles to ISO 748:2021 and ISO 5168:2005 in that it assigns uncertainty to components of the gauging then combines the component uncertainties to obtain overall uncertainty at the 95% level of confidence.

2.4.5 POEM instruments

There is no specific method for calculating uncertainty of discharge measured using POEM instruments, but the principles of ISO 5168:2005 and ISO 748:2021 can be applied.

Note: Hilltop Software applies the same calculation as for rotating element current meters, which may overstate the uncertainty for POEM gaugings because uncertainty associated with moving parts does not apply to the POEM.

2.4.6 Float-based surface velocity measurements

Use ISO 748:2021 Annex F.

2.4.7 Image velocimetry methods

A standardised method specific to surface velocity discharge measurements is still needed, but the uncertainty analysis framework for velocity-area discharge methods as used in ISO 748:2021 applies (Le Coz, pers. comm., 7 January 2021). Specific error sources to consider are:

- alpha errors (Hauet et al, 2018)
- image orthorectification errors (Le Coz et al, submitted)
- velocity errors, specific to signal processing (LSPIV/STIV/SVR), projection (SVR angles), time averaging, space averaging, extrapolation into unmeasured areas, etc.
- operator-related effects, and
- depth errors due to bed evolution, and positioning/projection errors.

Comparisons to reference discharges and intercomparison experiments are useful to document the likely uncertainty of surface velocity discharge measurements.

A typical uncertainty of at least ±15% at the 95% level of confidence is generally assumed for surface velocity measurements by a trained user in good conditions, for which the estimation of alpha is generally regarded as the dominant source of error if the riverbed is stable. Uncertainty in estimated wetted area due to bed movement adds more uncertainty to the discharge result.

2.4.8 Salt dilution methods

The SUNY – (Salt uncertainty) aligned methods and software has been developed (Hauet at al., 2020) and this shall be used when undertaking salt dilution flow measurements. This method and software takes into account uncertainties in:

- the mass of salt injected
- the measurement of time
- the conductivity to concentration relation

- possible exceedance of applicable range of the conductivity to concentration relation
- computation of the area under the conductivity curve
- imperfect tracer (salt) mixing
- loss or gain of tracer (salt) along the reach, and
- unsteadiness of the flow.

2.4.9 Volumetric methods

Use ISO 5168:2005 to combine the component uncertainties associated with measurement of volume and time.

2.4.10 Weirs and flumes for discharge measurement

Use ISO 5168:2005 to combine the component uncertainties associated with:

- measured head

  Note: Hook or point gauges with a vernier may be needed to improve resolution of head measurement at low stages with small structures.

- the dimensional measurements and correctness of the structure, for example, the angle, verticality, and straightness of a Vnotch

  Note: Dimensional measurement and correctness of the structure is critical for the theoretical discharge formulae to hold true.

- the various constants and corrective factors, for which estimates and tolerances are given in the relevant ISO standards.

  Note: In New Zealand, site factors such as sediment transport, relatively steep slopes, and lack of sufficiently large weir ponds, usually render theoretical ratings inaccurate and field rating by current meter is required. Thus, accuracy of flow determination at most sites with structures is generally governed by quality of the current meter gaugings, their scatter on the rating curve, and stability of the structures and their reaches.

2.4.11 Indirect methods

Apply the principles in ISO 5168:2005, although it may be difficult to get enough repeat measurements to calculate component standard deviations.

2.5 Review of results

The minimum measurement results required to be filed, as listed in NEMS *Open Channel Flow* 2.0.0, are:

- stage (mean gauge height) for the computed discharge (see Section C 2.3)

- the computed discharge
- gauged cross-section area (where applicable) (see Section C 2.7.1)
- mean velocity of discharge (where applicable) (see Section C 2.7.2)
- gauging method code (see Annex C of NEMS Open Channel Flow v1.1)
- calculated total uncertainty of the measurement (see Section C 2.4)
- quality code (see Section C 4.1)
- filed in NZST (or CHAST as applicable) (see Section 1.2.2) at the date and time of mean gauge height.

  Note: If a measurement is completed over a peak or trough then the time of mean gauge height may occur at more than one time. The time assigned to the measurement should be whichever is closer to when the larger portion of the flow was measured.

This Standard adds the following to the above list of required items:

- the unique gauging identifier (see Section C 1.2.1)
- alpha value(s) used for surface methods.

Additional items also commonly filed are listed in Appendix C.3.

Each measurement shall be reviewed by:

- the data collector, preferably in the field before departure so errors can be rectified or a repeat measurement done, and
- a second person, during or after processing of the measurement and before archiving.

In general, all results must be reviewed for errors of:

- configuration, deployment, and calibration, including:
  - metadata entry errors (site, party, location etc.)
  - poor choice of instrumentation and/or measurement location
  - inappropriate instrument settings
  - instrument out of calibration, not calibrated, or used outside calibrated range
  - failed pre- or post-deployment tests and checks (see Section C 2.2)
  - poor measurement technique
  - effect of inclement conditions e.g. strong wind or extreme temperature
- arithmetic in the computation, such as in calculating:
  - point velocities
  - means of depth, velocity, head, or time

- subsection areas and discharges
- total width, area, volume, and discharge

logic and consistency, such as:

- gauging number not sequential with date/time order of measurements
- number of verticals or transects disagrees with codes assigned
- stage assigned inconsistent with stage at start and end of the measurement, and rate of change
- file date/time not between start and end date and time of the measurement
- stage assigned deviates from corresponding filed stage by more than measurement tolerance
- mean velocity of discharge (discharge divided by wetted area) not plausible
- stage below CTF, but discharge is not zero
- muddled units
- adjustments for vertical and/or horizontal angles, or extrapolations into unmeasured areas, are not applied when needed, or results are not as expected.

Checks of arithmetic, logic and consistency can be automated.

2.5.1 ADCP moving boat method measurement review

ADCP discharge measurements have aspects that are specific to this method. The following items shall be confirmed in the data:

- transducer offsets, screening distances, edge distances and shape, temperature and salinity match the field notes
- a moving bed test using a proper technique has been conducted and assessed
- if a moving bed was detected, an appropriate alternative to bottom tracking was used (see Appendix C.2)
- total exposure time is greater than 720 seconds
- transects collected are reciprocal pairs
- the average boat speed was less than the water speed
- pitch and roll are within calibrated range and not excessive
- course changes are minimal and gradual
- sufficient edge cells have been properly measured

  Note: If the physical edge is a vertical wall the edge cells should be no closer than the equivalent of the depth of water at the wall.

- extrapolation methods are appropriate for the wind and velocity conditions observed at the time of measurement.

  Note: Wind and horizontally stratified density currents are the most common reasons for velocity profile not conforming to the 1/6th power law (WMO, 2010).

  Note: Use the QRev software for the purpose of assessing potential non-standard velocity situations. Details of QRev can be found here: https://www.genesishydrotech.com/qrevint .

Further details on reviewing ADCP measurements are summarised in Appendix F

2.5.2 ADCP stationary method measurement review

The following items shall be confirmed in the data:

- diagnostic test results are passed and logged
- the ADCP clock is set
- temperature readings are valid
- ADCP orientation is known, and controlled if and when required
- no errors in ADCP draft, water depths, or widths apparent from the contour plot
- number of panels and % of discharge per panel is acceptable; within 5% of total is preferred but otherwise within 10%
- flow vectors and flow direction are consistent, with no obvious errors
- SNR/intensity; look for spikes caused by obstructions
- minimum number of valid ensembles and sampling duration has been achieved
- edge assessments and treatment are representative of actual edge panel discharges
- top and bottom extrapolations are reasonable extensions of the measured portions; alternates to the 1/6th power law should reflect conditions observed at the time of measurement, refer to QRev MS software outcome.

  Note: For SxS Pro, check there are enough bins measured to allow reasonable extrapolations at the top and bottom. In clear water, there may be several missing bins.

  Note: QRevMS is to be used to show appropriate extrapolation choices.

2.6 QRevInt/QRevMS

QRev is software originally developed by the USGS and continues with Dave Mueller (Genesishydrotech) to improve processing of moving boat and mean section ADCP gaugings. It offers:

- consistent processing algorithms and discharge calculation methods irrespective of instrument brand
- automated data quality checks and filtering, and improved handling of invalid data
- automated application of loop corrections, stationary moving bed analysis, and in area extrapolations, and
- an estimated uncertainty, via OURSIN, for the measurement (see Section C 2.4.4).

QRev is recommended for field processing of moving boat and mean section ADCP gaugings and is required for field and office review of results (see Section C 2.5).

QRevInt is used for moving boat gaugings and QRevMS for mean section gaugings. Its design leads the user through the processing steps in the most effective order and uses a traffic light system and messages to inform the user of the status of each step.

The following is summarised from the User's Manual:

- work from left to right across the tabs in the interface to obtain the best navigation data, then the best depth data, and finally the best water data. The discharge result is then based on the best available data
- green indicates data under the respective tab have passed all internal quality checks
- yellow (or orange) with warning symbol indicates data have failed some of the internal quality checks and users should (re)evaluate that data
- red with attention symbol indicates data have failed some of the internal quality checks, with possible significant effect on discharge, and users must address the issue(s)
- blue text indicates a setting changed from the original by the user(s). Add a comment within QRevInt/QRevMS noting the reason for the change, to facilitate any further review and assist with compiling the Data Processing Comment (see Section C 4.2.5) needed when archiving the gauging.

QRev is fast, powerful, and easy to use. There is potential, therefore, to manipulate options until a desired result is achieved. It is important to know when to depart from automated selections and settings and why, and when to stop processing and accept the result. It is strongly recommended that organisations develop a Standard Operating Procedure for use of QRev to guide these aspects.

2.7 Derived and related data

Cross-sections and hydraulic variables derived from gaugings are useful:

- when developing stage–discharge rating curves
- when indirect methods are needed to estimate discharge, and
- for 'bulk' quality review such as during an audit (see Section 7.3).

2.7.1 Cross-sections

Gauged cross-sections should be plotted and reviewed for depth and width anomalies. If the sampling point locations and/or point velocities are also available, they should be reviewed for anomalies not consistent with any field notes.

Gauging cross-sections are most useful if they can be compared by overplotting or differencing. To do this effectively they should be on the same alignment at the same location with the same initial point, orientation, and datum.

For hydraulic analysis or determination of discharge using surface or indirect methods, cross-sections must be a true cross-section, oriented true left to true right, with offsets increasing. Values may be stored as depth below or elevation above some datum. Datum may be water surface or some other physical reference, such as a bridge deck, or an assumed or nominated survey datum, e.g. mean sea level (MSL) or New Zealand Vertical Datum (NZVD).

If archived cross-sections are intended for hydraulic analysis, data review must ensure that either the above conditions are satisfied for any cross-section stored or there are sufficient metadata stored with the gauged cross-section to enable the required manipulations (e.g. datum conversion) to be performed at time of analysis in the future.

Note: Oblique sections and transects adjusted by the horizontal angle of section may approximate a true cross-section if the reach is reasonably uniform but otherwise cross-sections from 'distance made good' oblique sections and transects may be misleading.

2.7.2 Hydraulic variables

Check that $Q/A = V$ and $A/P = R$ for each gauging where these are obtainable,

where Q is discharge, A is cross-section area, V is mean velocity of the discharge, P is wetted perimeter, and R is hydraulic radius.

These checks can be automated.

Sanity check any measured, derived, applied and/or stored values of (water surface) slope and resistance factors, e.g. Mannings 'n'.

Check that vertical and horizontal angle corrections intended to be applied have been applied and have altered component measurements as expected:

- vertical angle corrections reduce depths
- angle of section corrections reduce widths
- angle of current corrections reduce point velocities.

Confirm that, if the corrections are not stored with the measured data, the measurement metadata records what corrections have been applied.

3 Potential Errors and Recommended Editing

Errors can be difficult to identify. They may not be found unless the gauging plots off the rating curve. At unstable sites errors may still not be detected. Checks cannot compensate for careful and accurate observation and field documentation.

However, a gauging should not be assumed to be in error and disregarded simply because it plots off the rating.

Gaugings left to deviate by more than 8% from their relevant rating curve must have a Data Comment filed to verify that they have been checked and to provide an informed explanation for the deviation (see Section C 4.2.4).

3.1 Sources of errors

Errors in gauging data may be random, systematic, or spurious in nature.

3.1.1 Random error

Errors are random (stochastic) when measurements vary according to chance. Random errors follow a normal distribution. Scatter of individual measurements around their mean is unbiased.

Random error is influenced by sample size and sensitivity of measurement.

3.1.2 Systematic error

Systematic errors (biases) are a consequence of errors of method or use of instrumentation in compromised condition. If the cause of the bias can be determined an unbiased measurement may be recoverable. Some examples are:

- incorrect calibration of any measurement instrument, including the possibly less obvious such as distance markings on bridges and taglines that may have stretched
- sampling error, such as measuring single-point velocities at 40% of depth instead of 60% of depth
- scaling and configuration errors such as wrong magnetic declination, failing to apply an angle of section correction, or not

multiplying meter counts by multiples where required, e.g. Large Ott x5 or x10 options.

Unlike random errors that show as scatter of gaugings about a rating curve, systematic errors may not be detectable at an unstable site, being assumed instead to be due to a shift in rating. Particular care must be exercised to ensure that systematic error is minimal in any discharge measurement.

With respect to gaugings, most systematic errors behave like random errors and in many cases, one category may be embedded in the other. ISO 5168:2005 conforms to GUM methodology (GUM, 1995) in that it treats random and systematic error identically, this being a significant change from earlier versions of ISO 5168 (see Annex I of ISO 5168:2005).

3.1.3 Spurious error

Spurious errors are usually human in origin or the result of malfunction. Often, they are gross errors, identifiable, and possibly recoverable. Outlier tests may be applied (see ISO 5168:2005 Annex D).

It must be emphasised that in all cases outlier tests or discarding of data shall be done only if there is independent technical reason for believing that spurious errors may exist; data should not be thrown away lightly.

3.2 Editing gauging data

Depending on the error identified, measurement data, configuration settings, processing options, measurement metadata, or one or more summary results may need to be altered.

Editing methods are determined by the various software used to process, manage, and store the measurement and result data, and its associated metadata, but in general are largely manual processes.

Changes to measurement data, configuration settings or processing options will usually require the gauging to then be reprocessed and/or recalculated. In some cases, reimport of the measurement may be necessary.

Most software is sensitive to where in the gauging data structure editing is initiated from. Failure to start the editor at the correct level in the structure may result in inconsistent and/or orphaned related parts when changes are saved.

When editing gauging data, ensure that:

- the data to be edited are accessed from the ‘parent’ data source or primary record and are edited in the correct manner to ensure all changes roll through to all other related parts of the measurement and results
- derived data are also recalculated and amended as necessary (see Section C 2.7)

- any change to the site identifier(s) and/or unique gauging identifier is also noted on any other data, documents and files carrying those identifiers (see Section C 1.2.1)

  Note: In some systems it is extremely difficult to change an identifier once it has been assigned.

- stage height corrections are cross-checked against the filed stage (see Section C 2.3)

  Note: The filed stage rather than the gauging stage may be at fault.

- angle corrections are applied to the correct component variable(s) (see Section C 2.7.2)

  Note: Historically, angles of section and current were often lumped together and corrections applied only to the total area. Sometimes only the discharge was adjusted, or the corrections were not applied at all. This of course affects the reliability of stage–area and stage–velocity relations derived from this historic data.

- if the file time of the gauging is changed, or it is refiled under another site, the now defunct duplicate is removed from the dataset (see Section C 3.3)
- the Gauging Register is updated (see Section C 1.2.1)
- a Data Processing Comment is filed for any change to the original data collected (including configuration settings and field metadata) (see Section C 4.2.5)
- original data are annotated that it has subsequently been altered, when, why and by whom
- other measurements do not require the same or similar amendment

  For example: correcting a mistake in a meter calibration entered into a gauging logger used for a number of measurements across many sites.

- other related metadata are changed or added as needed to maintain consistency and integrity of all data filed, e.g. revised and/or new quality codes and other comments.

3.3 Deleting gauging data

A discharge measurement should only be deleted from a dataset in limited circumstances, such as:

- if it is a defunct duplicate (see Section C 3.2)
- if it is affected by non-recoverable known technical or operational issues that render it spurious (see Section C 3.1.3).

When deleting gauging data, ensure:

- all related parts of the deleted measurement are removed
- original data are annotated that it has subsequently been deleted from the record, when, why and by whom
- the deletion is noted in the Gauging Register (see Section C 1.2.1).

4 Metadata

4.1 Quality coding

The quality of a discharge measurement can be assessed:

- quantitatively by calculating uncertainty, and
- qualitatively based on performance objectives.

Both methods are necessary in combination because calculated uncertainty on its own does not account for all influences on measurement quality and/or quality of result (see Section C 2.4).

The relevant quality coding flowchart and quality coding matrices may be found in NEMS *Open Channel Flow v 2.0.0. (*Annex A – Annex D*)*

If the measurement location and conditions or practice at the time are not conducive to good measurement, the quality code assigned to the measurement must be reduced regardless of the calculated uncertainty:

The most significant practices affecting measurement quality relate to the choice of measurement section and sampling technique. The more uniform the measurement reach and flow conditions the less influence these factors have, except for dilution methods that require the opposite, i.e. maximum possible turbulence and mixing.

For ADCP gaugings, measurement quality is a combination of the above factors, the instrument knowing where it is (position and orientation), and its ability to reliably determine velocity using sound as a surrogate. These factors are reflected in the quality code assessment matrix and QRev result for acoustic methods section ADCP measurements that determines quality code for those measurements (see Annex D of NEMS *Open Channel Flow Measurement v 2.0.0).*

Quality code must also be reduced to QC 400 if the measurement has undergone significant modification from the original, and/or post-processing selections depart significantly from expected options, unless the changes are fully traceable (e.g. a revised calibration) and have not required interpretation and assumption.

For example: Quality code QC 400 would apply to an ADCP measurement with best-fit velocity profile extrapolations departing significantly from the 1/6th power law, and to a gauging subject to large angle corrections on the basis that the measured data have undergone significant modification.

Any discharge measurement assigned a quality code less than QC 500 shall be commented to explain the reason for the reduced code. If no other comment category is applicable a Data Comment must be filed to satisfy this requirement (see Section C 4.2.4).

4.2 Example gauging results comments

The following are templated examples of comments for gauging data.

Every comment must be assigned a fully specified timestamp and be associated with the relevant data (the time series of results and/or the measurement record) via some form of 'Site' and 'Measurement' database key combination. The database keys are usually specified in some form of record header not shown here.

4.2.1 Site/Initial Comments

The standard SI unit should be used from options shown in the example below unless data are required to be stored as integers or values are consistently very small, e.g. flows in ml/s.

Type: Site
Measurement: Gauging
Initial comment for the gauging station: *<station name>*
On the *<river name>* River, river number *<river number>*[12]
The station is situated at grid reference *<map co-ordinates and type*[13]*>*
Gaugings above stage height *<limit of safe wading>*mm are carried out by *<method(s) used for gaugings not waded>*
Units, unless otherwise stated, are
1) Mean stage height in metres *(or* millimetres*)*
2) Discharge in m^3/s *(or* l/s *or* ml/s*)*
3) Area in m^2 *(or* cm^2*)*
4) Mean velocity in m/s *(or* mm/s*)*
5) Maximum depth in metres *(or* millimetres*)*
6) Water surface slope in mm/1000m
7) Water surface width in metres *(or* millimetres*)*
8) Hydraulic radius in metres *(or* millimetres*)*
9) Wetted perimeter in metres *(or* millimetres*)*
10) Sediment concentration in g/m^3 (mg/l)
11) Water temperature in degrees C *(or* degrees C x1000*)*
12) Stage change in mm/hr
13) Gauging method code (ccnn) where cc = method and nn = number of verticals
14) Number of verticals and sample points (nnpnnpnnp) where nn = number of verticals and p = number of sample points

15) Calculated uncertainty of measurement to 95% level of confidence as % *(or* % x10*)*
16) A flag to indicate if a comment is also filed (1 = comment present, 0=no comment)
17) A numeric code for the agency that carried out the gauging
18) Gauging number as registered by the recording authority
The gauging result is filed at the time of mean stage height for the measurement.
Additional information: -1 indicates missing data. The format changed from 15 to 18 items in 2005. Earlier results may not have measurement uncertainty (item 15) or a comment flag (item 16) available. *<Add purpose of station, the flow controls if results are used for rating development, and persistent issues that affect gauging quality e.g. weed, turbulence, high sediment and/or debris load, geothermal, clarity (low SNR), periodic backwater, tidal etc.>*
The following is also measured at this site: *<list variables>*
The local recording authority is: *<name of recording/archiving agency>*

4.2.2 Equipment Comment examples

Type: Equipment
Measurement: Gauging
Instruments used to measure discharge at this site include: *<list types>*. Calibration of *<state type>* occurs *<state frequency> (repeat for each type)*. Calibration records are stored in *<provide database or file reference(s) as applicable to each type>* and accessible via *<provide means of access e.g. file request, computer application, intranet etc.>*.

Type: Equipment
Measurement: Gauging
Gaugings are assigned mean stage height calculated from primary reference gauge readings (*or* the logged stage, *or <state source e.g. the staff gauge, or internal plumb bob>*) unless otherwise stated.

Type: Equipment
Measurement: Gauging
Manned cableway decommissioned on *<dd-mm-yyyy hhmmss>*. High flow measurements from this date onward are done using an ADCP mounted in a remote-controlled moving boat.

4.2.3 Operational Comment examples

Type: Operational
Measurement: Gauging
Gauging *<unique identifier>* on *<dd-mm-yyyy hhmmss>* is recalculated using the 'as is' calibration of *<date/time of calibration>* due to damage to the meter during the measurement.

Type: Operational
Measurement: Gauging
Gauging *<unique identifier>* on *<dd-mm-yyyy hhmmss>* was carried out by *<other agency>* who hold the original records.

4.2.4 Data Comment examples

Type: Data
Measurement: Gauging
Gauging *<unique identifier>* on *<dd-mm-yyyy hhmmss>* has been checked with no obvious reason for the *<+ (or –) x%>* deviation from the rating but rating shift is unlikely.

Type: Data
Measurement: Gauging
Gauging *<unique identifier>* on *<dd-mm-yyyy hhmmss>* has point velocities observed over 20s instead of the normal 40s to minimise uncertainty in assigned stage height because of rapid change during the measurement.

Type: Data
Measurement: Gauging
Gauging *<unique identifier>* on *<dd-mm-yyyy hhmmss>* includes an estimate of overflow that bypassed the gauging cableway. Discharge measured was *<x m^3/s>*, estimated overflow was *<x m^3/s> (*added into the final result as a side flow*)*.

Type: Data
Measurement: Gauging
Stage for gauging *<unique identifier>* on *<dd-mm-yyyy hhmmss>* is affected by backwater.

The following examples are reproduced from NEMS *Rating Curves* v 2.0.0 where they are headed 'Gauging Deviation Comment'. NEMS *Rating Curves* will be updated in future to refer to the examples below, which are modified to be consistent with the comment framework and format established by this Standard.

Type: Data
Measurement: Gauging
Gauging *<unique identifier>* on *<dd-mm-yyyy hhmmss>* deviates *<+ (or –) x%>* from the rating curve. When compared with other gaugings on the same cross-section, the mean velocity is lower than expected. Significant problems with floating weed were experienced while gauging and it is suspected the meter remained weed-bound despite attempts to keep clear.

Type: Data
Measurement: Gauging
Gauging *<unique identifier>* on *<dd-mm-yyyy hhmmss>* deviates *<+ (or –) x%>* from the rating curve. When plotted on the stage–area curve, area is greater than expected. Accurate sounding was difficult and vertical angles severe. A rating change occurred on the event that prevented useful resurvey of the section after the event.

Type: Data
Measurement: Gauging
Gauging *<unique identifier>* on *<dd-mm-yyyy hhmmss>* deviates *<+ (or –) x%>* from the rating curve. Analysis of the ADCP gauging data indicates problems with a moving bed, causing velocities to be under-recorded.

4.2.5 Data Processing Comment examples

Type: Data Processing
Measurement: Gauging
Gauging *<unique identifier>* on *<dd-mm-yyyy hhmmss>* has been filed at a stage height of *<x mm>* consistent with the adjusted filed stage record. The weighted value of the original observations is *<y mm>* but these were affected by *<reason for the adjustment>*.

Type: Data Processing
Measurement: Gauging
Gauging *<unique identifier>* on *<dd-mm-yyyy hhmmss>* has been reprocessed with the following adjustment(s): *<list the changes to original settings>*. Original settings were *<explain need for change e.g. incorrectly entered or defaults not applicable etc.>*

4.2.6 Stationarity Comment examples

Type: Stationarity
Measurement: Gauging
Gaugings from *<dd-mm-yyyy hhmmss>* to *<dd-mm-yyyy hhmmss>* are filed at the end *(or* start*)* time of the measurement. Gaugings from *<dd-mm-yyyy hhmmss>* onwards are filed at the time of mean stage height for the measurement.

5 Audit

Further to the requirements of Section 7.3 of this Standard, combining audit of gauging data with audit of stage–discharge ratings for the site is recommended.

Gauging coverage and frequency should be reconciled periodically with rating requirements using methods described in Annex I of NEMS *Rating Curves* v 2.0.0. Audit is a convenient time to do this.

6 Preservation of Record

The following data shall be archived, retained indefinitely and, if electronic, backed up regularly by the recording agency:

- all original records
- unedited raw instrument data (the measured data as recorded)

  Note: The unedited raw data may be required at a later date, should the measurement need to be recalculated due to error, corruption, or loss.

- completed field sheets and gauging cards (paper or electronic). Paper records must be clear, legible, and protected from deterioration
- instrument validation data (results of pre- and post-deployment tests and checks, compass calibrations, GPS reliability, and loop and moving bed tests)
- supplementary measurements and observations (e.g. temperature, wind, salinity, SNR)
- configuration and deployment information (e.g. current meter rating, transducer depth, screening distances, magnetic declination, horizontal angle of section)
- discharge and uncertainty of discharge calculation method detail, including the software and version(s) used to obtain the archived result
- reviewed final measurement data
- calibration records
- site and time-series metadata.

Electronic files created in the field should be backed up while in the field whenever possible. Reusable storage such as datapaks, storage cards, and instrument memory must be downloaded, and data checked and backed up, before the storage is cleared.

Whenever possible archived measurements shall be locked to prevent further unintended alteration.

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Appendix C.1 Computation of Mean Gauge Height for a Gauging

This appendix is reproduced from Annex C of NEMS *Rating Curves*.

The mean gauge height for the period of the gauging shall be calculated according to the formulae below:

a) For larger rivers, if the fluctuations are less than 50 mm, an arithmetic mean shall be used.

For smaller rivers, the time-weighted method (c) is most often preferred.

b) If the fluctuation is 50 mm or more, ISO 748:2021 recommends using a discharge weighted calculation:

$$h = (q_1 h_1 + q_2 h_2 + q_3 h_3 + ... + q_n h_n) / Q$$

where: h is mean gauge height

Q is the total measured discharge = $(q_1 + q_2 + q_3 + ... + q_n)$

q1, q2, q3 ... qn = discharge measured during time interval 1, 2, 3, ... n, and

h1, h2, h3 ... hn = average gauge height during time interval 1, 2, 3, ... n.

c) However, Rantz et al (1982) demonstrates that method (b) tends to overestimate stage height, and suggests that where the change in discharge with stage height is linear in the range of stage that occurred during the measurement, a time-weighted mean is better.

This is calculated from:

$$h = (t_1 h_1 + t_2 h_2 + t_3 h_3 + ... + tn\ hn) / T$$

where: h is mean gauge height

T is the total time for measurement

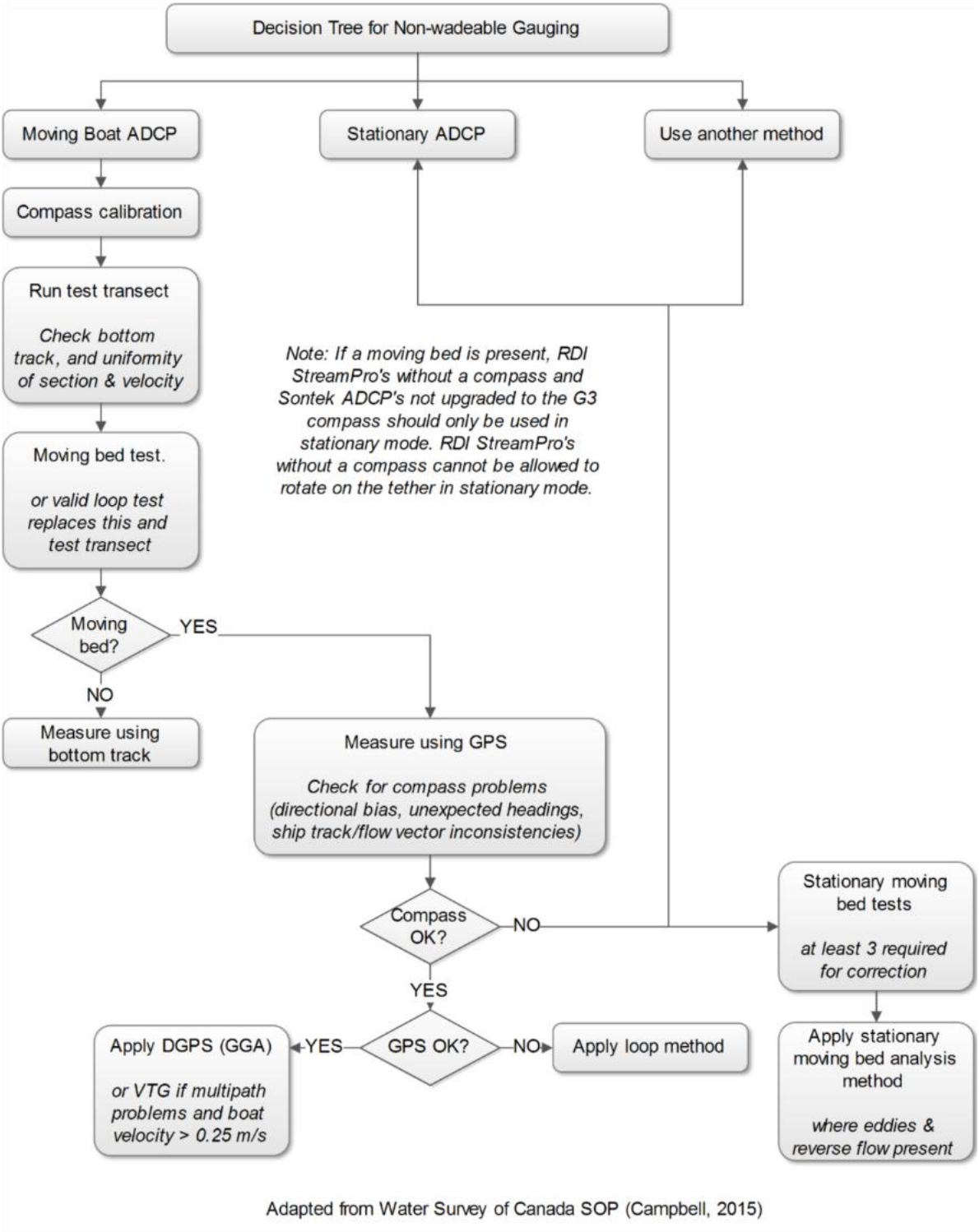
t_1, t_2, t_3 ... t_n = duration of time intervals between breaks in the slope of the gauge height versus time graph, and

h_1, h_2, h_3 ... hn = average gauge height during time interval 1, 2, 3, .. n.

d) Where the change in discharge with stage height is curvilinear, neither method (b) nor (c) is reliable, and Rantz et al (1982a, p. 173) recommend that the mean of the two estimates be used.

Note: Rantz et al (1982a) also provide examples of the calculations.

Appendix C.2 Decision Tree for Non-wadeable Gauging



Adapted from Water Survey of Canada SOP (Campbell, 2015)

Appendix C.3 Gauging Results – Items and Codes

The items and codes listed apply to any gauging, whether or not the station also has a water level recorder.

All gauging results are stored with an associated timestamp being the date and time of the mean water-level height (stage) for the measurement (see NEMS *Open Channel Flow Measurement v 2.0.0).*

1 Minimum Requirements

From 'The Standard – Open Channel Flow' in NEMS *Open Channel Flow Measurement – v2.0.0*):

- stage for computed discharge
- computed discharge
- cross-section area (where applicable)
- mean velocity of discharge (where applicable)
- method code
- uncertainty
- quality code
- time of mean gauge height, and
- From this Standard (Processing of Environmental Time-series Data):
  - the assigned unique gauging identifier.

2 10-item Gauging Results (historic)

Item 1 Mean stage height (for the gauging)

Item 2 Discharge (as measured)

Item 2 Area (of gauging cross-section)

Item 4 Mean velocity (usually determined from Discharge/Area)

Item 5 Maximum depth (of gauging cross-section)

Item 6 Wetted perimeter (of gauging cross-section)

Item 7 Hydraulic radius (usually determined from Area/Wetted perimeter)

Item 8 Water surface slope (if measured, otherwise -1)

Item 9 Sediment Transport (if measured, otherwise -1)

Item 10 Temperature (of water) (if measured, otherwise -1)

3 15-item Gauging Results (legacy & Hilltop)

The 10-item format was reordered and expanded to 15 items as follows:

Item 1 Mean stage height (for the gauging)

Item 2 Discharge (as measured)

Item 2 Area (of gauging cross-section)

Item 4 Mean velocity (usually determined from Discharge/Area)

Item 5 Maximum depth (of gauging cross-section)

Item 6 Water surface slope (if measured, otherwise -1)

Item 7 Width (surface width of gauged cross-section)

Item 8 Hydraulic radius (usually determined from Area/Wetted perimeter)

Item 9 Wetted perimeter (of gauging cross-section)

Item 10 Sediment Concentration (note change to 'concentration' in mg/l from 'transport' under the 10-item form)

Item 11 Temperature (of water)

Item 12 Stage change (in mm/hr over duration of gauging, 999 = over peak)

Item 13 Method (a code of format ccnn where cc is a code for gauging method, and nn is total number of measured verticals, if applicable)

Item 14 Number of verticals and sample points (if applicable, format nnpnnpnnp where nn is the number of verticals sampled at p points in the vertical)

Item 15 Gauging Number (format cnnnnn where c is an agency code originally issued by NIWA)

Note: Annex K (Discharge Measurement Method Codes] of the NEMS: Open Channel Flow Measurement – Measurement of Open Channel Flow v 2.0.0, incorporates additional codes to identify the "alpha" value utilised in surface velocity discharge measurements.

4 18-item Gauging Results (legacy NIWA)

NIWA (and by default, other users of TIDEDA) changed from 15 to 18 items in 2005. Items 1 to 14 are the same as for 15-item gauging results.

Item 15 Gauging Uncertainty (percent +/-)

Item 16 Comment Flag. (0=no comment, 1=comment in comment file)

Item 17 Gauging Agency (a hard-coded list of New Zealand agencies used by NIWA; if unassigned use 99: Other Agency)

Item 18 Gauging number (the ID assigned to each gauging when registered)

5 Missing Items

Any item not measured or not available was manually assigned a value of -1 in the historic and legacy results formats. Later implementations where gauging results are written automatically from the discharge calculation (e.g. Hilltop Software) may default to a value of 0 if no other result is available.

6 Gauging Method Codes

Gauging method codes can be found in Annex K 'Discharge Measurement Method Codes' of NEMS *Open Channel Flow Measurement - Measurement of Open Channel Flow v 2.0.0*).

7 Gauging Agency Codes

Gauging agency codes are not standardised for New Zealand. Some agencies are using NIWA's current national coding system, others have developed their own set of codes for their measurements and those they acquire from other organisations then store in their own systems. In long data series there may be a combination of both as agencies and practices have changed over time.

Discharge measurements exchanged between organisations are usually issued a new gauging number by the receiving agency with agency code for the source organisation assigned from the recipient's system. However, gauging results exchanged between organisations may not be recoded on receipt and therefore when assimilated, agency codes may conflict or mislead. If origin of a result is important to a data user additional enquiry should be made.

Annex D Water Temperature Data Processing

1 General Overview

This Annex contains further processing guidance specific to continuous water temperature data measured using in-situ sensors and stored as data type instantaneous (continuous) (see Section 1.1.1).

The general principles also apply to a time-series record of water temperature compiled from discrete measurements (see Section 1.1.2) obtained using a hand-held instrument.

1.1 Normative references

This Annex shall be read in conjunction with the following references:

- *NEMS Water Temperature – Continuous Measurements of Water Temperature Data for Environmental Monitoring Purposes*
- *NEMS Water Quality*
  - *Part 1 of 4: Discrete Sampling and Measurement of Groundwater Quality for Environmental Monitoring Purposes*
  - *Part 2 of 4: Discrete Sampling and Measurement of River Water Quality for Environmental Monitoring Purposes*
  - *Part 3 of 4: Discrete Sampling and Measurement of Lake Water Quality for Environmental Monitoring Purposes*
  - *Part 4 of 4: Discrete Sampling and Measurement of Coastal Water Quality for Environmental Monitoring Purposes*

Where reference is made from this Annex to specific sections of the above documents, the title is abbreviated and version stated, e.g. 'NEMS *Water Temperature* v3.0.0'. Where requirements and/or procedure in this Annex duplicate and possibly conflict, this Annex shall prevail.

1.2 Water temperature as a supplementary variable

Many other water quality variables are affected by water temperature. Measurement methods for these variables usually require concurrent measurements of water temperature that are applied to the dependent sensor output in some way to obtain the measurement results for the dependent variable.

Organisations may choose to permanently archive the collected water temperature data as a supplementary rather than primary time series, and therefore not apply all procedures in this Standard to those data. However, as a minimum, the supplementary data must be:

- identified in the Site/Initial Comment for the variable that is dependent on it (see Section 6.2.4.3)
- described in a Data Comment for the variable that is dependent on it (see Section 6.2.4.6).
- inspected and edited for gross errors
- quality coded QC 200 if edited from the original and/or if quality reviewed (see Sections 3.1 and 7.2), otherwise retain QC 0, and
- accompanied by Data Processing Comment(s) if editing was applied (see Section 6.2.4.7).

If the monitoring agency chooses to permanently archive the water temperature data as a primary time series, it may be changed by editing described in this annex, which may impact derivation of any dependent measurements. Processing inter-dependent time series together is strongly recommended.

In any case, the impact on the dependent variable of editing the associated water temperature record must be assessed when the dependent variable is processed, which would necessitate the water temperature data being processed first.

Quality code of dependent data may be affected by quality of the water temperature data. This is addressed in the annex applicable to the dependent variable.

2 Quality Control

2.1 Additional metadata required

General requirements for metadata are set out in Section 6.1. The following additional metadata, as applicable to the site, instrumentation and deployment (see NEMS *Water Temperature* v3.0.0, Sections 1, 2 and 3), are required to be available when verifying water temperature data:

- site details
  - type of environment (river, groundwater, lake, or coastal water)
  - the site purpose, measurement objective(s), and target characteristic(s) to be measured
  - the record documenting the site selection process and its evaluation, and
  - location (in GPS co-ordinates and WGS84 datum)
- instrument details (in-situ sensor and reference instrument):
  - sensor type, model, manufacturer, and serial number
  - sensor accuracy, resolution, and response time, as specified by the manufacturer
  - the units of primary measurement
  - the sensor range, as deployed

    - characteristics of any on-board anti-fouling mechanism
    - date, laboratory, and identifier for each calibration
    - the calibration relation(s), if and when supplied; these are essential if applied on the data logger by the user
    - date and results of any validations (i.e. checks on the calibration of the sensor other than by verification during field visits), and
    - date and time of each deployment
- sensor deployment details as applicable to the water body:
    - sampling method and data-logging interval
    - details of data logged as backup, secondary, and/or for which water temperature is intended as supplementary
    - method(s) used for verification of sensor readings
    - photos of the deployment showing mounting/housing detail and location context, including distance from margins and presence of structures or materials that may heat the water
    - characteristics of the water environment and installation details that have potential to impact data quality, such as signal conversion, transmission path and distance between sensor and logger, and logger bandwidth
    - the level of the temperature sensor(s) with respect to:
        - the water level gauge, where co-located
        - the water surface
        - the riverbed or lakebed
        - screen depths and water level range in bores
        - likely temperature and/or salinity gradients or stratification gradients
    - date, time, and reason(s) for any relocation of the sensor
    - any changes over time in the measurement environment
- reference readings, including:
    - instrument used
    - uncertainty in the result, and/or
    - information about when, where, and how each reading was obtained (e.g. proximity to the in-situ sensor).

These metadata must be verified and permanently archived with all other metadata as described in Section 6.

2.2 Plots and comparisons

Check around the time of each site visit for anomalies introduced by inspection, sampling, and maintenance activities, and to identify steps in the data introduced by cleaning, replacing or reconfiguring the sensor, data logger, and/or the installation.

Check continuity of the daily sine curve and that each daily maximum and minimum occurs at a plausible time.

2.2.1 Comparisons

Use comparisons to:

- cross-check data for anomalies, and
- confirm editing and adjustments have been properly carried out.

Compare the recorded data with:

- other relevant variables recorded at the site, e.g. water level, flow, air temperature, and water quality variables dependent on temperature (e.g. dissolved oxygen)
- a backup instrument at the same site, provided it is not also affected by the same data quality issue(s)
- an auxiliary instrument at the same site, e.g. a multi-variable instrument that may be recording over a different range, accuracy and/or resolution, provided it is not also affected by the same data quality issue(s)
- verification measurements, and validation results, if any.

2.2.2 Between-station comparisons

Unless there are local influences there will usually be good agreement between water temperatures recorded at quite distant sites within the same river system, and between nearby sites in adjacent rivers of similar physical character, sufficient to verify diel variation and weekly cycles.

Records of flow or water level at sites either upstream or downstream may also be useful to confirm occurrence and timing of rapid changes in water temperature.

For example, a fresh in a wide gravel-bed river during summer will tend to rapidly reduce water temperature while a fresh in winter will tend to raise water temperature, and tidal influx in estuaries will superimpose twice daily peaks on the daily sine curve.

In addition to cross-checking specific features in the data, use comparisons, including between-station comparisons to identify:

- sensor exposure due to low water levels or dry channel, and
- change in and/or disruption of:
  - diel and seasonal patterns
  - shape and pattern of temperature response to high flows, tide cycles, snow melt, or other flow fluctuations, e.g. abstractions, discharges, gate closures, or hydropower generation
  - relative timing of daily maxima and minima

- daily temperature range

Do not discount the possibility that problems may be transient and occur (and resolve) between site visits.

2.3 Reliability of reference values

Reference values used to verify a water temperature record are obtained directly, using an independent handheld reference sensor (or reference thermometer).

When using reference values to verify or to adjust recorded water temperature the following should be considered and assessed:

- results of validation of reference sensors (see Section D 2.3.1)
- results of validation, if performed, of in-situ sensors (see Section D 2.3.2)

  Note: Pre-deployment and subsequent periodic validation of in-situ sensors is not required under NEMS Water Temperature v3.0.0 but there are some circumstances where validation may be useful.

- measurement stability and location relative to the sensor
- timing of the reference measurement with respect to sensor readings

  Note: Simultaneous readings are the most reliable for data verification, especially when temperature is changing rapidly. See NEMS Water Temperature v3.0.0, Section 7.5.4.

- precision and accuracy of the reference reading.

A reference reading is unreliable, and must be identified as such, if:

- it is outside the validated range of the reference sensor (in which case the reference sensor may be retrospectively validated (see Section 5.3.2 and Annex C of NEMS *Water Temperature* v3.0.0)), or its uncertainty exceeds the verification tolerance of ± 0.5°C (see Section D 2.4), or
- the reference sensor used had not been successfully validated against a traceable primary reference within the last 12 months (see Section 5.3.1 and Annex A, NEMS *Water Temperature* v3.0.0), or
- repeat measurement with a second reference sensor agrees with its simultaneous logged value within verification tolerance (see Section D 2.4); the initial reading is assumed then to be unreliable.

An Operational Comment (see Section D 4.2.3) is required for any instance of verification reliant on repeat measurement with a second reference sensor.

A water temperature record should not be adjusted to any unreliable reference value unless there is other corroborating evidence of faulty recording. If adjusted, the

adjustment(s) should be reviewed when reliable reference readings resume. In any case the period of data associated with the unreliable reference cannot be quality coded higher than QC 500.

If a verification check is disregarded as unreliable:

- an Operational Comment is required giving reason(s), and
- the date of the disregarded visit cannot be used to determine the elapsed time between verifications for quality coding purposes, i.e. the initial quality code assigned (see section 9.4 and Annex A of NEMS *Water Temperature* v3.0.0) may need to be reviewed and possibly reduced.

2.3.1 Calibration of reference sensors

Reference sensors or thermometers are validated, rather than calibrated, as described in Section 5.3 of NEMS *Water Temperature* v3.0.0. Validation is required at least annually to accuracy ±0.3°C at all required validation points over the expected in-situ sensor measurement range. A validation history must be maintained and be accessible.

If a reference sensor fails validation:

- all reference readings with that instrument since its last successful validation must be reviewed for reliability, and
- any adjustments to in-situ data using subsequently unreliable reference readings must be reassessed and revised where necessary.

2.3.2 Validation of in-situ sensors

Validation of in-situ temperature sensors is not required under NEMS *Water Temperature* v3.0.0. In-situ sensor performance is only required to be checked by single point verifications at intervals of no more than 90 days. More frequent verifications are recommended during summer months (see NEMS *Water Temperature* v3.0.0, Section 7.5.3).

Note: Single point verifications, regardless of number or frequency, would not usually cover the full range of temperatures recorded by an in-situ sensor because site visits are unlikely to be in the very early morning. However, temperature sensor calibration drift is rare in instruments currently deployed in New Zealand; they usually maintain calibration or fail catastrophically. Failed sensors are replaced. A 'before repair' validation to assist with data recovery is not possible from a sensor that has failed catastrophically.

2.4 Deviation tests

For water temperature data, verification tolerance is an absolute difference between simultaneous in-situ and reference sensor readings of no more than 0.5°C (see Section 7.5.5.1 of NEMS *Water Temperature* v3.0.0).

Note: Verification tolerance of ±0.5°C when combined with reference sensor accuracy of ±0.3°C equates to an observation tolerance of ±0.8°C relative to the traceable reference sensor.

Performance can be monitored using a simple control chart (see Section 3.6.4.2) or deviation with time (see Section 3.6.4.4).

If pre-deployment and periodic validation of the in-situ sensor is not carried out analysis of deviation with range (see Section 3.6.4.5) is strongly recommended to monitor for loss of calibration, including evidence of loss of linearity, especially at the low end of temperature range for which there are usually few verification readings available (see Section D 2.3.2).

Where reliability of reference readings varies, account for their uncertainties (e.g. use error bars on plots).

Tests may be configured to update automatically with new data from the field.

3 Potential Errors and Recommended Editing

This section describes common problems specific to water temperature data, and guides selection of an appropriate method for data repair, including what metadata are then required to be applied and filed.

3.1 Sources of errors

The water environment, with respect to:

- location of the sensor in relation to:
  - water levels and river- or lakebed, and
  - physical heat sinks and sources that are not part of the usual environment, e.g. where a sensor may be affected by radiant heating of its own or an adjacent sensor's mounting or housing
- adequate mixing to avoid bias
- the relative locations of the sensor and point of collection of reference measurements at various flows (see Section D 2.3)
- Instrument deployment and operation, and conditions that adversely affect them (see Sections 1.3, 2.3.2 and 3.3 of NEMS *Water Temperature* v3.0.0)

  Note: The sensor and cable between it and the analogue to digital conversion needed for data logger input are a calibrated couplet. Unless electronically boosted, recording accuracy may be affected if length of the cable exceeds about 5 m. If digital conversion (e.g. to 4–

20 mA) is done at the sensor then this signal can be transmitted over much longer distances without loss of accuracy.

- Interference and damage (e.g. human, debris or biofouling, flood damage etc.), and
- Instrument performance, including:
  - maintenance of calibration
  - electronic transients, and
  - over-ranging.

Site factors and influences that are difficult to avoid are measured as part of the target characteristic(s) (see Section 1.3 of NEMS *Water Temperature* v3.0.0) and therefore are not sources of error. These factors and influences must be described in the Site/Initial Comment (see Section D 4.2.1).

3.2 Unintended offset or incorrect change of offset

Analogue sensors usually require an offset and multiplier to be programmed into the data logger to convert sensor signal to measurement units. If a mistake is made calculating or entering the offset, the data collected are biased by the amount of error in the programmed offset.

Note: An error in the multiplier also affects the value of the offset to be applied.

A sensor that has been shocked, for example, hit by debris or knocked during site maintenance, can sometimes develop an offset that biases all subsequent readings by a constant or near-constant amount.

With sufficient verification data, if an unintended or incorrect offset is present, deviation tests will show a persistent bias over the affected period. Investigate probable cause and confirm the period of data that is biased.

- If due to a logger programme change, there will be a step in the data at the time the programme was changed.
- If due to shock, carefully inspect a data plot and/or use a comparison with closely associated data to find the step.

The remedy depends on cause.

- If due to a logger configuration mistake that is known and fully traceable, the correct data can be re-established by calculation and transformation without doubt.
- If the offset is inferred from verification differences and/or steps in the data, the adjustment is a constant applied that minimises the steps and bias without creating a step in the data.

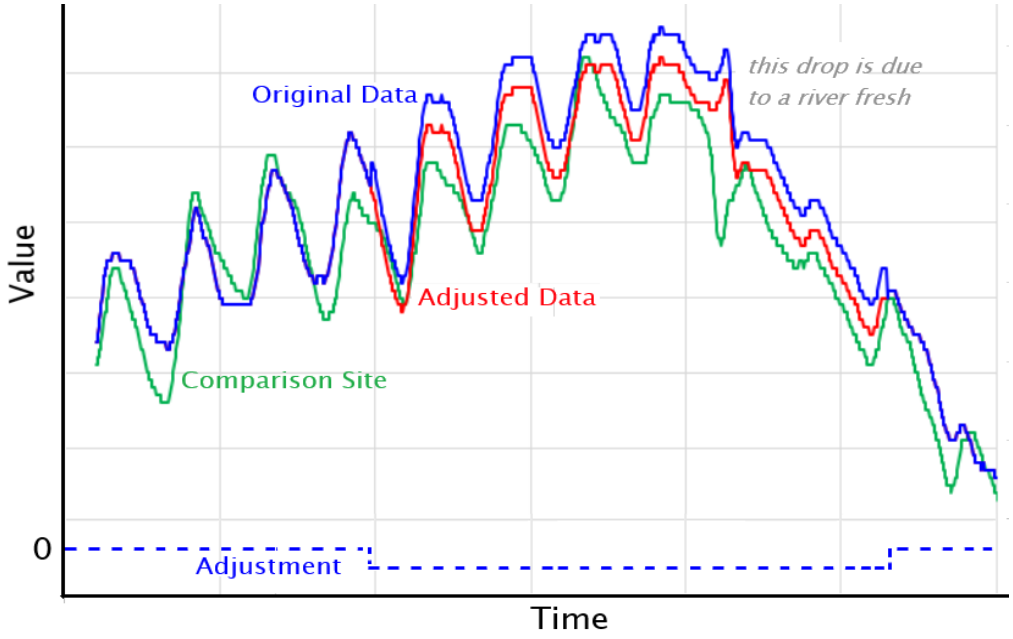


Figure D 1 - An example of a period of water temperature data offset by a constant amount (blue line) with the adjusted data (red line) and showing the comparison site used to identify the affected period (green line) and the adjustment applied (dotted line).

Table D 1 – Guidance for resolving an unintended offset or incorrect change of offset

Guidance for resolving an unintended offset, or incorrect change of offset		see Section(s)
Issue(s)	A period of data is biased by a constant or near-constant amount.	D 3.2
Evidence	Pairs of opposing steps in the data. Period between is 'offset' from surrounding data by a constant or near-constant amount; observable in a data plot and/or deviation track, e.g. control chart. Physical cause may be identifiable and traceable at site by checking the logger program.	Fig. D 1 D 3.2 D 2 3.6
Solution(s)	Apply an offset shift to the biased period.	4.2
Metadata	If the correction required is fully traceable, quality code is unaffected, but a Transformation Comment is required. Otherwise, 'minor' (QC 500) or 'significant' (QC 400) modification criteria apply and a Data Processing Comment explaining identified cause and details of the amount and period of adjustment is required.	D 4.2.6 6.2.4.8 6.2.3 D 4.2.5 6.2.4.7

3.3 Steps in the data

Steps in the data may result from:

- change of logger program offset (see Section D 3.2)
- replacement of the sensor
- moving the sensor to a different location (vertical or horizontal)
- interference or disturbance around the sensor
- clearing or cleaning the sensor.

Cause of the step dictates which data should be repaired and how.

Adjustments applied to the recorded data must reflect assumptions made about the nature, timing, duration, and magnitude of the error.

In most cases the appropriate adjustment is a simple special case of linear drift correction often referred to as a one-tailed ramp correction, where the adjustment is an offset that increases linearly with time from zero at the start of the affected period to a specified non-zero value at the end of the affected period (see Figure D 2).

3.3.1 Instrument replacement

If the new instrument is a different type, brand, or model, and/or it cannot be reinstalled in the same location, describe the change in an Operational Comment (see Section D 4.2.3) that references relevant Equipment Comment(s) (see Section D 4.2.2) as needed. If the data subsequently collected are offset from data previously collected as a result of the change, leave the step-change in the data but identify and explain it in a Stationarity Comment (see Section D 4.2.7).

If either instrument (existing or replacement) is an analogue sensor, confirm the relevant multiplier and offset applied. Rescale data affected by a configuration error (see Section D 3.9) and correct for any consequent offset error (see Section D 3.2), which should eliminate the step.

If neither of the above situations applies and calibration of the replacement instrument is confirmed by pre-deployment validation, assume some form of drift in the existing replaced instrument and address it (see Section D 3.4).

3.3.2 Interference or disturbance

Interference may be due to the actions of people or animals on or about the sensor. If the interference rapidly warms or cools the sensor and/or its immediate surrounds, the affected record will step up or down respectively over one or two recording intervals, then gradually recover when the interference moves or dissipates, or conditions equilibrate. Normal temperatures are expected to resume after one or two hours at most.

Disturbance may change position or location of the sensor, expose the sensor, or an event such as bank collapse, accumulation of debris, or bed movement may bury the sensor.

Site maintenance, self-cleaning mechanisms, and water sampling activities may themselves interfere with the recording of ambient water temperature by insulating the sensor or altering the movement of water around it.

Data recorded in these cases may be valid but not fit for purpose and therefore require, as a minimum, an appropriate lesser quality code and a Data Comment (see Section D 4.2.4).

Temperature changes due to tidal influence, salinity variations, geothermal or runoff inputs, and passage of floods are part of the target characteristics to be measured and not interference or disturbance that impacts data quality.

3.3.3 Sensor clearance or cleaning

Clearing or cleaning the sensor may result in a step in the recorded data. Temperature sensors that are buried or fouled may be insulated by the covering material, resulting in a delayed response to water temperature changes that resolves once the sensor is clean and clear.

Note: Partial clearing and/or cleaning may occur naturally during floods because of the drag induced by higher velocities and increased turbulence, and abrasion by suspended sediment.

If the sensor was buried by sediment or debris, treat as in Section D 3.3.2.

Biofouling (algal film growing on the sensor, compounded by fine sediment settling in the algae) and chemical fouling (a chemical film, e.g. from tannins or salts in the water) are gradual accumulations that may progressively affect temperature sensor readings.

Fouling behaviour and the corresponding evidence in the data is dependent on cause, and sensor cleaning frequency and method (e.g. wiper or brush, ultrasound, or pumped air or water). Fouling may affect sensor readings non-linearly with time, especially if the cause is biological accumulation. However, if magnitude of the error is small, a linear drift adjustment to eliminate any step introduced by cleaning is an acceptable solution.

Fouling may also cause noisy data, which should be smoothed or resampled (see Section D 3.6) before any adjustment is applied to eliminate a step (see Figure D 2).

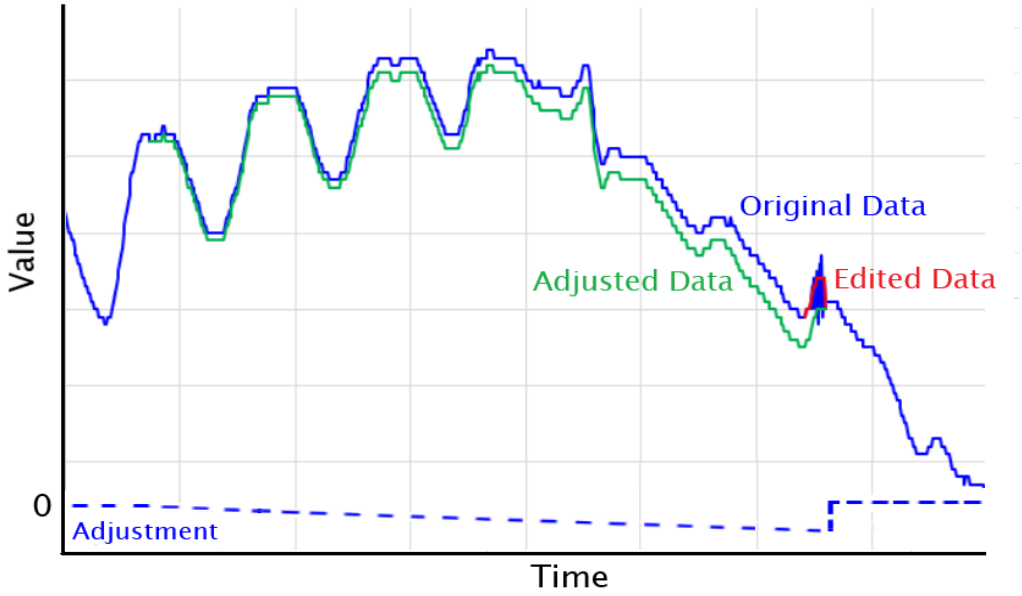


Figure D 2 - An example of a period of increasingly elevated data ending in a brief period of excessive noise before sensor cleaning returns readings to normal (blue line). Noise is edited first (red line), then a linear drift adjustment applied (dotted line) to progressively reduce the elevated values and eliminate the step at adjustment period end (green line).

Table D 2 – Guidance for resolving steps in the data

Guidance for resolving steps in the data		see Section(s)
Issue(s)	Sudden change in temperature between successive readings that disrupts continuity of the sine curve. Prior data are often biased.	D 3.3
Evidence	Physical cause is identified (observed or verified at site, or consequence of an event known to have occurred). Trace of data when plotted steps suddenly up (or down). May be evidence of increasing bias in prior data.	Fig. D 2 D 2 3.6
Solution(s)	No adjustment if due to different instrument type or change of location (stationarity is disrupted). Rescale if instrument configuration was wrong. Change or remove values affected by interference or fouling. Treat gaps created as missing data. Linear drift adjustment with no (i.e. zero) adjustment at onset of problem and maximum adjustment at the step in the trace.	D 3.3.1 D 3.9 D 3.5 D 3.6 D 3.11 D 3.4 4.4 & 4.5
Metadata	Operational Comment required for change of instrument or location. Equipment Comment also required if instrument type or specification changed. Stationarity Comment required at step. If rescaling is fully traceable, quality code is unaffected, but a Transformation Comment is required. Otherwise, 'minor' or 'significant' modification criteria apply and a Data Processing Comment explaining identified cause and	D 4.2 & 6.2.4 D 3.9 & D 4.2.6

	details of the adjustment(s) applied (amount, type, and period of adjustment) is required, OR Refer to missing data guidance as applicable.	6.2.3 D 4.2.5 6.2.4.7 D 3.11

3.4 Drift

It is relatively rare for temperature sensors to drift with time but an unstable analogue to digital converter (the device delivering volts or milliamps to the logger from the sensor output) might drift. Elapsed time before drift is detected and confirmed depends on verification frequency and rate of drift. If drift is identified, and confirmed linear with time, apply a linear drift correction to the affected period.

3.4.1 Calibration drift

Linearity of temperature sensor response is usually achieved by applying a calibration relation to the sensor output. The calibration relation may be anything from linear to a high order polynomial. For some sensors, the polynomial may be supplied as part of the calibration information with the expectation that the user will apply the calibration equation on the logger.

Temperature sensor calibration drift is range dependent (rather than time dependent) and likely non-linear. It is usually associated with loss of linearity of response; however, it is rare for this to occur and the sensor to remain operable. A sensor exhibiting loss of linear response must be replaced.

Instances of fouling (see Section D 3.3.3), over-ranging (see Section D 3.7), or sensor exposure (see Section D 3.8) must be isolated from analysis of calibration drift and treated beforehand.

Affected data may be adjusted by applying a non-linear transformation to the values as determined from results of instrument validation, and/or from several verifications over as wide a range of values as possible within a relatively short period of time. The transformation may be applied as one or more equations, or by a look-up function, or as a rating curve.

Note: Sensor validation in the field is impractical so the in-situ sensor will usually have been removed and replaced. Verification checks may not be available for the lower end of the temperature range because temperature minima tend to occur before dawn.

Proper adjustment of the prior data should eliminate any step-change resulting from instrument replacement. If affected data cannot be reliably adjusted, it must be deleted from the record and the period treated as missing data (see Section D 3.11).

Table D 3 – Guidance for resolving drift

Guidance for resolving drift		see Section(s)
Issue(s)	Recorded values are biased by an increasing amount over time.	D 3.4
Evidence	Differences between recorded and reference temperature increase with time and/or vary with value. Physical cause may be identifiable, such as biofouling or sensor validation results. Drift with time may be evident when plotted with a comparison trace.	D 3.4 D 2 3.6
Solution(s)	Apply linear or non-linear drift adjustments as applicable depending on whether drift is determined to be linear or non-linear with time. A non-linear drift adjustment with time can be approximated by a series of small, short-duration linear drift adjustments, with care. Apply a transformation derived from instrument validation results if drift is value dependent. Remove affected record if transformation is not possible, then treat as missing data.	D 3.4 4.4 or 4.5 4.7 & 4.9 D 3.11
Metadata	QC 500 or QC 400 depending on 'minor' or 'significant' change, and Data Processing Comment required explaining identified cause of drift and details of each adjustment applied (type, amount, and period of adjustment), OR Refer to missing data guidance as applicable.	6.2.3 D 4.2.5 6.2.4.7 D 3.11

3.5 Spikes

Unexpectedly low values are usually associated with data transmission interruptions or power supply problems. Solitary unexpectedly high values can occur due to electronic transients.

Isolated spikes may be deleted or replaced. If deleted, the interpolation engine can be left to interpolate between the remaining adjacent values unless regular interval data are required.

Intermittent spikes may be deleted manually or discarded using a threshold filter. If only one or two successive values are removed at each occurrence the interpolation engine can be left to interpolate between the remaining adjacent values unless regular interval data are required. If more than a few successive values are removed gap processes are then required (see Sections 4.16 to 4.20 and D 3.11).

If spiking is frequent, persistent, and affecting consecutive values, treatment as noise is necessary (see Section D 3.6).

Table D 4 – Guidance for resolving spikes in the data

Guidance for resolving spikes in the data		see Section(s)
Issue(s)	Spurious values recorded.	D 3.5
Evidence	Value significantly different from adjacent values. Observable in a plot of the data. Confirmation by field investigation, and elimination of cause if possible.	D 2 3.6
Solution(s)	Delete or replace spurious values. If more than a few consecutive values are removed, missing data processes are also then required. If spiking is frequent, persistent, and affecting consecutive values, treatment as noise is necessary.	4.11 or D 3.11 or D 3.6
Metadata	QC 500 and Data Processing Comment required explaining identified cause and whether values are deleted or replaced, OR Refer to missing data or noise treatment guidance as applicable. Comments may be aggregated if frequent and repetitive.	6.2.3 D 4.2.5 6.2.4.7 or D 3.11 or D 3.6

3.6 Noisy data

Noise in water temperature data is most often caused by interference (see Section D 3.3.2) or faulting electronics. Interference is usually of short duration and the effect generally random. Faulting electronics may be due to poor connections or imminent failure of the sensor, requiring replacement, and effect on the data may be erratic.

Noise with random effect due to interference may be edited or resampled by hand or filtered using a fixed or moving interval mean or median. Ensure the results of filtering do not disrupt the expected range and timing of diel cycles nor create a step at the boundary with adjacent unadjusted data.

Delete periods of noise due to faulting electronics and treat as missing data (see Section D 3.11).

Table D 5 – Guidance for resolving noisy data

Guidance for resolving noisy data		see Section(s)
Issue(s)	Noise obscures representative signal. Fluctuations are high frequency and exceed expected sensor accuracy. Range of fluctuation compromises use as supplementary data for other variables.	D 3.6
Evidence	Noise not seen in independent observations. Trace when data are plotted is 'fuzzy'. Variation between adjacent values is larger than is normal or expected from resolution of the instrument. Noise is absent after cause is addressed.	Fig. D 2 D 2 3.6
Solution(s)	Method choice is determined by identified cause. Manually edit or resample, or 'smooth' with a statistical filter, if random noise due to interference. Otherwise delete affected period and treat as missing.	D 3.6 Fig. D 2 4.12 or D 3.11
Metadata	QC 500 or QC 400 depending on 'minor' or 'significant' change, and Data Processing Comment explaining identified cause and method applied, OR Refer to missing data guidance as applicable.	6.2.3 D 4.2.5 6.2.4.7 or D 3.11

3.7 Over-ranging

Over-ranging occurs when water temperature measurements are outside a sensor's calibrated range. In New Zealand this would normally only be encountered in geothermal areas (high temperatures) or during severe winters in the deep south (low temperatures). Data loggers and some sensors may prevent the recording of over-range values. Occurrences truncate (clip) water temperature at a constant maximum or minimum value or create a gap in the record. Other sensors may continue to output a non-linear response.

In any case an in-situ sensor must not be used outside its calibrated range. Any over-range values recorded must therefore be clipped to the calibrated range (see Figure D 3) or deleted and treated as missing data (see Section D 3.11).

Datasets that include periods of truncated or clipped over-ranging may be filed as a censored time series with appropriate metadata (see Sections 1.1.5 and D 4); however, treating affected periods as missing data is preferred (see Section D 3.11), especially if the temperature record is required for accurate determination of another variable, e.g. dissolved oxygen. A change of over-range threshold and/or over-range treatment may affect stationarity so must be noted in a Stationarity Comment (see Section D 4.2.7).

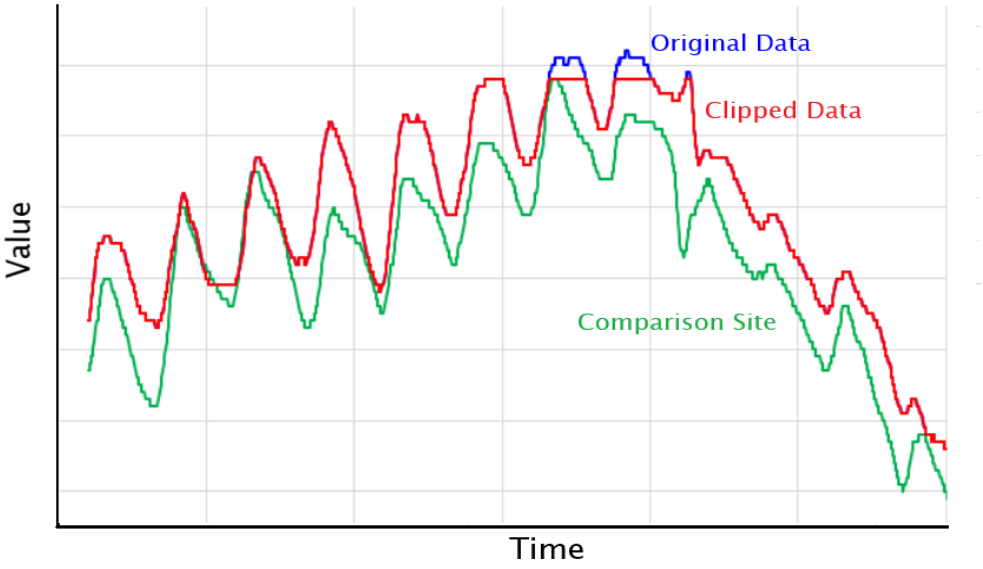


Figure D 3 - An example of a period of over-range data (blue line) clipped at the maximum of calibrated range (red line) to be stored as censored data.

Table D 6 – Guidance for resolving over-ranging

Guidance for resolving over-ranging		see Section(s)
Issue(s)	Measured values are outside calibration range of the sensor, or full range of water temperature is not recorded.	D 3.7
Evidence	Values exceed known calibrated range of the sensor or over-ranged record flatlines or has gaps when temperatures are at or near extremes of calibrated range. May be verified by independent measurements.	Fig. D 3 D 2 3.6
Solution(s)	Remove over-range values and treat as missing data or clip data at extremes of calibration range and store as censored data.	4.16 to 4.20 incl. D 3.11 1.1.5
Metadata	QC 100 if left missing, or QC 400 if stored as censored data. Data Comments are required explaining identified cause and providing details of decisions made and methods applied. A Stationarity Comment is required if threshold and/or treatment is changed.	6.2.3 D 4.2.4 6.2.4.6 D 4.2.7 6.2.4.8

3.8 Sensor exposure

Sensors may become exposed inadvertently, and possibly intermittently, by a drop in water level caused by bed scour, channel migration, channel works, drawdown, storage depletion, tide, or deliberate interference, or when removed for cleaning.

Measurements while exposed will be of air temperature with radiant heating also possible.

Complementary measurements of air temperature or water level available from or near the monitoring site may assist with determining periods of sensor exposure (see Section 7.2.4, NEMS *Water Temperature* v3.0.0). For example, if the level of the temperature sensor is known relative to water level datum a water level threshold can be determined below which the corresponding temperature data collected must be regarded as not representative of water temperature.

A change in water temperature characteristics will also likely be observed that persists until the sensor is re-immersed and has reached equilibrium.

Remove data affected by sensor exposure from the record and treat the period as missing data (see Section D 3.11).

Table D 7 – Guidance for resolving sensor exposure

Guidance for resolving sensor exposure		see Section(s)
Issue(s)	Air rather than water temperature is recorded.	D 3.8
Evidence	Physical cause is known or identified (observed or verified at site, and/or from calculation of relative levels of sensor and water, or consequence of an event known to have occurred).	D 3.8 D 2 3.6
Solution(s)	Remove false data and treat as missing.	4.16 to 4.20 incl. D 3.11
Metadata	QC 300 if replaced with synthetic infill, or QC 100 if left missing. Data Comments are required explaining identified cause and providing details of decisions made and methods applied.	6.2.3 D 4.2.4 6.2.4.6

3.9 Incorrect scaling

Incorrect scaling means that the range of the data is either wrongly reduced or expanded by some factor. The problem usually arises from:

- wrong measurement units, or
- incorrect sensor/logger configuration.

Water temperature data collected in the wrong measurement units is usually recoverable. Explicit conversion by mathematical relation between different units of temperature measurement, e.g. Fahrenheit to Celsius, is possible.

Metadata must state the units of measurement, and the conversion applied and units in which the data are stored when different.

Verification data must be in the same measurement units as the continuous data collected to be directly comparable.

Sensor output as current (Amps) or potential (Volts) requires conversion to temperature units on the data logger using a multiplier and possibly an offset. If the multiplier is incorrect a scaling error arises that will show as differences in subsequent verification checks that vary in proportion to the logged value.

To correct the data, remove any offset applied, then divide by the incorrect scaling multiplier to obtain raw signal, then multiply the raw signal by the correct scaling multiplier, then apply an appropriate revised offset (i.e. recalculated using the raw signal and its correct multiplier).

If the necessary transformations are fully traceable and do not compromise precision, there is no effect on quality code.

Table D 8 – Guidance for resolving incorrect scaling

Guidance for resolving incorrect scaling		see Section(s)
Issue(s)	Scale and/or units of the data is/are wrong.	D 3.9
Evidence	Recorded extremes do not agree with those independently observed. Differences between reference and logged values are highly variable and often large. Comparison plots indicate range of the data is wrong.	D 3.9 D 2 3.6
Solution(s)	Apply conversion equations, to equivalent precision, if measurements are in the wrong units. For instrument configuration errors, apply linear transformations reversing the applied instrument configuration parameters to obtain raw signal, then apply the correct configuration parameters to the recovered raw signal.	D 3.9 4.7
Metadata	If the correction required is fully traceable, quality code is unaffected, but a Transformation Comment is required. Otherwise, 'minor' or 'significant' modification criteria apply and a Data Processing Comment explaining identified cause and details of the amount and period of adjustment is required.	D 3.9 D 4.2.6 6.2.3 D 4.2.5 6.2.4

3.10 Time faults

A time shift may be needed to obtain data in NZST or to correct for an incorrectly configured or defaulted logger (see Section 4.3).

If the time fault caused existing data to be overwritten or conflicting new data elements to be discarded, some missing record at period start if shifted forward, or period end if shifted back, is also a consequence that must be addressed (see Section D 3.11).

Time drift adjustment is rarely needed with modern electronic loggers (see Section 4.6). If logger date/time does not agree with actual date/time it is more likely the logger has stopped and there is a gap in the record, possibly unmarked, needing to be identified and addressed.

Most time-series management software has the ability to make time adjustments simultaneously with value adjustments. There is risk when using drift adjustment tools that time is unintentionally adjusted and time faults are introduced into the processed data. This is relatively easy to detect in fixed interval data by analysing the timesteps or inspecting the timestamps.

Table D 9 – Guidance for resolving time faults

Guidance for resolving time faults		see Section(s)
Issue(s)	Temporal distribution of recorded data is wrong. and/or data are missing.	D 3.10
Evidence	Logger date/time is different from actual at inspection. Investigation finds configuration error or reset, and/or temporal distribution anomalies are apparent when compared with data from a similar nearby site.	Fig. 18 Fig. 26 D 2 3.6
Solution(s)	If wrong time zone, apply time shift then address any missing record created at the start (or end) by the shift. If a clock fault, replace with reliable backup if independently logged and available, OR if clock is slow or fast, apply time drift adjustment, OR if clock stopped, treat period until restart as missing record.	4.3 or 4.6 Fig. 19 Fig. 27 and/or D 3.11
Metadata	If the time shift is fully traceable, quality code is unaffected, but a Data Processing Comment is required explaining identified cause and details of the shift applied. QC 100 if missing, or QC 300 if infilled, and a Data Comment. Some cautions apply. Otherwise, 'minor' or 'significant' modification criteria apply and a Data Processing Comment explaining identified cause and details of the amount and period of adjustment is required.	4.3.3 D 4.2.5 6.2.3 D 4.2.4 6.2.3 D 4.2.5 6.2.4

3.11 Missing data

When considering the treatment and associated metadata requirements for missing continuous water temperature data the following broad descriptions of duration are helpful:

- a brief period is a few recording intervals up to an hour
- short duration is between adjacent peaks and troughs of the diel cycle, i.e. within the rising or falling side of the sine curve, but not over the peak or trough
- a longer period may be one or more days up to one week, and
- an extended period may be a week or more.

A maximum duration of one month for any period of synthetic infill is recommended, dependent on:

- the typical and expected variation in temperature at the sensor location
- the possibility of one or more significant events having occurred that may have altered the sensor environment, and
- reliability of the relationship(s) used to generate the synthetic record.

Water temperature can be strongly influenced by local factors such as location of the sensor in the cross-section and depth profile, nature of the surrounds above and below water, and the degree of mixing brought about by velocity distribution. If the water is not well mixed the data can be quite specific to the location at which the temperature is measured. When selecting and applying an appropriate method for resolving missing data, the likely variation at the sensor location must be taken into account with consideration of the duration of the period missing (see Appendix D.1).

For water temperature, backup data include data obtained from another sensor at site of a different type and/or standard, and manual observations using a reference sensor that are intended to fill a brief or short period of missing data, provided the backup data are collected near the primary sensor or in a well-mixed environment.

Periods of synthetic infill of more than short duration must not be used as supplementary data for other measurements, e.g. dissolved oxygen.

3.11.1 Methods for infilling gaps

For details on specific methods for infilling gaps in water temperature series, see Appendix D.1 to this Annex.

Table D 10 – Guidance for resolving missing data

Guidance for resolving missing data		see Section(s)
Issue(s)	Data are missing.	D 3.11
Evidence	Expected timestamps are not present in the original data. A gap marker may or may not be present depending on data collection method. Comparison plot shows entire cycles or parts of cycles are missing. Investigation confirms data were not logged and/or not collected. Data have been intentionally removed.	4.16 Fig. 9 D 2 3.6
Solution(s)	Use at-site backup data and manual observations including verification readings where available, OR if brief, interpolate across gap, except if a peak or a trough if short period, interpolate across gap or infill with a curve, but not over a peak or trough for longer and extended periods, apply methods to infill with synthetic data, or mark the gap if a month or more is missing, mark the gap or note a temporary site closure.	App. D.1 D 3.11 4.16 to 4.20 incl. 5.4 & 5.5
Metadata	No effect on quality code if brief and interpolated. Otherwise, quality code as applicable to the backup record or manual observations, or QC 300 if infilled, or QC 100 if left as missing. Data Comments are required explaining identified cause and providing details of decisions made and methods applied, including expected reliability of any synthesised infill.	6.2.3 D 4.2.4 6.2.4.6

4 Metadata

4.1 Quality coding

Quality code for water temperature data is set by three different but related sets of criteria:

- the quality coding flowchart
- the Quality Coding Matrix, and
- data editing actions and adjustments.

The quality coding flowchart and Quality Coding Matrix may be found in NEMS *Water Temperature* v3.0.0. The flowchart is also available in NEMS *National Quality Code Schema*.

4.2 The Quality Coding Matrix

The Quality Coding Matrix uses information about the site, instruments, records, and results of each verification to differentiate between a maximum possible quality code of QC 400, QC 500, or QC 600 for the data collected between each inspection. This assessment should, for quality assurance preventive action purposes, be completed

before departing the site, but if not, becomes the first step of quality control during data processing.

By applying the Quality Coding Matrix at the time of data collection it is possible to assign quality codes higher than QC 200 to unprocessed data, but this may be misleading because data editing actions may result in periods of data acquiring a different code (see Section D 4.1.2).

An initial quality code of QC 200 (quality unknown) is also a possible outcome of the Quality Coding Matrix if data quality is unable to be determined without further investigation during data processing. In many cases, issues leading to the initial quality code of QC 200 can be resolved during data processing and QC 200 then replaced with one of the other quality codes, either because of additional checks and evidence indicating a code of QC 400 or higher is justified, or by replacing or removing faulty data.

4.2.1 Data editing actions and adjustments

The quality code of any data collected may be affected by subsequent editing actions and adjustments made to the data. Minor modifications reduce quality code to QC 500. Significant modifications reduce quality code further to QC 400. Refer to Section 6.2.3 for definitions of 'minor' and 'significant'.

Further guidance on how and when quality code must change as a consequence of data processing is provided in Section D 3 of this Annex.

4.3 Example water temperature comments

The following are templated examples of comments for water temperature stations.

Every comment must be assigned a fully specified timestamp and be associated with the relevant data (the time series of water temperatures) via some form of 'Site' and 'Measurement' database key combination. The database keys are usually specified in some form of record header not shown here.

4.3.1 Site/Initial Comments

River station

Type: Site
Measurement: Water Temperature
Initial comment for *<river name>* River temperature at *<site name>*
Site number *<network number, ID or code>* on river *<river number>*[10]
The site is situated *<distance to coast>* km from the mouth at grid reference *<map co-ordinates and type*[11]*>* Drains *<catchment area to site>* km^2 and is monitored for *<site purpose and target characteristics>*.
Additional information: Site is affected by *<persistent adverse conditions at site (e.g. weed growth, abstractions or discharges, bed movement)>*. Sensor is located *<brief description of sensor placement and environment>*. Data are affected by *<influences incorporated in target characteristics>*. Site evaluation is available from *<reference>*. *<Some (or All) quality control (and/or data editing) is automated; refer to the relevant Data Processing Comments.> <Data are stored as a censored series.>*.
The following is also measured at this site: *<list variables, including any backup temperature recorder>; <This record is used to derive <list variables e.g. DO% saturation>>*.
The local recording authority is: *<name of recording/archiving agency>*

Lake station

Type: Site
Measurement: Water Temperature
Initial comment for *<name of water body>* temperature at *<site name>*
Site number *<network number, ID or code>* on river *<river number>*12
The site is situated *<distance to outlet>* km from the outlet at grid reference *<map co-ordinates and type13>* Drains *<catchment area>*km2 of *<river name>* River catchment and is monitored for *<site purpose and target characteristics>*. Lake area is *<surface area>*km2 and level is controlled by *<describe features e.g. natural outlet, dam, weir etc.>*
Additional information: Site is affected by *<persistent adverse conditions at site (e.g. weed growth, exposure to wind and waves, periodic drying up)>*. Sensor is located *<brief description of sensor placement and environment>*. Data are affected by *<influences incorporated in target characteristics>*. Site evaluation is available from *<reference>*. *<Some (or All) quality control (and/or data editing) is automated; refer to the relevant Data Processing Comments.> <Data are stored as a censored series.>*
The following is also measured at this site: *<list variables, including any backup temperature recorder>*; *<This record is used to derive <list variables e.g. DO% saturation>>*.
The local recording authority is: *<name of recording/archiving agency>*

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[10] from *Catchments of New Zealand* (SCRCC, 1956).
[11] state the co-ordinate system: NZTopo50 or NZGD 2000 preferred (latitude/longitude to 6 decimal places)
[12] from *Catchments of New Zealand* (SCRCC, 1956).
[13] state the co-ordinate system: NZTopo50 or NZGD 2000 preferred (latitude/longitude to 6 decimal places)

Sea station

Type: Site
Measurement: Water Temperature
Initial comment for *<name of water body>* Sea temperature at *<site name>*
Site number *<network number, ID or code>* at grid reference *<map co-ordinates and type14>* Situated *<brief location description>* and is monitored for *<site purpose and target characteristics>*.
Additional information: Site is affected by *<persistent adverse conditions at site (e.g. biofouling, exposure (wind and waves))>*. Sensor is located *<brief description of sensor placement and environment>*. Data are affected by *<influences incorporated in target characteristics>*. Site evaluation is available from *<reference>*. *<Some (or All) quality control (and/or data editing) is automated; refer to the relevant Data Processing Comments.> <Data are stored as a censored series.>*
The following is also measured at this site: *<list variables, including any backup temperature recorder>*; *<This record is used to derive <list variables e.g. DO% saturation>>*.
The local recording authority is: *<name of recording/archiving agency>*

Groundwater level station

Type: Site
Measurement: Water Temperature
Initial comment for *<name, ID, or bore number>* Groundwater temperature.
Located at *<map co-ordinates and type15>* and monitored for *<site purpose and target characteristics>*.
Drilled on *<dd-mm-yyyy hhmmss>* to depth of *<depth of well>*m >. Well construction: from *<depth>* to *<depth>*m diameter *<bore dia.>*mm and is *<cased, uncased, or screened>*
Well type *<type>*16 for *<purpose>*17 Aquifer type *<type>*18 depth *<depth>*m
Aquifer lithology *<brief description>*. Log available from *<name and contact details>*
Consent *<number or permitted use>*
Ground elevation *<level and datum>*m, Static water level *<level and datum>*m
Additional information: Sensor is located *<brief description of sensor placement and environment>*. Data are affected by *<influences incorporated in target characteristics>*.
Site evaluation is available from *<reference>*. *<Additional bore location information if more than one bore in vicinity, and aquifer properties, water quality grade if available>*. *<Some (or All) quality control (and/or data editing) is automated; refer to the relevant Data Processing Comments.> <Data are stored as a censored series.>*
The following is also measured at this site: *<list variables, including any backup temperature recorder>*; *<This record is used to derive <list variables e.g. pH>>*.
The local recording authority is: *<name of recording/archiving agency>*

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[14] state the co-ordinate system: NZTopo50 or NZGD 2000 preferred (latitude/longitude to 6 decimal places)
[15] state the co-ordinate system: NZTopo50 or NZGD 2000 preferred (latitude/longitude to 6 decimal places)
[16] drilled, driven, bored or augured, dug, pit, infiltration gallery, or spring
[17] water supply (domestic, industrial, or public), waste disposal, irrigation, stock, recharge, observation, or disused
[18] confined, unconfined, perched, or fissure

4.3.2 Equipment Comment examples

Type: Equipment
Measurement: Water Temperature
Recorder installed on *<dd-mm-yyyy hhmmss>* is a *<describe main logger features e.g. how powered, compact (or otherwise e.g. PLC), multi- or single input, programmable etc.>* data logger, recording *<describe logging and sampling regime e.g. instantaneous readings at fixed intervals of x-minutes>*. The temperature sensor is a *<type and output e.g. 4-20mA or 0-5V etc. thermistor or resistance temperature detector etc.>* installed in (or on) *<brief description e.g. weighted cable x-m down well, or below moored buoy, plastic conduit attached to timber pier, steel box section secured on piles etc.>* positioned at *<reduced level and datum, or equivalent stage, or briefly describe>*. Sensor range is *<range and units>* with resolution of *<resolution>* and nominal accuracy of *<accuracy specification>* validated on *<validation date if applicable>*. Sensor output is converted to degrees Celsius by *<details of any transformations applied at the time of data capture or collection e.g. scaling multiplier and/or offset>*. Site is visited *<verification frequency>*. Data are collected by *<method e.g. telemetry and occasional manual download>*.

Create a similar but separate comment for any backup sensor or secondary source of water temperature data at the site, to avoid the comments becoming too long and complex.

Create a similar but separate comment for any replacement sensor if any of the previously described details change as a consequence. Include confirmation that all other details have not changed. For example:

Type: Equipment
Measurement: Water Temperature
Replacement temperature sensor is a *<type and output e.g. 4-20mA or 0-5V etc., thermistor or resistance temperature detector etc.>* installed on *<dd-mm-yyyy hhmmss>* in the existing installation. New sensor range is *<range and units>* with resolution of *<resolution>* and nominal accuracy of *<accuracy specification>* validated on *<validation date if applicable>*. Sensor output, site visit frequency, and data collection method are unchanged.

Type: Equipment
Measurement: Water Temperature
Verification data are obtained *<state frequency>* by *<describe method and instrument(s) used e.g. manual readings from a validated handheld reference sensor positioned as close to the sensor as possible, etc.> <Add other relevant information such as range, units, serial number, and validation frequency of the reference sensor>*.

4.3.3 Operational Comment examples

Type: Operational
Measurement: Water Temperature
Sensor moved on *<dd-mm-yyyy hhmmss>* to *<where in relation to previous>* because *<provide reason for relocation e.g. exposed, fouled, buried, inaccessible, poor mixing etc.>*. New location is *<describe new environment>*. New sensor position is *<reduced level and datum, or equivalent stage, or briefly describe>*.

Type: Operational
Measurement: Water Temperature
Sensor cleaned on *<dd-mm-yyyy hhmmss>*. *<Recorded temperature was briefly elevated (or lowered) while sensor was temporarily exposed>*.

Type: Operational
Measurement: Water Temperature
Verification reference reading on *<dd-mm-yyyy hhmmss>* was collected *<distance vertical and/or horizontal>* from the sensor due to *<provide reason e.g. high flood preventing access>*. Some deviation from recorded value is expected.

Type: Operational
Measurement: Water Temperature
Sensor replaced on *<dd-mm-yyyy hhmmss>* because *<provide reason>*. *<Replacement sensor is a different type (or model) (or range). Refer to the associated Equipment Comment for its specifications.>*

Type: Operational
Measurement: Water Temperature
Verification reference reading adopted for *<dd-mm-yyyy hhmmss>* was collected using a second handheld reference sensor. The initial reference reading is assumed unreliable.

4.3.4 Data Comment examples

Type: Data
Measurement: Water Temperature
Missing record from *<dd-mm-yyyy hhmmss>* to *<dd-mm-yyyy hhmmss>* due to *<identified cause of recording failure>*. *<Add any other relevant information such as why the gap has not been filled>*.

Type: Data
Measurement: Water Temperature
Backup record used from *<dd-mm-yyyy hhmmss>* to *<dd-mm-yyyy hhmmss>* due to *<identified cause of primary recording failure>*.

Type: Data
Measurement: Water Temperature
Change of datalogging interval on *<dd-mm-yyyy hhmmss>* from *<previous interval>* to *<new interval>*.

Type: Data
Measurement: Water Temperature
From *<dd-mm-yyyy hhmmss>* (to *<dd-mm-yyyy hhmmss>*) data above the calibrated sensor range of *<x degrees C>* is clipped (or deleted) and the data series is filed as censored (or with gaps, and/or with missing record infilled).

Type: Data
Measurement: Water Temperature
Synthetic record from *<dd-mm-yyyy hhmmss>* to *<dd-mm-yyyy hhmmss>* due to *<identified cause of recording failure>*. Record generated from *<provide or describe the relation e.g. state the regression equation>* obtained by *<method e.g. least squares or multiple regression, etc.>* with input data *<list sites, variables, and periods used>*. *<Add indication of reliability e.g. regression coefficient or standard error and analysis sample size, or some other assessment of uncertainty etc.>*, *<Add limitations on usefulness e.g. not recommended as supplementary data or for model calibration etc.>*

Type: Data
Measurement: Water Temperature
Data may be compromised from *<dd-mm-yyyy hhmmss>* to *<dd-mm-yyyy hhmmss>* due to *<describe cause e.g. poor mixing, suspected interference, intermittent flow, fouling, low power, pumping, etc.>*. *<Add other relevant information e.g. comparison records not available, possible reasons for data being correct, etc.>*

4.3.5 Data Processing Comment examples

Type: Data Processing
Measurement: Water Temperature
Values deleted and record interpolates from *<dd-mm-yyyy hhmmss>* to *<dd-mm-yyyy hhmmss>* to remove spikes caused by *<identified cause>*. Edited by *<name>* on *<date of processing>*.

Type: Data Processing
Measurement: Water Temperature
Values replaced from *<dd-mm-yyyy hhmmss>* to *<dd-mm-yyyy hhmmss>* to remove spikes caused by *<identified cause>*. Edited by *<name>* on *<date of processing>*.

Type: Data Processing
Measurement: Water Temperature
Data adjusted from *<dd-mm-yyyy hhmmss>* to *<dd-mm-yyyy hhmmss>* by *<method and parameters e.g. offset shift of x degrees C, linear drift adjustment of x0 degrees C to x1 degrees C etc.>* to compensate for *<identified cause>*. Edited by *<name>* on *<date of processing>*.

Type: Data Processing
Measurement: Water Temperature
From *<dd-mm-yyyy hhmmss>* (to *<dd-mm-yyyy hhmmss>*) automated quality control (and/or editing) is applied to this data. Actions include: *<briefly describe each action in specific terms e.g. Range Test: values < x °C or > x'* °C not accepted (or, removed (and gapped)); Flat Line Test: error flagged if n consecutive values are same; etc.> (or Actions are documented in *<provide reference to processing system documentation that contains specific detail of the tests applied to this data e.g. the site file, quality management system etc.>*), applied *<describe where in the process, with respect to what is original data, e.g. on the data logger (or telemetry system, etc.) prior to archiving as original data, or, after original data have been preserved but before near real-time web publication etc.>*, using *<provide name(s) of software and version and briefly describe how the actions are specified and/or configured in the system, and/or provide reference to where the code is permanently preserved, configuration files or screenshots are retained or similar>*.

Similar 'automation' comments must be provided each time any relevant detail changes, from change to an action threshold through to a change of organisational procedure and/or software. Cross-reference relevant Equipment and Operational Comments as required to avoid unnecessary duplication. File a corresponding Stationarity Comment if change of methods potentially disrupts stationarity of the data.

The level of detail required in 'automation' comments depends on the extent to which the comments are necessary to ensure traceability of changes made to the raw measurements (see Sections 3.1.1 and 8.2).

4.3.6 Transformation Comment examples

Transformations applied to a water temperature record prior to its archiving must be included in the water temperature metadata.

Type: Transformation
Measurement: Water Temperature
A calibration adjustment is applied from *<dd-mm-yyyy hhmmss>* to *<dd-mm-yyyy hhmmss>* by *<describe method e.g. equation, look-up function, or rating etc.>* Maximum adjustment is *<x>* degrees within the range *<temperature range affected>*. Edited by *<name>* on *<date of processing>*.

Type: Transformation
Measurement: Water Temperature
Data from *<dd-mm-yyyy hhmmss>* to *<dd-mm-yyyy hhmmss>* is transformed by Y' = [(Y – *<C>*) x (*<m'/m>*)] + *<C'>* to correct a scaling error. Logger parameters applied from *<dd-mm-yyyy hhmmss>* were multiplier *<m>* and offset *<C>*. Correct logger parameters are multiplier *<m'>* and offset *<C'>* applied on the logger from *<dd-mm-yyyy hhmmss>*.
Edited by *<name>* on *<date of processing>*.

Type: Transformation
Measurement: Water Temperature
Water temperatures are archived in degrees Celsius (C) transformed from sensor readings in Fahrenheit (F) using the relation C = (F -32)/1.8 rounded to nearest 0.1°C.

4.3.7 Stationarity Comment examples

Type: Stationarity
Measurement: Water Temperature
Sensor moved on *<dd-mm-yyyy hhmmss>* to *<where in relation to previous>* because *<provide reason for relocation e.g. exposed, fouled, buried, inaccessible, poor mixing etc.>*. Measurement of the target characteristics may be affected. Location and position details are available from the relevant Operational Comment.

Type: Stationarity
Measurement: Water Temperature
New effluent discharge consent *<provide consent number and consenting agency>* operative from *<dd-mm-yyyy hhmmss>* at *<location relative to sensor e.g. x m (or km) upstream>* on *<name of stream, or unnamed tributary>* may affect water temperature data recorded at this site after this date.

Type: Stationarity
Measurement: Water Temperature
Data are a censored series. Maximum calibrated range and therefore censoring threshold was changed on *<dd-mm-yyyy hhmmss>* from *<x degrees C>* to *<x' degrees C>*. *<Refer to the <reference e.g. site file, asset management system etc.>* for validation details.>

Stationarity Comments can also be used to capture and collate information about historical methods and data.

5 Preservation of Record

Refer to Section 8 of this Standard.

6 References

Soil Conservation and Rivers Control Council (SCRCC). 1956. *Catchments of New Zealand.* SCRCC, Wellington.

Appendix D.1 Methods for Infilling Gaps

1 Information Requirements

The method chosen to infill a gap (i.e. a period of missing record) will depend on:

- the type of water body (e.g. river, lake, estuarine, sea, or groundwater)
- location of the sensor in the cross-section and depth profile
- the nature of the surrounds above and below water, e.g. presence of any heat sources or sinks
- the duration requiring infilling
- the degree of mixing at-site during the period missing
- availability of other relevant time series, such as:
  - at-site backup water temperature data (see Section D 3.11)
  - at-site flow or water level data
  - water temperature, flow, or water level data from elsewhere in the same water body
- likelihood during the period missing, of:
  - an event causing disturbance or alteration of the sensing environment, or
  - inflows that may affect temperature, e.g. a nearby discharge
- availability of supporting observations and other evidence, such as:
  - verification readings
  - manual observations using the handheld reference sensor intended as infill, and
  - other readings, e.g. during sampling or gauging, that may have been measured using an instrument other than the reference sensor.

2 Recommended Methods

The following methods are candidates for infilling gaps in water temperature records:

- inserting one or more of:
  - at-site backup water temperature data
  - at-site verification readings
  - other at-site manual readings obtained using the handheld reference sensor
  - readings obtained at-site or nearby in the same water body from other instruments, e.g. a Doppler current meter.
- synthesising a record.

Synthetic infill can be created using one or more of the following methods:

- manual entry of intuitive estimates for brief and short periods (see Section D 3.11)
- mathematical calculation of the sine curve or copying from a reference trace (from the same or another site) for short periods (see Section D 3.11)
- generating a record from results of a linear or curvilinear regression with one or more donor sites.

Manual readings can be incorporated into all the above methods to improve confidence in the synthesised data.

Periods of a month or more should not be filled with synthetic data.

2.1 Infilling with backup water temperature data

Backup water temperature data must be verified as for the primary record for the period it is required, including assessment for over-ranging and sensor exposure that would preclude its use.

Local effects and differences in instrument design and calibration make it unlikely the two records will directly overlap. Small adjustments may be needed to eliminate steps at the junction of the primary and infill backup series.

2.2 Infilling with observations

Verification readings may be used to assist with infilling a gap.

If a logger and/or sensor is disconnected for a period during a site visit, manual observations should be collected so they may be inserted into the record to avoid missing data. These will usually be additional reference sensor readings and their uncertainty should be noted in a filed comment and their quality appropriately quality coded by following the schema.

2.3 Infilling by manual entry

Unless a more sophisticated method is readily to hand, often the most efficient way to fill a short gap (see Section D 3.11) is to intuitively 'draw it by hand', i.e. manually insert values to complete a straightforward rise or fall within a diel cycle. If a straight line is a good approximation, deleting the gap marker may be all that is required to close the gap.

2.4 Infilling the curve between adjacent peaks and troughs

It may be sufficient to copy values from a similar period of record at the same site, or from another site in the same water body that is sufficiently representative.

Note: Seasonal variation in diel cycles may need to be taken into account.

An unbroken curve can be estimated by connecting the adjacent periods of good water temperature record with a straight line or smooth curve on a semi-logarithmic plot.

Otherwise, the curve may be calculated from the sine curve formula $y = a\sin(bx + c)$ where a is the amplitude, b is the period, and c is the phase shift of the sine curve.

2.5 Infilling by regression analysis

The method is described in Appendix 2 to the main document.

Do not use equations forced to zero for regression of water temperature. If negative temperatures are predicted, their significance, and the likelihood of periods of below zero water temperature at the recipient site, must be assessed. If periods of below zero temperature are not plausible the analysis should be discarded.

Apply the regression equation intended to generate the synthetic record to another period of record of similar duration and season where recipient site data exists and compare actual and predicted maximum and minimum temperature. If the difference between actual and predicted for either extreme exceeds ±0.5°C the analysis should be discarded.

Ensure the summary statistics from the regression are documented in the associated comment, including period used for analysis, interval and type of the regressed data, sample size, equation(s) used to generate the infill, and the regression coefficient (R^2).

2.5.1 Selecting suitable donor sites

One or more donor sites should be selected from other water temperature recording sites in the same water body; however, acceptable results may be obtained from regression with water temperature recording sites in adjacent water bodies with similar physical characteristics.

If more than one suitable donor site is available, multiple regression can be used. The regression analysis determines the relative contributions of each donor site. Multiple donor sites are also useful to test for and minimise bias from and/or dependence on a single donor source (Joenssen and Bankhofer, 2012).

Compare an extended period of record from all candidate sites. Assess whether lag is needed on any input.

Note: Lag times, if needed at all, will usually be small compared to flow travel times.

2.5.2 Time resolution of the synthetic record

Time resolution of the synthetic record should match the primary recording interval.

Note: Although a longer interval average may improve the correlation, incorporating average in preceding or succeeding interval data into an instantaneous series with diel

cycles distorts the timing of those cycles unless the time-series manager permits mixing of average in interval and instantaneous data in the same series.

The filed comment(s) must make clear how the synthetic infill was derived and then incorporated into the record.

2.5.3 Seasonality of relationships

Seasonal variation in water temperature is typical for most water bodies except deep groundwater. The effect of seasonality on the relationship used to derive a synthetic record should be explored, especially if potentially influenced by factors such as snow melt or stratification. If significant, relationships may be required for each season.

3 References

Joenssen D, Bankhofer U. 2012. *Hot deck methods for imputing missing data*. In: International workshop on machine learning and data mining in pattern recognition (pp. 63-75). Springer Berlin Heidelberg. Available from http://link.springer.com/chapter/10.1007/978-3-642-31537-4_6 (14 July 2020).

Annex E Turbidity Data Processing

1 General Overview

This Annex contains further processing guidance specific to continuous turbidity data measured using in-situ sensors and stored as data type instantaneous (continuous) (see Section 1.1.1).

The general principles also apply to a time-series record of turbidity compiled from discrete measurements (see Section 1.1.2) obtained using a hand-held device or sampled and analysed in a laboratory.

1.1 Normative References

This Annex shall be read in conjunction with the following references:

- NEMS *Turbidity – Measurement, Processing and Archiving of Turbidity Data*
- NEMS *Measurement of Fluvial Suspended Sediment Load and its Composition*
- NEMS *Water Quality*
  - *Part 1 of 4: Sampling, Measuring, Processing and Archiving of Discrete Groundwater Quality Data*
  - *Part 2 of 4: Sampling, Measuring, Processing and Archiving of Discrete River Water Quality Data*
  - *Part 3 of 4: Sampling, Measuring, Processing and Archiving of Discrete Lake Water Quality Data*
  - *Part 4 of 4: Sampling, Measuring, Processing and Archiving of Discrete Coastal Water Quality Data*

Where reference is made from this Annex to specific sections of the above documents, the title is abbreviated and version stated, e.g. 'NEMS *Turbidity* v1.2'. Where requirements and/or procedure in this Annex duplicate and possibly conflict, this Annex shall prevail.

Note: At date of publication of this Annex, NEMS Turbidity and NEMS Suspended Sediment are undergoing review, and significant changes are expected, including the introduction of additional time series and data processing procedures to improve standardisation of turbidity measurement between sites and instruments. This Annex will be revised to align with the updated NEMS soon after their release.

2 Quality Control

2.1 Additional metadata required

General requirements for metadata are set out in Section 6.1. The following additional metadata, as applicable to the site and deployment, are required to be available when verifying turbidity data:

- instrument details:
  - sensor model, manufacturer, and serial number
  - the instrumentation standard; for example, ISO 7027
  - the sensor range, as deployed
  - characteristics of the on-board anti-fouling mechanism
  - date, laboratory, and identifier for each calibration, and
  - date and time of each deployment
- sensor deployment details (see also Sections 1.2 and 1.4 of NEMS *Turbidity* v1.2):
  - sampling method and data-logging interval
  - details of any backup, secondary and/or supplementary data logged
  - method(s) used for verification of sensor readings
  - photos of the deployment showing detail and bankside context
  - date, time, and reason(s) for any relocation of the sensor
  - the level of the turbidity sensor with respect to the water level gauge, where co-located
  - bed clearance under the sensor, and
  - any changes over time in composition of the bed material
- results of samples analysed in a laboratory, including:
  - uncertainty in the result, reported to 95% level of confidence
  - analysis method, and
  - information about when, where, and how each sample was taken (see Section 3.3 of NEMS *Turbidity* v1.2).

These metadata must be verified, and permanently archived with all other metadata as described in Section 6.

2.2 Plots and comparisons

- Check around the time of each site visit for anomalies introduced by inspection and sampling activities, and to identify steps in the data introduced by cleaning, recalibrating, or replacing the sensor.

- Check each high turbidity event for anomalies or gaps due to over-ranging or sensor saturation.

2.2.1 Comparisons

- Use comparisons to:
  - cross-check data for anomalies, and
  - confirm editing and adjustments have been properly carried out.
- Compare the recorded data with:
  - other associated variables recorded at the site, e.g. water level, flow, and suspended sediment concentration
  - a backup instrument at the same site, provided it is not also affected by the same data quality issue(s)
  - an auxiliary instrument at the same site, e.g. one that may be recording over a different range, provided it is not also affected by the same data quality issue(s)
  - verification measurements and validation results.

In addition to cross-checking specific features in the data, look for change in and/or disruption of:

- shape and pattern of turbidity response to high flow events
- baseline turbidity (usually coincident with low flows)
- relative timing of peak turbidity to peak flow (or water level)
- relative scale of events.

Do not discount the possibility that problems may be transient and occur (and resolve) between site visits.

2.2.2 Between-station comparisons

Compare recorded data with reliable catchment rainfall and/or upstream and/or downstream records of turbidity, flow and/or suspended sediment concentration to confirm occurrence and timing of events, but otherwise, due to the local variability and relative nature of turbidity measurement, comparison with neighbouring stations is of limited use.

2.3 Reliability of reference values

Reference values used to verify a turbidity record can be obtained while on site, using an independent hand-held meter, or by way of samples collected then analysed later in a laboratory.

When using reference values to verify or to adjust recorded turbidity the following should be considered and assessed:

- results of validation of field instruments (see Section E 2.3.1)

Note: Laboratory instruments are subject to the calibration and validation requirements of the laboratory method of analysis.

- measurement or sample location relative to the sensor (see NEMS *Turbidity* v1.2: Sections 3.3.2.1 and 3.3.2.2)
- timing of the reference measurement or collection of the sample

Note: NEMS Turbidity v1.2 Sections 3.3.2.1 and 3.3.2.2 require these to be coincident with the data-logger reading but after any disturbance caused by sampling and/or sensor cleaning has settled. NEMS Turbidity v1.2 Section 3.3.5 recommends an additional measurement or sample before any servicing of the sensor.

- integrity of the sample(s) (see Section 3.3.2.2 of NEMS *Turbidity* v1.2)
- laboratory analysis method(s) (see NEMS *Turbidity* v1.2: Sections 3.3.2 and 3.3.4)
- precision and accuracy of the reference readings or sample results, which may vary with range, or if samples are intended for multiple uses.

Note: Samples exceeding 750 FNU may require dilution procedures in the laboratory that increase uncertainty in the result.

Note: Precision and accuracy requirements differ between NEMS Turbidity (Measurement, Processing and Archiving of Turbidity Data) and NEMS Water Quality (Part 2 of 4: Sampling, Measuring, Processing and Archiving of Discrete River Water Quality Data.

Turbidity record should not be adjusted to any reference value where the difference between the reference and corresponding recorded value is overwhelmed by uncertainty in the reference reading unless there is other corroborating evidence of faulty recording. If adjusted, the adjustment(s) should be reviewed when reliable reference readings resume.

If the field instrument used to obtain reference readings fails validation, all reference readings obtained using that instrument, since its last successful validation or calibration, are unreliable and must be identified as such on any quality plots.

If reference reading uncertainty exceeds verification tolerance, or a reference reading is disregarded as unreliable, the period of record that would be verified by that information shall be quality coded no higher than QC 500.

2.3.1 Validation of field instruments

Calibration of any instrument used in the field is validated:

- pre-deployment (see Section 2.3 of NEMS *Turbidity* v1.2), and
- at the zero-point, annually, after cleaning (see Section 3.3.7 of NEMS *Turbidity* v1.2), and

- when quality charts indicate a possible loss of calibration (see Appendix 1 and Section E 2.4).

2.3.2 Laboratory results

Laboratory results must be supplied as the raw unrounded measurement value with its associated uncertainty of measurement (UoM) to be useful for:

- verifying the continuous data collected, and
- calibrating relationships when the data are intended as a surrogate.

Note: For laboratories this is a departure from their standard practice and will require prior arrangement (see 'The Standard – Discrete Water Quality (Rivers)' and Section 5.5.1 of NEMS Water Quality Part 2 of 4: Sampling, Measuring, Processing and Archiving of Discrete River Water Quality Data).

Laboratory results are subject to extensive quality processes but errors, usually of human origin, may still arise. Agencies making use of laboratory results must ensure procedures exist and are implemented to ensure any error found is identified, and corrected wherever possible, at every instance of the result being stored, including at the source laboratory, to prevent future transfers of results reintroducing the error.

2.4 Deviation tests

From NEMS *Turbidity (Measurement, Processing and Archiving of Turbidity Data)*, tolerance is expressed as absolute or percent deviation depending on turbidity value. The performance criteria can be combined into a single control or run chart by using a secondary axis on the one chart (Figure E 1) or stacking the charts (Figure E 2).

Use deviation with range analysis to monitor issues such as reference reading uncertainty, sensor baseline drift, and loss of calibration, including loss of linearity.

For turbidity that ranges over several orders of magnitude, scatter-plotting logged values versus corresponding reference readings is of limited use. It is best to work with the differences.

Where reliability of reference readings varies, account for their uncertainties (e.g. use error bars on plots).

Tests may be configured to update automatically with new data from the field.

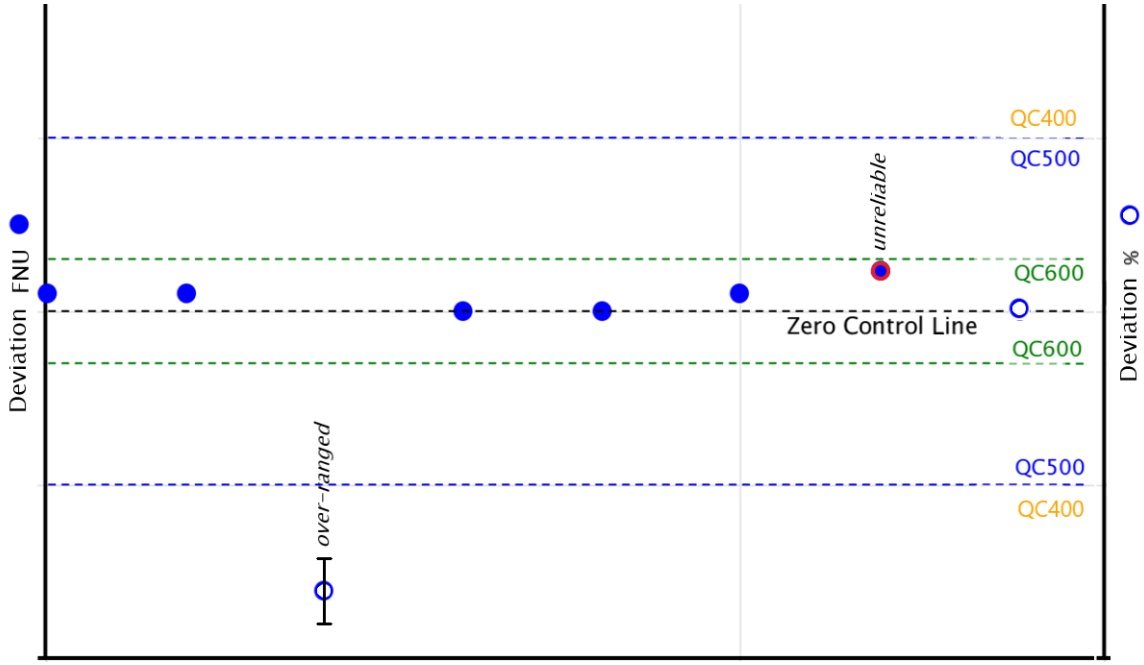


Figure E 1 - An example of a control chart with secondary axis scaled to align the limits, where data are plotted in sequence using the axis applicable for the tolerance test, and with error bars when the uncertainty is significant, and annotated to aid interpretation.

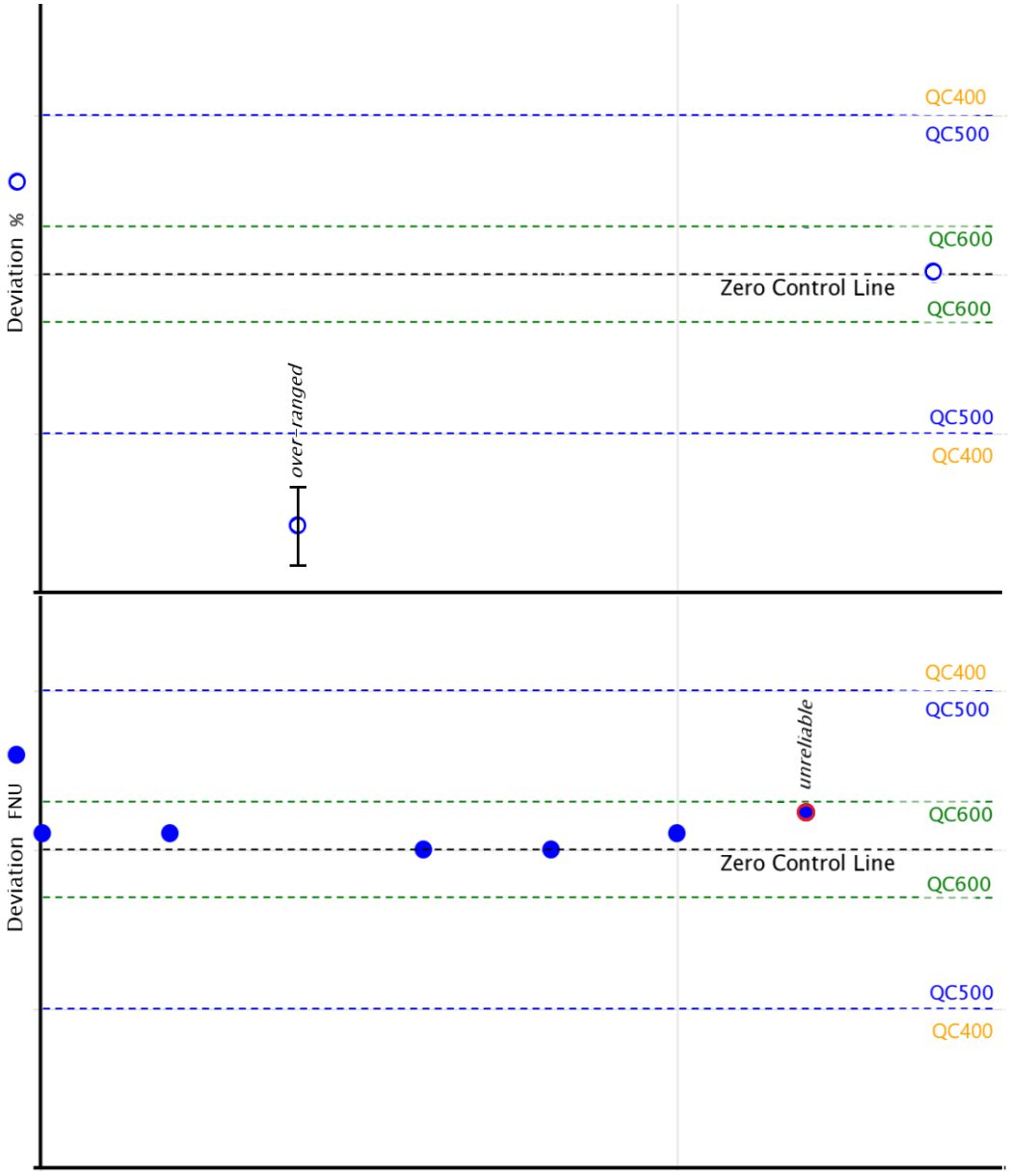


Figure E 2 - An example of a stacked control chart where data are plotted in sequence on the top or bottom chart depending on the applicable tolerance test, with error bars when the uncertainty is significant, and annotated to aid interpretation,

3 Potential Errors and Recommended Editing

This section describes common problems specific to turbidity data, and guides selection of an appropriate method for data repair, including what metadata are then required to be applied and filed.

3.1 Sources of errors

- The water environment, with respect to:
  - location of the sensor in relation to water level
  - the relative locations of the sensor and point of collection of reference measurements at various flows (see NEMS *Turbidity* v1.2: Sections 1.2.2, 1.4, 3.3.2 and Annex B), and
  - the nature and distribution of the suspended material (NEMS *Turbidity* v1.2 'Introduction').
- Site factors (see Section 1.2.4 of NEMS *Turbidity* v1.2).
- Instrument deployment and operation, and conditions that adversely affect them (see NEMS *Turbidity* v1.2: Sections 1.2, 1.4 and 2.2).
- Interference, deterioration, and damage (e.g. human, fouling, hydraulic conditions etc.) (see NEMS *Turbidity* v1.2: Sections 1.4.2 and 3.2).
- Instrument performance, including:
  - maintenance of calibration (see NEMS *Turbidity* v1.2: Sections 2.2, 2.3 and 3.3.7)
  - electronic transients, and
  - over-ranging and/or saturation.

3.2 Unintended offset or incorrect change of offset

Analogue sensors usually require an offset and multiplier to be programmed into the data logger to convert sensor signal to measurement units. If a mistake is made calculating or entering the offset the data collected are biased by the amount of error in the programmed offset.

Note: An error in the multiplier also affects the value of the offset to be applied.

Annual clear water zero-point validation (see Section 3.3.7 of NEMS *Turbidity* v1.2) may reveal the sensor has developed an offset. Investigate probable cause of the offset and identify the period of prior data that is biased. Quality control deviation tests may show a trend or persistent bias that helps reveal the affected period. The adjustment required depends on cause. If due to gradual lens deterioration, the adjustment should be gradual, i.e. compensation for a 'baseline' drift (see Section E 3.4.1) rather than an offset correction.

Note: Gradual deterioration due to abrasion is unlikely with modern turbidity sensors unless the suspended sediments are highly abrasive, such as volcanic glass.

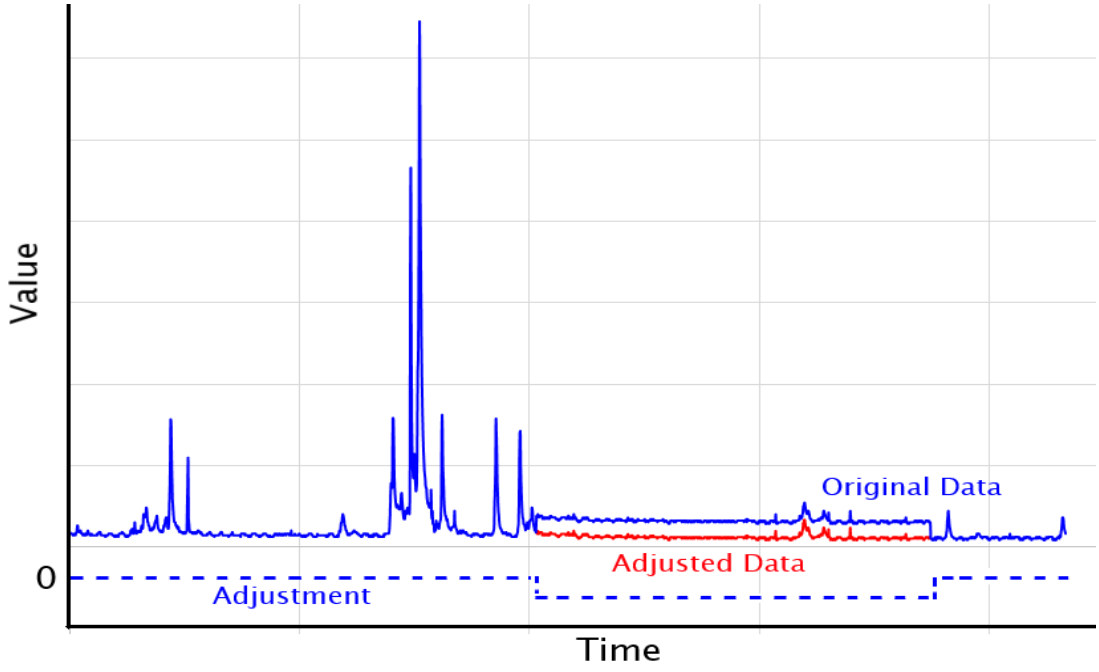


Figure E 3 - An example of a period of turbidity data offset by a constant amount (blue line) with the adjusted data (red line) and showing the adjustment applied (dotted line).

Table E 1 – Guidance for resolving an unintended offset or incorrect change of offset

Guidance for resolving an unintended offset, or incorrect change of offset		see Section(s)
Issue(s)	A period of data is biased by a constant or near-constant amount.	E 3.2
Evidence	Pairs of opposing steps in the data. Period between is 'offset' from surrounding data by a constant or near-constant amount, observable in a data plot and/or deviation track, e.g. control chart. Physical cause may be identifiable and traceable at site by clear water zero-point validation and/or checking the logger program.	Fig. E 3 E 3.2 E 2 3.6
Solution(s)	Apply an offset shift to the biased period.	4.2
Metadata	If the correction required is fully traceable, quality code is unaffected, but a Transformation Comment is required. Otherwise, 'minor' (QC 500) or 'significant' (QC 400) modification criteria apply and a Data Processing Comment explaining identified cause and details of the amount and period of adjustment is required.	E 5.2.6 6.2.4.8 6.2.3 E 5.2.5 6.2.4.7

3.3 Steps in the data

Steps in the data may result from:

- replacement of the sensor
- sudden occurrences of interference, or macro-fouling (values step up)
- clearing or cleaning the sensor (values step down).

Cause of the step dictates which data should be repaired and how.

3.3.1 Instrument replacement

If the new instrument is a different type, brand, or model, and/or it cannot be reinstalled in the same location, and data subsequently collected are offset from data previously collected, the step-change created must remain in the data and be identified and explained by a Stationarity Comment (see Section E 5.2.7).

If either instrument (existing or replacement) is an analogue sensor, confirm the relevant multiplier and offset applied. Data affected by a configuration error must be rescaled (see Section E 3.9) and corrected for any consequent offset error (see Section E 3.2), which should eliminate the step.

If neither of the above situations applies and calibration of the replacement instrument is confirmed by its pre-deployment validation, some form of drift in the existing replaced instrument must be assumed and addressed (see Section E 3.4.2).

3.3.2 Interference and macro-fouling

Interference may be due to the actions of people or animals, on or about the sensor, malfunction of the cleaning wiper leaving it 'parked' over the optics, light contamination during daylight hours caused by insufficient deployment depth, or an event such as a flood or bank collapse burying the sensor or raising the streambed into the sensor's field of view.

Macro-fouling occurs when solid objects are caught within, or otherwise invade, the sensor's detection volume. Examples include vegetation snagged on the sensor or its housing, loitering fish, and encroaching in-stream vegetation (macrophytes).

Affected record typically steps up significantly over one or two recording intervals, then maintains exceptionally high or over-range values until the cause moves, or is removed, either naturally, or by way of maintenance during a site visit.

Site maintenance, self-cleaning air or water purges, and water sampling activities may themselves interfere with the recording of normal turbidity by stirring up sediment around the sensor.

If the object moves frequently in and out of the sensor's view the affected data may be treated as for spikes (see Section E 3.5) or noise (see Section E 3.6). Otherwise affected data must be removed, and the consequent gap treated as missing record (see Section E 3.11).

3.3.3 Sensor clearance or cleaning

Clearing or cleaning a sensor removes fouling that has caused elevated turbidity readings. Baseline turbidity is re-established, often with a step down apparent in the data at the time, or shortly after if turbidity is also temporarily elevated by the disturbance of sediments during cleaning operations.

Macro-fouling and sensor burial are addressed in Section E 3.3.2.

Biofouling occurs when an algal film grows on the sensor lens that can be compounded by fine sediment settling in the algae. Chemical fouling occurs when a chemical film accumulates on the sensor lens, e.g. from tannins in the water. Both forms of fouling are gradual accumulations that progressively elevate back-scatter readings until the lens is cleaned of the accumulated material.

Note: Partial lens cleaning may occur naturally during floods because of the drag induced by higher velocities and increased turbulence, and abrasion by suspended sediment.

Adjustments applied to the elevated data must reflect assumptions made about the nature, timing, duration, and extent of the fouling and its subsequent clearance. In many cases the appropriate adjustment is a simple special case of drift correction often referred to as a one-tailed ramp correction, where the adjustment is an offset that increases linearly with time from zero at the start of the affected period to a non-zero (and in this case, negative) value specified at the end of the period of adjustment (see Figure E 4). However, fouling may increase sensor readings non-linearly, especially if the cause is biological, in which case a non-linear drift adjustment is required (see Section E 3.4).

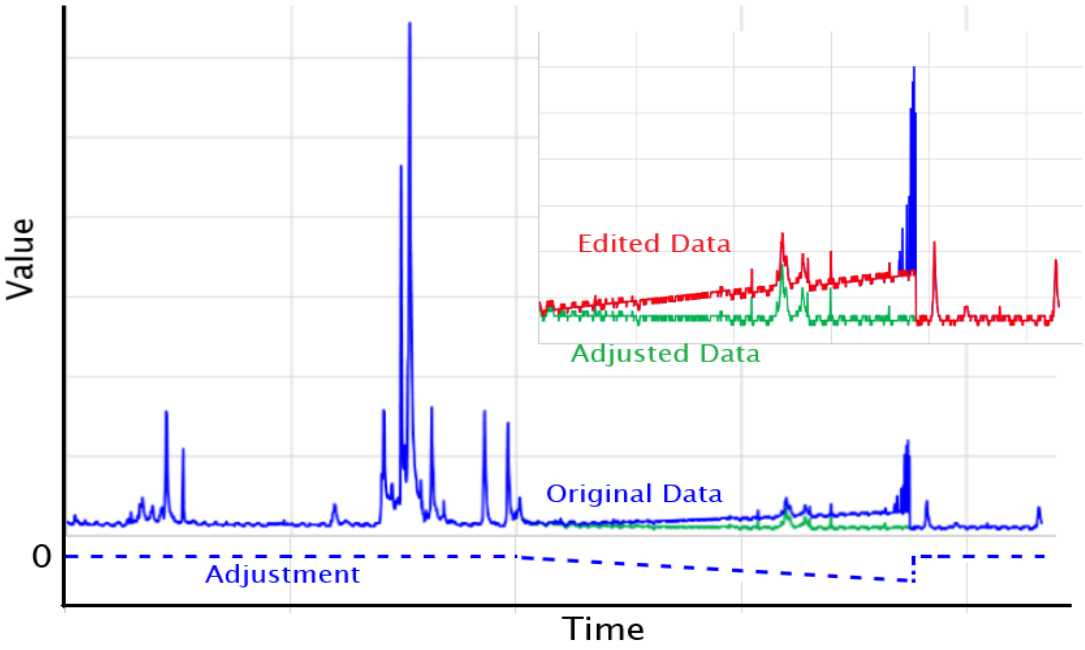


Figure E 4 - An example of a period of increasingly elevated data ending in a brief period of excessive noise before sensor cleaning returns readings to normal (blue line). Noise is edited first (red line), then a linear drift adjustment applied (dotted line) to progressively reduce the elevated values and eliminate the step at adjustment period end (green line).

Fouling may also cause noisy data, which should be smoothed or resampled (see Section E 3.6) before any adjustment is applied to eliminate a step (see Figure E 4).

Table E 2 – Guidance for resolving steps in the data

Guidance for resolving steps in the data		see Section(s)
Issue(s)	Large change in turbidity between successive readings that is not due to change in turbidity of the water body. If used as a surrogate for suspended sediment concentration (SSC) the step translates to an unlikely sudden change in sediment load.	E 3.3
Evidence	Physical cause is identified (observed or verified at site, or consequence of an event known to have occurred). Trace of data when plotted steps suddenly up (or down) and may flatline or appear 'held' down (or up) before the step.	Fig. E 4 E 2 3.6
Solution(s)	No adjustment if due to different instrument type or change of location (stationarity is disrupted). Rescale if instrument configuration was wrong. Change or remove values affected by interference or fouling. Treat gaps created as missing data. Drift adjustment (linear or non-linear as applicable) with no (i.e. zero) adjustment at onset of problem and maximum adjustment at the step in the trace. Avoid applying drift adjustments over significant events.	E 3.3.1 E 3.9 E 3.5 E 3.6 E 3.11 E 3.4 4.4 & 4.5
Metadata	Operational Comment required for change of instrument or location. Equipment Comment also required if instrument type or specification changed. Stationarity Comment required at step. QC 200 applies to all data from non-NEMS compliant instruments. If rescaling is fully traceable, quality code is unaffected, but a Transformation Comment is required. Otherwise, 'minor' or 'significant' modification criteria apply and a Data Processing Comment explaining identified cause and details of the adjustment(s) applied (amount, type, and period of adjustment) is required, OR Refer to missing data guidance as applicable.	E 5.2.3 E 5.2.2 E 5.2.7 E 5.1 E 3.9 E 5.2.6 6.2.3 E 5.2.5 6.2.4 E 3.11

3.4 Drift

Drift may occur for some time before detection and confirmation. Verification data normally used to control a drift adjustment may therefore include reference readings that encompass a wide range of turbidity values, some with large uncertainties. Avoid invalid adjustments by being selective about the reference values used to assess and control adjustment for drift.

3.4.1 Baseline drift

Baseline drift may be caused by gradual deterioration of the sensor lens or its internal electronics. Both situations are relatively uncommon with modern good quality sensors but highly abrasive sediment such as volcanic ash, or moisture ingress, may still cause problems. Baseline drift may also be due to biofouling or chemical fouling (see Section E 3.3.3).

Baseline drift many be linear or non-linear with time but is not value dependent, i.e. all readings are elevated by an offset that increases with time until cause is resolved, e.g. by polishing the lens. Linearity over time should be investigated by inspection of a plot of the data and evidence of trend in a deviation with time plot. Value independence should be confirmed using a deviation with range plot.

If the baseline drift is linear with time a linear drift adjustment is appropriate to re-establish the unbiased baseline (see Figure E 5).

Non-linear baseline drift with time may be adjusted using suitable non-linear drift adjustment tools or may be approximated by a sequence of small, short-duration linear drift adjustments with time (see Figure E 6), but these must be applied carefully to avoid distortion of the record, especially during periods of low turbidity and/or flow recession.

Possible over-ranging or sensor saturation as a consequence of elevated baseline must also be considered (see Section E 3.7).

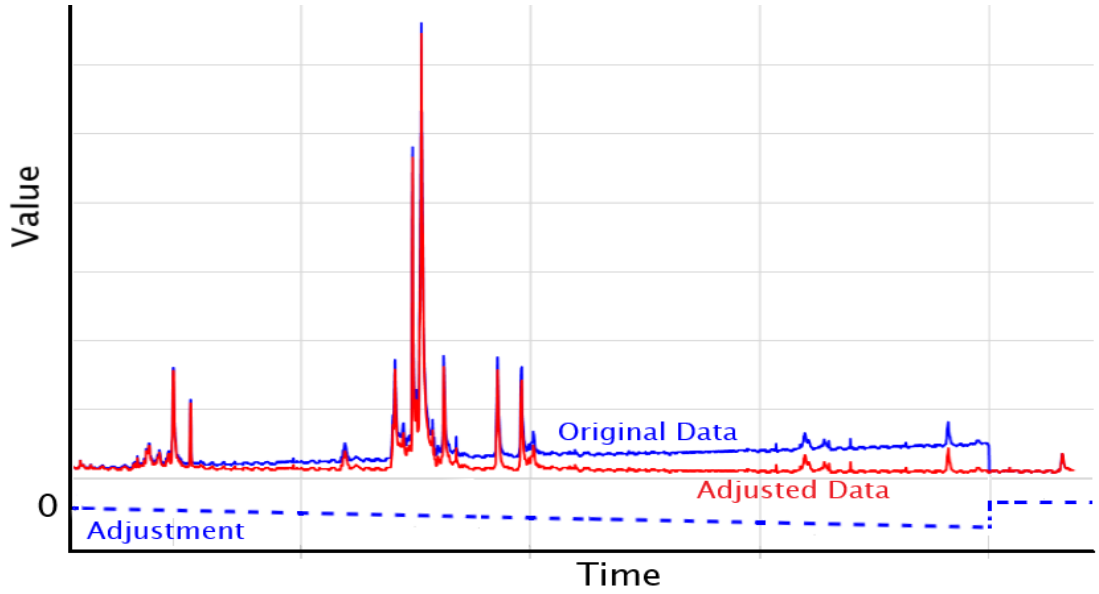


Figure E 5 - An example of baseline drift (blue line), with the adjusted data (red line) and showing the linear drift adjustment applied to remove the increasing bias (dotted line).

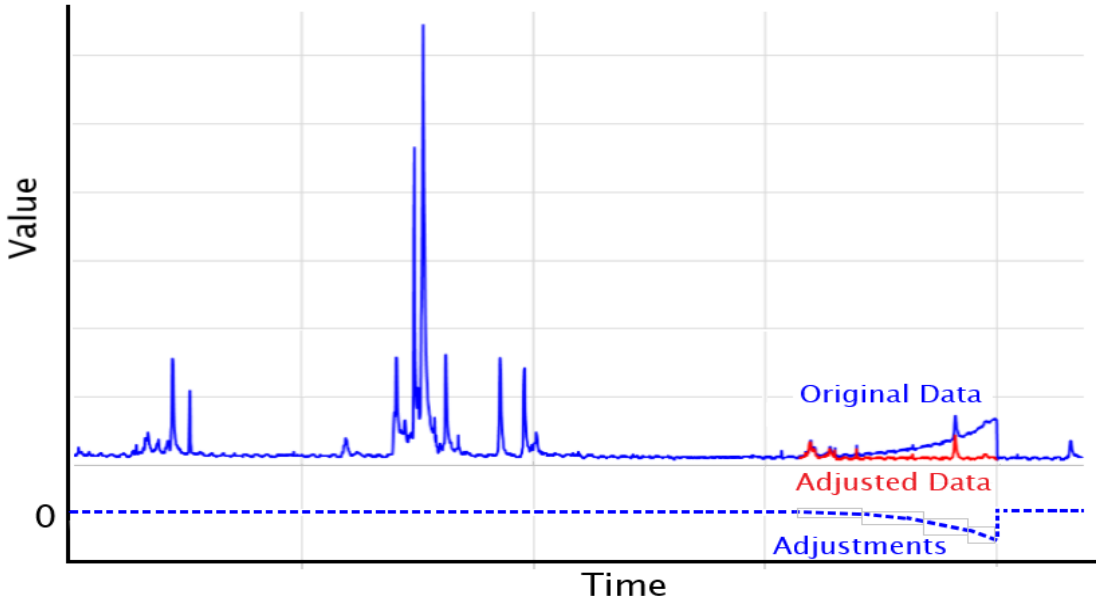


Figure E 6 - An example of non-linear calibration drift offsetting the baseline (blue line), with the adjusted data (red line) and showing the succession of small, short-duration linear drift adjustments (grey boxes) applied to remove the increasing bias (dotted line).

3.4.2 Calibration drift

Calibration drift may be linear or non-linear in value and/or time dimensions and may introduce a variable offset and/or alter the scale of the data. The nature of the drift must be determined wherever possible, by analysis of deviations from reference with time and with range, and/or from successive instrument validations. Instances of sensor over-ranging and/or saturation (see Section E 3.7) or sensor exposure (see Section E 3.8) must be isolated from analysis of calibration drift.

Calibration drift over the range of the sensor is usually associated with loss of linearity of response over the calibrated range. Affected data may be adjusted by applying a non-linear transformation to the values as determined from results of the instrument validations. The transformation may be applied as one or more equations, or by a look-up function, or as a rating curve. A sensor exhibiting loss of linear response must be replaced. Proper adjustment of the prior data should eliminate any step-change resulting from instrument replacement. If affected data cannot be reliably adjusted, it must be deleted from the record and the period treated as missing data (see Section E 3.11).

Non-linear drift adjustment that progressively alters the scale of the data with time, e.g. a linear %value drift adjustment (see Figure E 7), is not appropriate if the calibration drift causes a worsening offset but does not affect the relative range of measured values, i.e. the drift affects only the baseline (see Section 3.4.1).

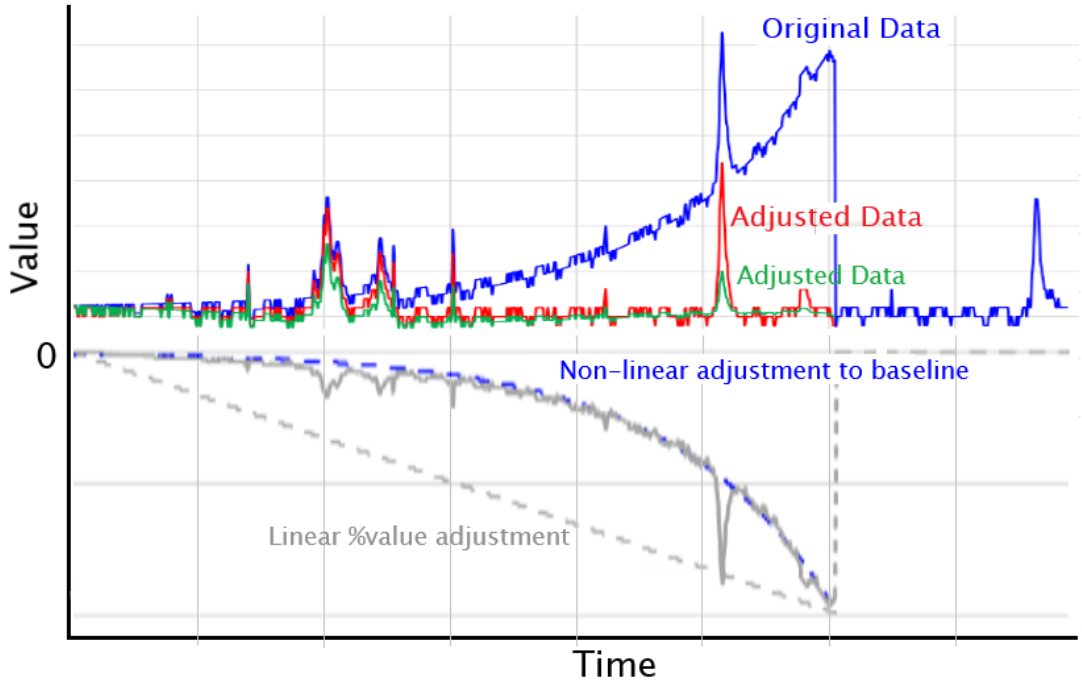


Figure E 7 – Comparison between a non-linear adjustment (blue dashed line) applied to a baseline affected by non-linear drift (blue line) and the resulting adjusted data (red line), and a linear %value drift adjustment (grey dashed line) that subtracts an increasing proportion of the logged values with time (grey line) to eliminate the drift but also progressively reduces the scale of the data (green line).

Table E 3 – Guidance for resolving drift

Guidance for resolving drift		see Section(s)
Issue(s)	Recorded values are biased by an increasing amount over time.	E 3.4
Evidence	Differences between recorded and reference turbidity increase with time and/or vary with value. Physical cause may be identifiable, such as biofouling or sensor validation results. Drift with time causes 'uphill' recessions, evident when plotted.	Fig. E 5 Fig. E 6 Fig. E 7 E 2 3.6
Solution(s)	Apply linear or non-linear drift adjustments as applicable depending on whether drift is determined to be linear or non-linear with time. A non-linear drift adjustment with time can be approximated by a series of small, short-duration linear drift adjustments, with care. Apply a transformation derived from instrument validation results if drift is value dependent. Remove affected record if transformation is not possible, then treat as missing data.	E 3.4 Fig. E 5 Fig. E 6 Fig. E 7 4.4 or 4.5 4.7 E 3.11

Metadata	QC 500 or QC 400 depending on 'minor' or 'significant' change, and Data Processing Comment required explaining identified cause of drift and details of each adjustment applied (type, amount, and period of adjustment), OR Refer to missing data guidance as applicable.	6.2.3 E 5.2.5 6.2.4.7 E 3.11

3.5 Spikes

Unexpectedly low values are relatively rare in turbidity data and usually associated with power supply failure. Solitary unexpectedly high values can occur due to electronic transients or floating debris passing within range of the sensor's optics. Data affected by intermittent macro-fouling may exhibit continual and possibly erratic spiking to high values if the cause is moving back and forth in the current.

Isolated spikes in continuous turbidity data may be deleted or replaced. If deleted, the interpolation engine can be left to interpolate between the remaining adjacent values unless regular interval data are required.

Intermittent spikes may be deleted manually or discarded using a numerical filter. A track minimum filter may be more successful than a threshold filter if there is frequent spiking to values within the range of the reliable data. If only one or two successive values are removed at each occurrence the interpolation engine can be left to interpolate between the remaining adjacent values unless regular interval data are required. If more than a few successive values are removed gap processes are then required (see Sections 4.16 to 4.20 and E 3.11).

If spiking is frequent, persistent, and affecting consecutive values, treatment as noise is necessary (see Section E 3.6).

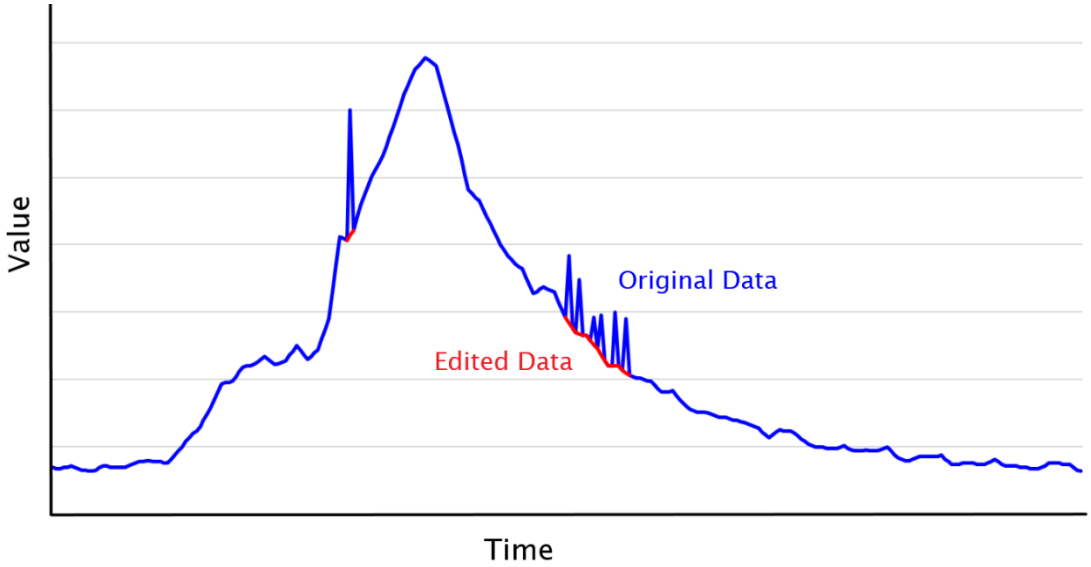


Figure E 8 - An example of a solitary spike (rising side) and frequent spiking (falling side, blue line) and the result of deleting or replacing the implausibly high values (red line).

Table E 4 – Guidance for resolving spikes in the data

Guidance for resolving spikes in the data		see Section(s)
Issue(s)	Spurious values recorded.	E 3.5
Evidence	Value significantly different from adjacent values. Observable in a plot of the data. Confirmation by field investigation and elimination of cause if possible.	Fig. E 8 E 2 3.6
Solution(s)	Delete or replace spurious values. If more than a few consecutive values are removed, missing data processes are also then required. If spiking is frequent, persistent, and affecting consecutive values, treatment as noise is necessary.	4.11 or E 3.11 or E 3.6
Metadata	QC 500 and Data Processing Comment required explaining identified cause and whether values are deleted or replaced, OR Refer to missing data or noise treatment guidance as applicable. Comments may be aggregated if frequent and repetitive.	6.2.3 E 5.2.5 6.2.4.7 or E 3.11 or E 3.6

3.6 Noisy data

Noise in turbidity data is usually caused by interference or transient fouling that results in elevated values (see Section E 3.3.2). Affected values may be filtered out by tracking the minima by hand or machine algorithm (see Figure E 5). Because the noise is not randomly distributed about the expected true value an averaging, moving mean, or median of values filter is not appropriate. The edited data must be carefully assessed to confirm that the minima selected are not also elevated.

If insufficient values are retained to reliably represent the turbidity measured, treat the period as missing data (see Section E 3.11).

Table E 5 – Guidance for resolving noisy data

Guidance for resolving noisy data		see Section(s)
Issue(s)	Noise obscures representative signal. Range of fluctuations is outside tolerance. Range of fluctuations compromises use as a surrogate to determine suspended sediment concentrations.	E 3.6
Evidence	Noise not seen in independent observations. Trace when data are plotted is 'fuzzy'. Variation between adjacent values is larger than is normal or expected from resolution of the instrument. Noise is absent after cause is addressed.	Fig. E 8 E 2 3.6

Solution(s)	Resample, or 'smooth' with a statistical filter. Method choice is determined by instrument type and identified cause. Tracking minima is usually the most appropriate. Some cautions apply.	E 3.6 Fig. E 8 4.12
Metadata	QC 400 and Data Processing Comment explaining identified cause and method applied.	6.2.3 E 5.2.5 6.2.4.7

3.7 Over-ranging and sensor saturation

Over-ranging occurs when turbidity exceeds a sensor's calibrated range. The value returned when the range is exceeded varies according to the type and brand of sensor and may be an error code.

Data loggers and some sensors may prevent the recording of values exceeding the sensor's stated calibrated range. Occurrences truncate turbidity events at a constant high value or create a gap in the record. Other sensors may continue to output a non-linear response until reaching saturation (plateauing) at a maximum value.

Over-ranging may be difficult to detect in the record from some instruments because turbidity beyond the instrument's range results in reduced turbidity values due to absorption of the light emitted from the sensor dominating over back-scattering. In some cases, the peak of a turbidity event may appear to collapse or invert due to this effect (see Figure E 9).

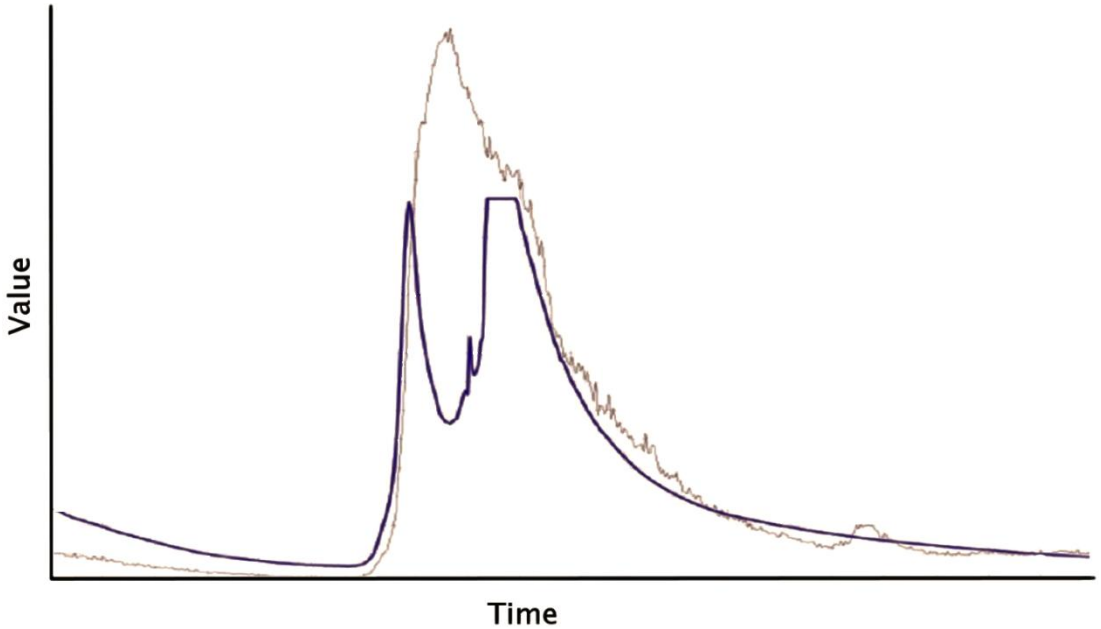


Figure E 9 - An inverted turbidity peak caused by the absorption of light emitted from the sensor dominating over backscattering (dark line) compared with the same event as recorded by another sensor at the site with a larger calibrated range (ghosted line).

When processing turbidity data, it is important to understand how the sensor responds as turbidity increases beyond its stated calibrated range and be alert to the possibility of false readings or data loss near the top of that range.

False readings must be removed from the record, then treat as for missing data.

Datasets that include periods of truncated over-ranging may be filed as a censored time series with appropriate metadata (see Sections 1.1.5 and E 5); however, treating affected periods as missing data is preferred (see Section E 3.11). A change of over-range threshold and/or over-range treatment may affect stationarity so must be noted in a Stationarity Comment (see Section E 5.2.7).

See also Section 8 of NEMS *Fluvial Suspended Sediment Load* v0.1.1.

Table E 6 – Guidance for resolving over-ranging and sensor saturation

Guidance for resolving over-ranging and sensor saturation		see Section(s)
Issue(s)	Full range of turbidity is not recorded. False readings may be recorded that cause suspended sediment concentrations derived from turbidity as a surrogate to be grossly under-estimated.	E 3.7
Evidence	Over-ranging record flatlines or has gaps when turbidity is at or near top of calibrated range. Peak collapses or inverts at high turbidity if saturation occurs. May be verified by independent measurements.	Fig. E 9 E 2 3.6
Solution(s)	Replace with backup or secondary data, or remove and treat as missing, or in limited circumstances accept as censored data. If removed, the gap created may be infilled with synthetic data if appropriate. Method choice is determined by site purpose, identified cause, and available supporting data. Some cautions apply.	4.16 to 4.20 incl. E 3.7 E 3.11 1.1.5 App. E.1
Metadata	Quality code applicable to the replacement backup or secondary record (QC 200 applies to data from non-NEMS compliant instruments). QC 300 if replaced with synthetic infill, or QC 100 if left missing, or QC 400 if stored as censored. Data Comments are required explaining identified cause and providing details of decisions made and methods applied. A Stationarity Comment is required if threshold and/or treatment is changed.	6.2.3 E 5.1 E 5.2.4 6.2.4.6 E 5.2.7 6.2.4.8

3.8 Sensor exposure

Sensors may become exposed inadvertently because of bed scour or deliberately to avoid biofouling at low flows. The value returned varies according to the type and brand of sensor and may not necessarily be zero.

The level of the sensor lens in relation to the water surface, and the minimum required deployment depth of the sensor, must be known when verifying and processing turbidity data. Combine this information to obtain a threshold water level below which the turbidity data must be regarded as compromised.

Remove data affected by sensor exposure or light contamination from the record and treat the period as missing data (see Section E 3.11).

See also Section 8 of NEMS *Fluvial Suspended Sediment Load* v0.1.1.

Table E 7 – Guidance for resolving sensor exposure

Guidance for resolving sensor exposure		see Section(s)
Issue(s)	False values are recorded.	E 3.8
Evidence	Physical cause is known or identified (observed or verified at site, and/or from calculation of relative levels, or consequence of an event known to have occurred).	E 3.8 E 2 3.6
Solution(s)	Remove false data and treat as missing.	4.16 to 4.20 incl. E 3.11
Metadata	QC 300 if replaced with synthetic infill, or QC 100 if left missing. Data Comments are required explaining identified cause and providing details of decisions made and methods applied.	6.2.3 E 5.2.4 6.2.4.6

3.9 Incorrect scaling

Incorrect scaling means that the range of the data is either wrongly reduced or expanded by some factor. The problem usually arises from:

- wrong measurement units, or
- incorrect sensor/logger configuration.

For turbidity, data collected in the wrong measurement units are not recoverable. Explicit conversion by mathematical relation between different units of turbidity measurement is not possible.

- Units assigned to measured values must be consistent with the measurement protocol used.
- Data must be stored in the units in which it was measured.
- The metadata must state the units of measurement.
- Verification data must be in the same units of measurement as the continuous data collected to be directly comparable.

- Any change in turbidity units of measurement at a site must be identified by a Stationarity Comment (see Section E 5.2.7).
- Data in different units for the same site must be differentiated and preferably be stored as separate time series.

Note: Design of the sensor and its calibration standard determine the units of turbidity measurement. Because turbidity is a relative measure of an optical property of water, there is no mathematical relationship between any two units of measurement. This is true for all field deployments despite calibrating sensors of different type to the same standard, i.e. NTU and FNU are not the same unless the substance being measured is the formazin colloid. In the field, variations in colour, and particle size and shape, also affect the scattering of light of different wavelengths such that turbidity measured in NTU will not be the same as turbidity measured in FNU.

Turbidity series measured in different units at a site over time cannot be combined into a homogenous series of turbidity but may be used as a surrogate for a homogeneous series of suspended sediment concentration if separate relationships are developed with each turbidity series.

Sensor output as current (Amps) or potential (Volts) requires conversion to measurement units on the data logger using a multiplier and possibly an offset. If the multiplier is incorrect a scaling error arises that will show as differences in subsequent checks that vary in proportion to the logged value.

To correct the data, remove any offset applied, then divide by the incorrect scaling multiplier to obtain raw signal, then multiply the raw signal by the correct scaling multiplier, then apply an appropriate revised offset (i.e. recalculated using the raw signal and its correct multiplier). If the necessary transformations are fully traceable there is no effect on quality code.

Table E 8 – Guidance for resolving incorrect scaling

Guidance for resolving incorrect scaling		see Section(s)
Issue(s)	Scale and/or units of the data is/are wrong.	E 3.9
Evidence	Recorded extremes do not agree with those independently observed. Differences between reference and logged values are highly variable and often large. Comparison plots indicate range of the data is wrong.	E 3.9 E 2 3.6
Solution(s)	Turbidity data in the wrong units are not recoverable. File turbidity data in the units in which they were measured. For instrument configuration errors, apply linear transformations reversing the applied instrument configuration parameters to obtain raw signal, then apply the correct configuration parameters to the recovered raw signal.	E 3.9 4.7
Metadata	QC 200 applies to data from non-NEMS compliant instruments. Equipment and Stationarity Comments may also be needed.	E 5.1 E 5.2.2

	If the correction required is fully traceable, quality code is unaffected, but a Transformation Comment is required. Otherwise, 'minor' or 'significant' modification criteria apply and a Data Processing Comment explaining identified cause and details of the amount and period of adjustment is required.	E 5.2.7 E 5.2.6 6.2.3 E 5.2.5 6.2.4

3.10 Time faults

A time shift may be needed to obtain data in NZST or to correct for an incorrectly configured or defaulted logger (see Section 4.3).

If the time fault caused existing data to be overwritten or conflicting new data elements to be discarded, some missing record at period start if shifted forward, or period end if shifted back, is also a consequence that must be addressed (see Section E 3.11).

Time drift adjustment is rarely needed with modern electronic loggers (see Section 4.6). If logger date/time does not agree with actual date/time it is more likely the logger has stopped and there is a gap in the record, possibly unmarked, needing to be identified and addressed.

Most time-series management software has the ability to make time adjustments simultaneously with value adjustments. There is risk when using drift adjustment tools that time is unintentionally adjusted and time faults are introduced into the processed data. This is relatively easy to detect in fixed interval data by analysing the timesteps or inspecting the timestamps.

Table E 9 – Guidance for resolving time faults

Guidance for resolving time faults		see Section(s)
Issue(s)	Event timing and/or temporal distribution of recorded data is wrong and/or data are missing.	E 3.10
Evidence	Logger date/time is different from actual at inspection. Investigation finds configuration error or reset, and/or event timing and/or temporal distribution anomalies are apparent when compared with discharge data from the same site.	Fig. 18 Fig. 26 E 2 3.6
Solution(s)	If wrong time zone, apply time shift then address any missing record created at the start (or end) by the shift. If a clock fault, replace with reliable backup if independently logged and available, OR if clock is slow or fast, apply time drift adjustment, OR if clock stopped, treat period until restart as missing record.	4.3 or 4.6 Fig. 19 Fig. 27 and/or E 3.11

Metadata	If the time shift is fully traceable, quality code is unaffected, but a Data Processing Comment is required explaining identified cause and details of the shift applied. QC 100 if missing, or QC 300 if infilled, and a Data Comment. Otherwise, 'minor' or 'significant' modification criteria apply and a Data Processing Comment explaining identified cause and details of the amount and period of adjustment is required.	4.3.3 E 5.2.5 6.2.3 E 5.2.4 6.2.3 E 5.2.5 6.2.4

3.11 Missing data

When considering the treatment and associated metadata requirements for missing turbidity data the following broad descriptions of duration are helpful:

- a brief period is a few recording intervals up to an hour
- a short duration is up to a day within an event or cycle, or period of stable conditions
- a longer period may be one or more days up to one week, and
- an extended period may be a week or more.

Turbidity is highly variable, and the data can be quite specific to the location at which the turbidity is measured. Catchment and local factors combine to influence the at-site turbidity. When selecting and applying an appropriate method for resolving missing data, the likely variation at site must be taken into account with consideration of the duration of the period missing (see Appendix E.1).

Note: Catchment factors include the combination of rainfall, soil type, landcover, land use, drainage network complexity and sediment composition each with its own spatial and temporal distribution and variability. Dissolved colour and microscopic algae influence low turbidity readings but are not directly related to suspended sediment composition and transport. Other influences may change rapidly or arise from very small, localised areas, e.g. runoff from a localised thunderstorm cell, or input or disturbance due to some upstream activity.

A continuous period of a week or more missing shall only be filled with backup or secondary data, or synthetic data corroborated by at least weekly supplementary measurements within the period synthesised.

For turbidity, backup data are data obtained from another sensor at site of the same type and conforming to the same standard and measurement units as the primary sensor. Secondary data may be obtained from another sensor at site of a different type, standard and/or units but for which a reliable relationship between it and the primary turbidity data can be derived. Supplementary measurements include verification data and results of water samples intended to fill gaps and/or calibrate surrogate relationships.

A maximum duration of one month for any period of infill is recommended, although this is dependent on:

- the typical and expected variation in turbidity at the site
- the possibility of a significant event having occurred, and
- reliability of the relationship(s) used to generate the synthetic record.

If the turbidity record is intended only as a surrogate for suspended sediment concentration, gaps must be marked (see Section 4.16) but infilling of gaps can and should be left until the series is converted to suspended sediment concentration (see Section 8.2 of NEMS *Fluvial Suspended Sediment Load* v0.1.1).

3.11.1 Methods for infilling gaps

For details on specific methods for infilling gaps in turbidity series, see Appendix E.1 to this Annex.

Table E 10 – Guidance for resolving missing data

Guidance for resolving missing data		see Section(s)
Issue(s)	Data are missing.	E 3.11
Evidence	Expected timestamps are not present in the original data. A gap marker may or may not be present depending on data collection method. Comparison plot shows entire, or parts of events are missing. Investigation confirms data were not logged and/or not collected. Data have been intentionally removed.	4.16 Fig. 9 E 2 3.6
Solution(s)	Use at-site backup, secondary and/or supplementary data, and manual observations where available, OR if brief with stable conditions, interpolate across gap if short with stable conditions, infill with baseline or a curve if longer period or unstable conditions, apply methods to infill with synthetic data, or mark the gap if an extended period, apply methods to infill with synthetic data if within recommended maximum duration, or mark the gap, or note a temporary site closure.	App. E.1 E 3.11 4.16 to 4.20 incl. 5.4 & 5.5
Metadata	No effect on quality code if brief and interpolated. Otherwise, quality code as applicable to the alternate record and manual observations, or QC 300 if infilled, or QC 100 if left as missing. Data Comments are required explaining identified cause and providing details of decisions made and methods applied, including expected reliability of any synthesised infill.	6.2.3 E 5.2.4 6.2.4.6

4 Post-processing Data Manipulation

4.1 Combining two concurrent at-site records

At sites that experience high sediment loads it may not be possible to cover the range of likely values during high turbidity events and obtain turbidity readings with sufficient resolution at low turbidity using the same instrument. In such cases two instruments of the same type, standard, and measurement units, but different range and resolution, may be installed (see Figure E 9).

Record from the two sensors should be processed simultaneously with one used to aid verification of the other. Once verified, the two records must be combined into a single time series for archiving. The value at which to accept one record over the other is dependent on issues of over-ranging and sensor saturation of the lower range instrument (see Section E 3.7) and may not be the same for every event. Small time corrections may also be required to eliminate any steps due to timing issues at the junction of the lower and full range series.

4.2 Transformations

It is not possible to mathematically convert between different turbidity measurement units. There are no physical formulae for this purpose (see Annex E Section 3.9).

Transformations that apply a graphically or statistically derived relationship may be used for infilling gaps (see Appendix E.1) and conversion of turbidity as a surrogate to the target variable, usually suspended sediment concentration (see Annexes E and F of NEMS *Fluvial Suspended Sediment Load* v0.1.1).

5 Metadata

5.1 Quality Coding

The relevant quality coding flowchart may be found in NEMS Turbidity (Measurement, Processing and Archiving of Turbidity Data) or in NEMS National Quality Code Schema.

The quality code of any data collected may be affected by subsequent actions on and adjustments made to the data. Guidance on how and when quality code must change as a consequence of data processing is provided in Section E 3 of this Annex.

Data from any sensor not conforming to ISO 7027 are not NEMS-compliant and cannot be quality coded higher than QC 200.

5.2 Example turbidity comments

The following are templated examples of comments for turbidity stations.

Every comment must be assigned a fully specified timestamp and be associated with the relevant data (the time series of turbidity) via some form of 'Site' and

'Measurement' database key combination. The database keys are usually specified in some form of record header not shown here.

5.2.1 Site/Initial Comments

River station

Type: Site
Measurement: Turbidity
Initial comment for *<river name>* River turbidity at *<site name>*
Site number *<network number, ID or code>* on river *<river number>*[19]
The site is situated *<distance to coast>* km from the mouth at grid reference *<map co-ordinates and type[20]>*
Drains *<catchment area to site>* km^2 and channel is *<describe main bed/bank features e.g. willow-lined alluvial, silt bed with erodible grassed banks, rock-lined gorge, etc.>*
Additional information: *<site purpose, including whether a surrogate for suspended sediment; anything relevant to general interpretation of the record; persistent adverse conditions at site (e.g. biofouling, bed mobility, very high sediment loads); upstream or downstream site(s) also measuring turbidity> <Some (or All) quality control (and/or data editing) is automated; refer to the relevant Data Processing Comments.> <Data are stored as a censored series.>*
The following is also measured continuously at this site: *<list variables e.g. water level, flow, backup and/or secondary turbidity>* Samples are collected and analysed for *<list variables measured by laboratory analysis>*
The local recording authority is: *<name of recording/archiving agency>*

Lake station

Type: Site
Measurement: Turbidity
Initial comment for *<name of water body>* turbidity at *<site name>*
Site number *<network number, ID or code>* on river *<river number>*[21]
The site is situated *<distance to outlet>* km from the outlet at grid reference *<map co-ordinates and type[22]>*
Drains *<catchment area>*km^2 of *<river name>* River catchment
Lake area is *<surface area>*km^2 and level is controlled by *<describe features e.g. natural outlet, dam, weir etc.>*. Inflow source is *<groundwater, rainfall, snowmelt, glacial etc.>*
Additional information: *<site purpose, anything relevant to general interpretation of the record, persistent adverse conditions at site (e.g. biofouling, recreational boating, algal blooms, drying out, etc.), site(s) on inflows also measuring turbidity> <Some (or All) quality control (and/or data editing) is automated; refer to the relevant Data Processing Comments.> <Data are stored as a censored series.>*
The following is also measured continuously at this site: *<list variables e.g. water level, flow, backup and/or secondary turbidity>* Samples are collected and analysed for *<list variables measured by laboratory analysis>*
The local recording authority is: *<name of recording/archiving agency>*

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[19] from *Catchments of New Zealand* (SCRCC, 1956).
[20] state the co-ordinate system: NZTopo50 or NZGD 2000 preferred (latitude/longitude to 6 decimal places)
[21] from *Catchments of New Zealand* (SCRCC, 1956).
[22] state the co-ordinate system: NZTopo50 or NZGD 2000 preferred (latitude/longitude to 6 decimal places)

5.3 Equipment Comment examples

Type: Equipment
Measurement: Turbidity
Recorder installed on *<dd-mm-yyyy hhmmss>* is a *<describe main logger features e.g. how powered, compact (or otherwise e.g. PLC), multi- or single input, programmable etc.>* data logger, recording *<describe logging and sampling regime e.g. instantaneous readings at fixed intervals of x-minutes>*. The turbidity sensor is a *<type and output e.g. 0-20mA ISO 7027 compliant optical back-scatterer reporting in FNU, etc.>* installed in (or on) *<brief description e.g. weighted cable x-m below moored buoy, conduit attached to pier, steel box section secured to bank etc.>*. Sensor range is *<range and units>* with resolution of *<resolution and units>* and nominal accuracy of *<accuracy specification>*. Sensor output is converted to turbidity units by *<details of any transformations applied at the time of data capture or collection e.g. scaling multiplier and/or offset>*. Sensor calibration is valid for *<calibration period>*. *<Zero point is checked annually>*. Site is visited *<state frequency e.g. weekly, monthly, or as required from inspection of the data>* to clean the sensor and obtain verification data. Data are collected by *<method e.g. telemetry and occasional manual download>*.

Create similar but separate comments for any backup sensor or secondary source of continuous turbidity data at the site, to avoid the comments becoming too long and complex.

Type: Equipment
Measurement: Turbidity
Verification data are obtained *<state frequency>* by *<describe method and instrument(s) used e.g. readings from handheld instrument positioned as close to the sensor as possible, or grab samples, or by auto-sampler, then laboratory analysed etc.> <Add other relevant information such as range, units and calibration frequency of the handheld; collection location and laboratory method for water samples; any other intended uses for the data e.g. developing surrogate relations>*.

5.4 Operational Comment examples

Type: Operational
Measurement: Turbidity
Sensor moved on *<dd-mm-yyyy hhmmss>* from true left bank bridge pier to true right bank bridge pier. New location provides more bed clearance at low flows. Sensor optics are now positioned at *<reduced level and datum, or equivalent stage>*.

Type: Operational
Measurement: Turbidity
Sensor cleared of silt and debris on <dd-mm-yyyy hhmmss>. Turbidity briefly elevated by activity then settled 10 FNU lower than before.

Type: Operational
Measurement: Turbidity
Verification sample on *<dd-mm-yyyy hhmmss>* was collected 20m from the sensor due to high flood preventing access. Significant deviation from recorded value is expected.

Type: Operational
Measurement: Turbidity
Sensor replaced on *<dd-mm-yyyy hhmmss>* with an ISO 7027 compliant instrument. Refer to the associated Equipment Comment for its specifications.

Type: Operational
Measurement: Turbidity
Zero-point validation completed on *<dd-mm-yyyy hhmmss>* with no offset apparent and no action required.

5.5 Data Comment examples

Type: Data
Measurement: Turbidity
Missing record from *<dd-mm-yyyy hhmmss>* to *<dd-mm-yyyy hhmmss>* due to *<identified cause of false recording or failure>*. *<Add any other relevant information such as why the gap has not been filled>*.

Type: Data
Measurement: Turbidity
Synthetic record from *<dd-mm-yyyy hhmmss>* to *<dd-mm-yyyy hhmmss>* due to *<identified cause of false recording or failure>*. Record generated from *<provide the relation e.g. state the equation(s) or function(s)>* obtained by *<method e.g. simple least squares or multiple regression, LOWESS etc.>* with input data *<list sites, variables, and periods used>*. *<Add indication of reliability e.g. regression coefficient or standard error and analysis sample size, or some other assessment of uncertainty etc.>*, *<Add limitations on usefulness e.g. not recommended for use as a surrogate measure>*.

Type: Data
Measurement: Turbidity
Synthetic record from *<dd-mm-yyyy hhmmss>* to *<dd-mm-yyyy hhmmss>* due to *<identified cause of false recording or failure>*. Record generated by *<describe non-statistical method e.g. graphical extension of turbidity-discharge event loop, manually inserting values to complete the rise or recession, etc.>* with reference to the following data *<list sites, variables, and periods used>*. *<Add information relevant to reliability of the synthetic record e.g. flow conditions, antecedent rainfall, suspected sensor saturation accounted for (or not) in period etc.>*. *<Add limitations on usefulness e.g. not recommended for use as a surrogate measure>*.

Type: Data
Measurement: Turbidity
Backup record used from *<dd-mm-yyyy hhmmss>* to *<dd-mm-yyyy hhmmss>* due to *<identified cause of primary recording failure>*.

Type: Data
Measurement: Turbidity
Change of datalogging interval on *<dd-mm-yyyy hhmmss>* from *<previous interval>* to *<new interval>*.

Type: Data
Measurement: Turbidity
Gap in record from *<dd-mm-yyyy hhmmss>* to *<dd-mm-yyyy hhmmss>* due to the sensor over-ranging beyond *<top of calibrated range and units>*. Period is not able to be infilled because the autosampler also failed.

Type: Data
Measurement: Turbidity
Maximum calibrated range of the sensor is *<value and units>* *<Add date/time range if relevant>*. Turbidity exceeding this range is assigned the stated maximum value when logged. The record interpolates and is therefore a continuous but censored series.

Type: Data
Measurement: Turbidity
Data may be compromised from *<dd-mm-yyyy hhmmss>* to *<dd-mm-yyyy hhmmss>*. Cause is unknown but may be due to (or affected by) *<describe suspected cause>*. *<Add other relevant information e.g. comparison records not available, possible reasons for data being correct, etc.>*

5.6 Data Processing Comment examples

Type: Data Processing
Measurement: Turbidity
Values deleted and record interpolates from *<dd-mm-yyyy hhmmss>* to *<dd-mm-yyyy hhmmss>* to remove spikes caused by *<identified cause>*. Edited by *<name>* on *<date of processing>*.

Type: Data Processing
Measurement: Turbidity
Data resampled using a track minima filter from *<dd-mm-yyyy hhmmss>* to *<dd-mm-yyyy hhmmss>* to minimise noise due to frequent elevated readings caused by *<identified cause>*. *<Some bias may still be present>*. Edited by *<name>* on *<date of processing>*.

Type: Data Processing
Measurement: Turbidity
Values replaced from *<dd-mm-yyyy hhmmss>* to *<dd-mm-yyyy hhmmss>* to remove spikes caused by *<identified cause>*. Edited by *<name>* on *<date of processing>*.

Type: Data Processing
Measurement: Turbidity
Data adjusted from *<dd-mm-yyyy hhmmss>* to *<dd-mm-yyyy hhmmss>* by *<method and parameters e.g. offset shift of C mm, linear drift adjustment of C0mm to C1mm etc.>* to compensate for *<identified cause>*. Edited by *<name>* on *<date of processing>*.

Type: Data Processing
Measurement: Turbidity
From *<dd-mm-yyyy hhmmss>* (to *<dd-mm-yyyy hhmmss>*) automated quality control (and/or editing) is applied to this data. Actions include: *<briefly describe each action in specific terms e.g. Range Test: values < x FNU or > x'* FNU not accepted (or, removed (and gapped)); Flat Line Test: error flagged if n consecutive values are same; etc.> (or Actions are documented in *<provide reference to processing system documentation that contains specific detail of the tests applied to this data e.g. the site file, quality management system etc.>*), applied *<describe where in the process, with respect to what is original data, e.g. on the data logger (or telemetry system, etc.) prior to archiving as original data, or, after original data have been preserved but before near real-time web publication etc.>*, using *<provide name(s) of software and version and briefly describe how the actions are specified and/or configured in the system, and/or provide reference to where the code is permanently preserved, configuration files or screenshots are retained or similar>*.

Similar 'automation' comments must be provided each time any relevant detail changes, from change to an action threshold through to a change of organisational procedure and/or software. Cross-reference relevant Equipment and Operational Comments as required to avoid unnecessary duplication. File a corresponding Stationarity Comment if change of methods potentially disrupts stationarity of the data.

The level of detail required in 'automation' comments depends on the extent to which the comments are necessary to ensure traceability of changes made to the raw measurements (see Sections 3.1.1 and 8.2).

5.7 Transformation Comment examples

Transformations applied to a turbidity record prior to its archiving must be included in the turbidity metadata. Transformations to convert turbidity records intended as surrogate, to the variable of interest, are outside scope of the turbidity metadata (see Section 6.2.4.8).

Type: Transformation Measurement: Turbidity Data from *<dd-mm-yyyy hhmmss>* to *<dd-mm-yyyy hhmmss>* is transformed by Y' = [(Y – *<C>*) x (*<m'/m>*)] + *<C'>* to correct a scaling (and/or offset) error. Logger parameters applied from *<dd-mm-yyyy hhmmss>* were multiplier *<m>* and offset *<C>*. Correct logger parameters are multiplier *<m'>* and offset *<C'>* applied on the logger from *<dd-mm-yyyy hhmmss>*. Edited by *<name>* on *<date of processing>*.

5.8 Stationarity Comment examples

Type: Stationarity Measurement: Turbidity Change of sensor location on *<dd-mm-yyyy hhmmss>* caused a -3 FNU step-change in recorded baseline turbidity, verified by subsequent adjacent independent readings. The data have not been adjusted to eliminate the difference.

Type: Stationarity Measurement: Turbidity Sensor replaced on *<dd-mm-yyyy hhmmss>* with an ISO 7027 compliant instrument conforming to NEMS Standard (see associated Operational Comment). Prior record, measured in (or by) *<state key difference(s) in sensor characteristics, measurement units etc.>* is available from *<state the site and/or data source and/or variable/measurement under which the previous data are stored>*. The two series are not homogenous for turbidity *<but may be used with appropriate calibrations to derive a homogenous series of suspended sediment concentration>*.

Type: Stationarity Measurement: Turbidity Data are a censored series. Maximum sensor range and therefore censoring threshold was changed on *<dd-mm-yyyy hhmmss>* from *<x FNU>* to *<x' FNU>*. Refer to the corresponding Equipment Comment for sensor details. Stationarity Comments can also be used to capture and collate information about historical methods and data.

6 Preservation of Record

Refer to Section 8 of this Standard.

7 References

Soil Conservation and Rivers Control Council (SCRCC). 1956. *Catchments of New Zealand.* SCRCC, Wellington.

Appendix E.1 Methods for Infilling Gaps

1 Information Requirements

The method chosen to infill a gap (i.e. a period of missing record) will depend on:

- the type of water body (e.g. river, lake, or estuarine)
- the duration requiring infilling
- the availability of other relevant time series, such as:
  - at-site backup turbidity data
  - at-site secondary turbidity data
  - at-site flow or water level data
  - upstream or downstream turbidity, flow, or water level data
- the likelihood of:
  - stable flow conditions during the period missing
  - heavy rainfall within the catchment during the period missing
  - other upstream or localised sediment input and/or disturbance events, e.g. engineering works, dam releases, recreation
- availability of supporting observations and other evidence such as:
  - verification readings
  - water sample results
  - ad hoc observations, and
  - photographs and/or video.

2 Recommended Methods

The following methods are candidates for infilling gaps in turbidity records:

- inserting one or more of:
  - at-site backup turbidity data
  - values derived from at-site secondary turbidity data
  - water sample results collected with the purpose of infilling missing periods such as anticipated over-ranging
  - other at-site ad-hoc and manual observations, including verification readings and water sample results collected for surrogate calibration purposes
- synthesising a record.

Synthetic infill can be created using one or more of the following methods:

- manual entry of intuitive estimates for short periods in stable conditions
- mathematical calculation or copying from a reference trace to infill a period known to be in recession
- generating a record from a relationship between turbidity and discharge.

2.1 Infilling with backup turbidity data

Backup turbidity data must be verified as for the primary record for the period it is required, including assessment for over-ranging and/or sensor saturation, or sensor exposure, that would preclude its use.

Local effects and any differences in instrument range and resolution make it unlikely the two records will directly overlap. Small time corrections may be required to eliminate any steps due to timing issues at the junction of the primary and infill backup series.

2.2 Infilling using secondary turbidity data

Secondary turbidity data may be collected at site from a different turbidity sensor or a suspended sediment sensor.

Note: Suspended sediment sensors usually also measure light transmission or scattering but their output is calibrated directly to suspended sediment concentration.

Using a recent period of overlapping primary and secondary data covering as much of the anticipated range of the missing primary turbidity data as possible:

- derive a relationship between the primary and secondary data
- fit one or more functions to the relationship

Note: When fitting functions be mindful of issues of over-ranging, sensor saturation or exposure, and interference.

Note: Locally weighted scatterplot smoothing techniques that fit a continuously varying function over the turbidity range are preferred. Simple regression techniques may be used with care to ensure regression equations are appropriate over the full range of data to which they will be applied, for example, so as to not produce negative turbidity values. This may require the relationship to be partitioned by time and/or range of values.

- apply the function(s) to transform secondary data for the period of missing primary data
- insert the transformed data into the primary record
- make minor adjustments if needed at the junction of the primary and infill series to eliminate any steps between them.

2.3 Infilling using water samples collected for this purpose

Samples may be collected manually or by auto-sampler.

If collected at adequate temporal resolution, results of laboratory analysis of the samples (using the same measurement protocol and reported in the same measurement units as the primary data) may be inserted directly into the primary record and the interpolation engine left to create the continuous record.

If there are insufficient samples to ensure adequate form of the data, i.e. resolution and definition of turbidity peaks and recessions is poor, the sample results should be treated as ad-hoc observations (see Section 2.4 of this Appendix E.1).

If the measurement protocol and units are different the samples must be treated as secondary data (see Section 2.2 of this Appendix E.1).

2.4 Infilling with ad-hoc and manual observations

If a logger and/or sensor is disconnected for a period during a site visit, manual observations should be collected that can be inserted directly into the record to avoid missing data. Most often these will be readings using a handheld meter, but they may be results from laboratory analysis of samples taken at the time. In either case their uncertainty should be noted in a filed comment and their quality appropriately quality coded by following the schema.

Verification readings, and water samples intended for calibration of the conversion relation when turbidity is measured as a surrogate, may also be used to assist with infilling a gap. These observations can and should be incorporated as one or more points through which any synthetic infill must pass.

If the turbidity record is intended only as a surrogate, infill any gaps directly in the target record once generated (see Section E 3.11).

2.5 Infilling by manual entry

Unless a more sophisticated method is readily to hand, often the most efficient way to fill a short gap (see Section E 3.11) in a turbidity record is to intuitively 'draw it by hand', i.e. manually insert values to complete a straightforward rise or recession curve. A straight line should only be used for brief periods.

2.6 Infilling a recession or baseline

These methods can be used if a longer gap (see Section E 3.11) occurs over a period of expected declining or baseline turbidity where flow is known to be in recession, upstream turbidity is also declining or at baseline respectively, no rainfall has occurred in the vicinity during the period, and local sediment disturbance is unlikely.

Baseline values may be extended forward to infill the gap.

For recessions:

- it may be sufficient to copy the recession of an upstream turbidity station, or a previous recession at the same site, or
- a recession can be estimated by connecting the adjacent periods of good turbidity record with a straight line or smooth curve on a semi-logarithmic plot, or
- the recession may be estimated from the discharge series using a suitable relationship (see Section 2.8 of this Appendix E.1).

2.7 Infilling by regression analysis

The method is described in Appendix 2 to the main document.

Because of the variability of turbidity over time and between sites, regression between turbidity records from different sites shall not be used.

Regression between discharge and turbidity at the same site is more acceptable but because of turbidity variability between individual events, other than for filling a recession (see Section 2.6 of this Appendix E.1), the method described in Section 2.8 of this Appendix E.1 is preferred.

Regression between at-site turbidity and suspended sediment concentration is an acceptable method of obtaining the relationship needed to infill using secondary data (see Section 2.2 of this Appendix E.1).

Do not force the regression through zero. If zero turbidity is predicted, its significance and likelihood must be assessed. Regression analysis that results in periods of predicted negative turbidity or implausible zero turbidity should be discarded.

Ensure the summary statistics from the regression are documented in the associated comment, including period used for analysis, interval and type of the regressed data, sample size, equation(s) used to generate the infill, and the regression coefficient (R^2).

2.8 Infilling using relationships with discharge

2.8.1 Characteristics of turbidity–discharge relationships

Relationships between turbidity and discharge typically show substantial variability over time and from site to site. This variability stems largely from the dependence of turbidity on the concentration and characteristics (mainly grain size) of suspended material, which can vary, for any given discharge:

- within high-flow events
- between events
- seasonally
- over multi-year periods, because of legacy effects of large catchment-disturbing events (e.g. rainstorms, landslips, earthquakes, change of land cover and/or land use), and

- from catchment to catchment.

Although suspended sediment is generally understood to be preferentially carried on the rising limb of a discharge hydrograph, the timing of peak turbidity typical for a site may be before, with, or after the peak discharge (see Figure E 10).

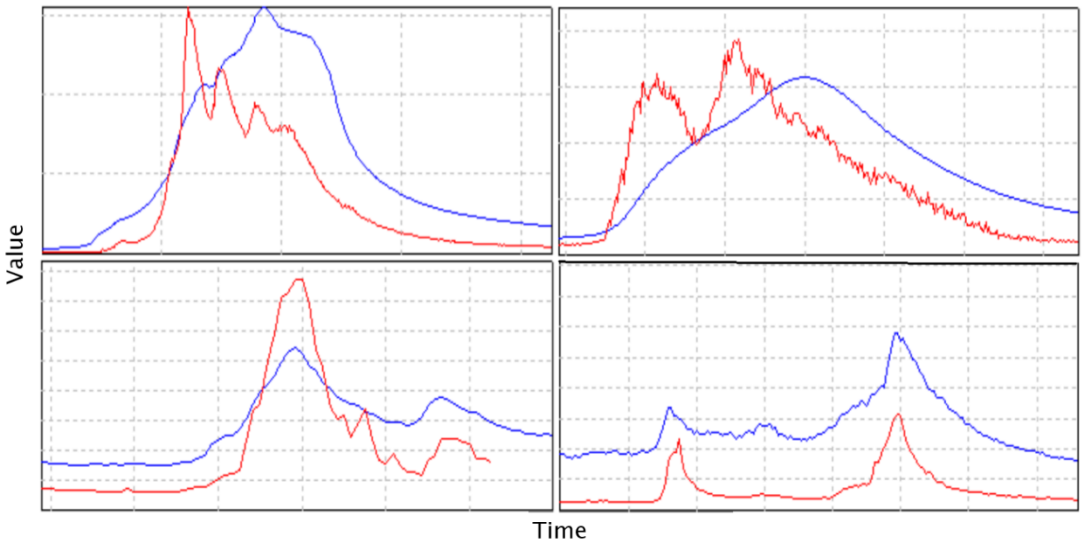


Figure E 10 - Examples of the relative timing of peak discharge (blue) and peak turbidity (red) in three North Island rivers: a large catchment with disparate tributaries (top left), a medium-sized catchment with high loads of fine sediment (top right), and a smaller mountain catchment with rapid runoff and homogenous sediment (bottom).

Within-event variability can be relatively simple, affected only by some hysteresis between rise and fall, or complex, where, for example, there is staggered arrival and varying durations of different contributing inputs from different tributaries.

The turbidity–discharge relation may therefore have one or more of the following characteristics:

- simple bivariate, i.e. turbidity able to be adequately and uniquely predicted from only the at-site discharge
- stationary in time
- varies with the rate of change of discharge
- varies with suspended sediment composition, which may be source dependent, e.g. one or more specific tributaries, or bank versus bed erosion
- event-dependent hysteresis, i.e. the relation forms a loop that varies with each event
- varies seasonally, and/or
- changes over time.

2.8.2 Developing and applying turbidity-discharge functions

Any turbidity–discharge relation shall be developed using periods of reliable turbidity and discharge record.

The form of function(s) selected, and the method(s) used to apply them, must be consistent with the typical patterns of variability in the turbidity–discharge relationship at site (see above Section 2.8.1 of this Appendix E.1). Options include:

- regression equations (simple, linear, polynomial, or multiple) applied using transformations or lookup functions
- locally weighted scatterplot smoothing techniques that fit a continuously varying function over the turbidity range using lookup functions, or
- one or more rating curves, that may be linear or non-linear, simple, or looped, change over time, and be applied and managed by the time-series manager's rating engine.

If a relation is applied to other periods of missing turbidity data where corresponding discharge range is greater than that used to derive the relation, the synthetic turbidity record generated must remain within the sensor's calibrated range or be censored.

2.8.3 Infilling truncated events

When turbidity data are missing or have been discarded because the sensor over-ranged or saturated, generate synthetic infill from a looped turbidity–discharge relation as follows:

1. Plot processed turbidity versus discharge, linking the data points in their time sequence (see Figure E 11).

2. Identify where the loop is incomplete or truncated beyond the maximum recorded turbidity, and/or is affected by saturation (i.e. the peak is inverted) (see Figure E 11).

3. Extend the two ends of the reliable data until the extensions intersect to complete and close the loop (see Figure E 11). There must be enough reliable adjacent data for the extensions to converge. If convergence within a plausible range of predicted turbidity values is not possible another infilling method must be used, or the period remain as a gap.

4. Read values from the plot to obtain two turbidity–discharge functions, one each for the missing portions of the rising and falling limbs of the turbidity event (see Figure E 11).

5. Apply the functions to discharge values as applicable to complete the record of the turbidity event (see Figure E 12).

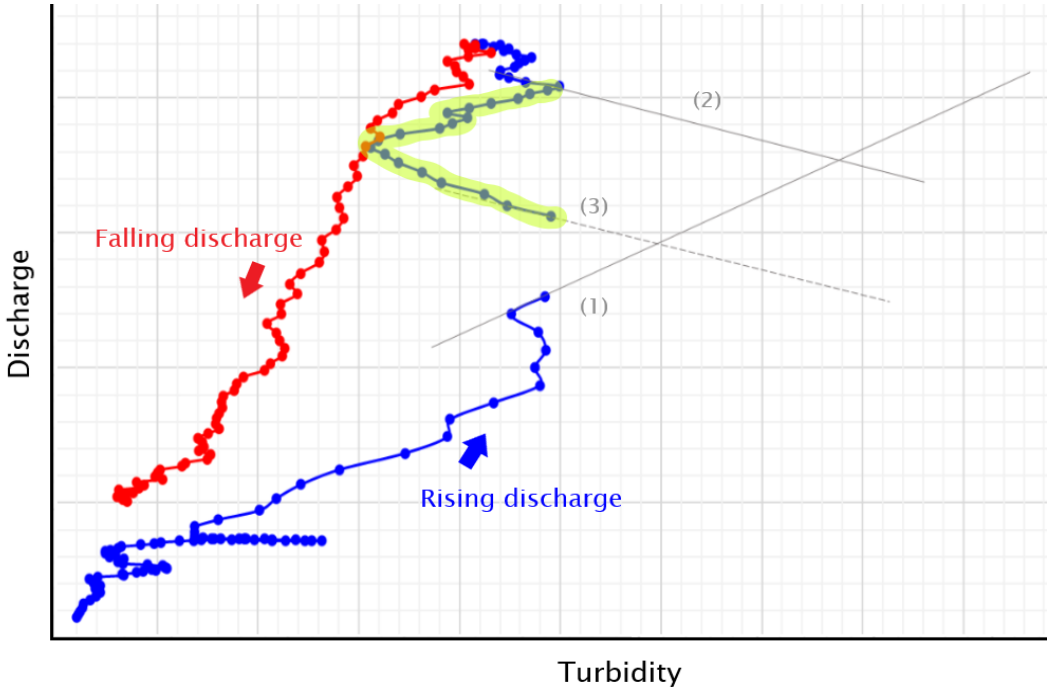


Figure E 11 – An example of a turbidity–discharge event loop with a gap due to over-ranging and a possible saturation inversion (highlighted). If saturation is assumed, extensions (1) and (2) extrapolate and close the loop. If the sensor is believed to have over-ranged but not saturated, extensions (1) and (3) apply (see also Figure E 12).

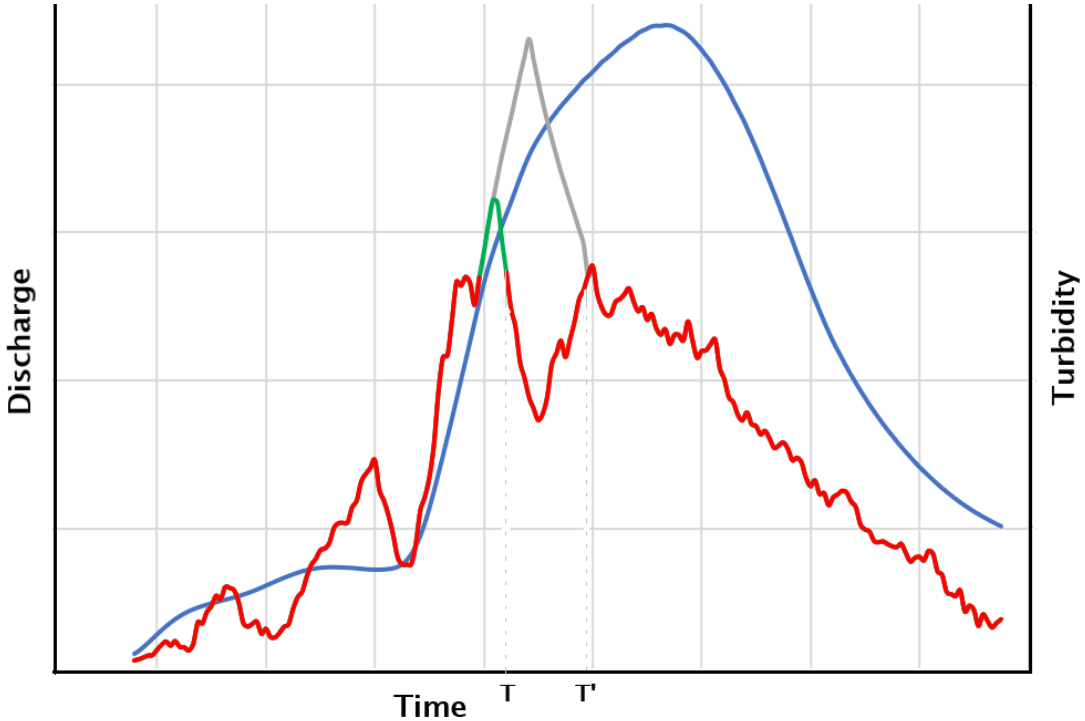


Figure E 12 - Example of two possibilities to infill a turbidity record using the extensions shown in Figure E 11. If sensor saturation is assumed between time T and T', equations for straight lines (1) and (2) in Figure E 11 produce the grey turbidity peak. If the dip in recorded turbidity (red line) is not due to saturation and is retained, equations for straight lines (1) and (3) in Figure E 11 produce the green turbidity peak.

Annex F Water Meter Data Processing

1 General Overview

1.1 Normative references

This Annex shall be read in conjunction with the following references:

- NEMS *Water Metering – Measurement, Processing and Archiving of Water Meter Data*
- New Zealand Water Measurement Code of Practice (Irrigation New Zealand, 2018)

Where reference is made from this Annex to specific sections of the above NEMS document, the title is abbreviated and version stated, i.e. "NEMS *Water Metering* v3.1.0". Where requirements and/or procedure in this Annex duplicate and possibly conflict, this Annex shall prevail.

Reference to specific sections of the *New Zealand Water Measurement Code of Practice* (Irrigation New Zealand, 2018) ('the COP'), an industry best practice guide to meeting requirements of the Resource Management (Measurement and Reporting of Water Takes) Regulations 2010, is via NEMS *Water Metering (Measurement, Processing and Archiving of Water Meter Data)*.

The COP precedes the Resource Management (Measurement and Reporting of Water Takes) Amendment Regulations 2020, implementation of which is staged from September 2022. The Amendment Regulations increase the required frequency of data recording and reporting but otherwise do not affect data processing procedure.

1.2 Scope of this annex

While NEMS *Water Metering (Measurement, Processing and Archiving of Water Meter Data)* has a current focus on near real-time data, the processing guidance contained in this Annex is applicable to any continuous time series of water take measured using in-situ water meters in full pipes and managed in electronic form as value in interval data (see Section 1.1).

The data may be collected and logged pulse by pulse (i.e. 'on event' of a known volume, also known as 'heartbeat'), or as incremental total volume in fixed regular intervals of time, and transmitted:

- via telemetry, pulse by pulse in real time, or pushed or pulled in batches at some regular polling interval in near real-time
- by upload to servers using, for example, FTP or cloud services or webpages, at intervals ranging from near real-time to annually that satisfy information needs and consent and regulatory requirements

- by import from CSV, XML or WML2 files (or similar data exchange format as desired by the agency), submitted daily, weekly, seasonally, or annually according to consent and regulatory requirements, or
- by transfer or import from a field device when the data logger has been manually downloaded during a service visit.

1.3 Effect of data type

The data may be captured as a flow rate or by counting pulses generated when a known fixed volume has passed through the meter. The data are required to be stored as a volume in the interval, achieved by integrating flow rates or totalling pulses.

The intervals may be of fixed duration with regular timestep or variable with irregular timesteps, including pulse by pulse timestamped as they occur, referred to as 'heart' or 'on-event' data logging.

Values may be volume in preceding interval or cumulative volume with time. Some devices, e.g. Harvest units, log cumulative volume by counting the pulses themselves rather than replicating the meter totaliser display, i.e. differences between successive stored values should match the simultaneous change in meter totaliser readings but the numbers logged will not necessarily be the same as those displayed by the meter totaliser.

The data in all cases are incremental with interpolation. Each value stored represents accumulation at a constant rate in the interval between adjacent timestamps that can be apportioned to any part-interval between the timestamps.

Note: Discrete totals are not considered suitable for water meter data because requesting a total for a period between adjacent data elements will return a value of zero.

For volume in preceding interval data, each timestamp also sets the start of the next value's accumulation. Water take is considered to have ceased when a zero value is encountered in the record. The period of no take is the time between the immediately preceding timestamp and the timestamp of the zero value.

Some time-series managers can store water meter data as cumulative totals and resolve the data to volume in the interval without explicit manual transformation, e.g. Hilltop data type 'Meter Reading'. With this data type, a period of no take is indicated by successive data elements of the same value.

'Heart' and 'on-event' systems only log when a pulse or change of state has occurred. When an interpolating incremental data type is used for this data, zero values must be inserted into the record to define periods of no take. Thus, zero values generated by the logger and stored for the purpose of confirming the site is operative alter interpretation of the data. Logging a different variable, e.g. battery voltage, or generating status values into a separate data storage area avoids this problem.

Hilltop Software provides a hybrid data type, 'Thirty minute Rainfall', for water meter 'event' data whereby, instead of storing zero values in the record, the software inserts a

zero when reading the stored data if there is a period of more than thirty minutes between timestamps. In other words, zero take is assumed between the timestamp of the previous stored value and thirty minutes prior to the current value, and the apparent rate of take derived from the current value increases.

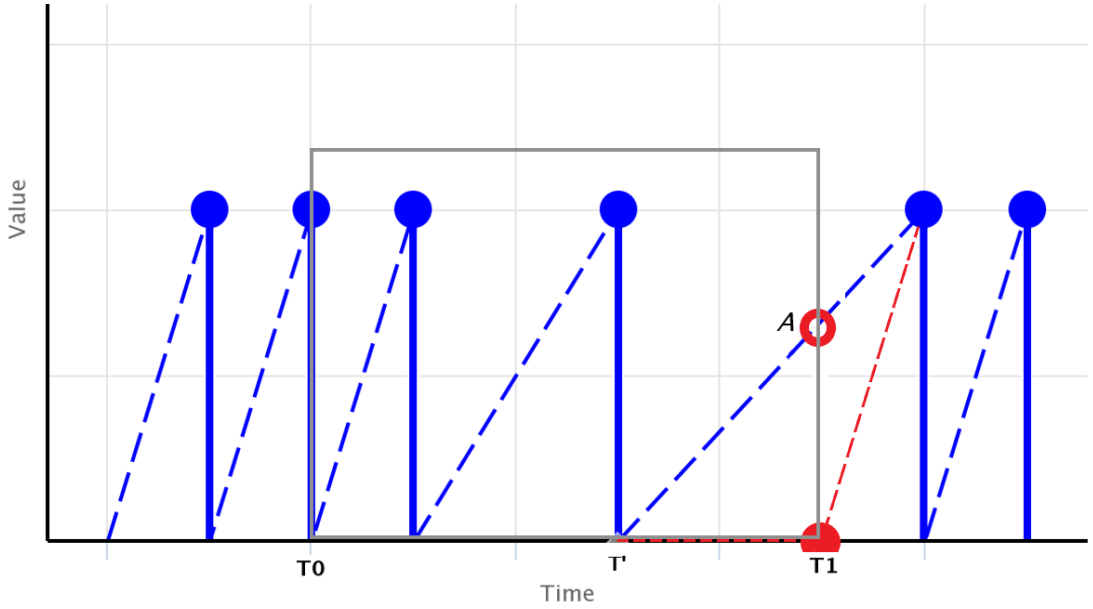


Figure F 1 – An example of how inserting zeros into a record of 'on-event' ('heart') pulses, stored as an interpolating incremental data type, alters interpretation of the data. If a zero value is inserted at T1 the total volume in interval T0 to T1 (grey box) is two pulses, whereas without the inserted zero value the total is two pulses plus the interpolated value A (the pro-rated portion of the next pulse assuming a constant rate from T' (blue dashed line)). If the volume between T' and T1 was queried, without a zero inserted at T1 the value returned is A, but if a zero value is inserted at T1 the value returned is zero.

It is critical to accuracy and interpretation of water use data that capture method and data type used to store the data are understood and correctly matched. Both must be comprehensively described in the time-series metadata.

2 Quality Control

2.1 Additional metadata required

General requirements for metadata are set out in Section 6.1. The following additional metadata, as applicable to the site and deployment, are required to be available when verifying water meter data:

- meter details:
  - the unique meter identifier used by the consenting agency to associate the meter with its corresponding consent and location of abstraction, and with the site name or number under which the data and metadata are stored if different from this identifier

Note: Over the lifetime of a consent a meter identifier may have several meter serial numbers associated with it as all or parts of physical meters are replaced.

  - meter type, model, manufacturer, and serial number(s) (see Section 1.4 of NEMS *Water Metering* v3.1.0 (refers to Section B2.1.5 of the COP))
  - the instrumentation standard and accuracy class; for example, OIML R49-1 class 2 (see Section 1.2 of NEMS *Water Metering* v3.1.0 (refers to Sections B1.1.2, B2.1.1 and B2.2.1 of the COP))
  - units, resolution, and display range of meter totaliser (see Section 1.3 of NEMS *Water Metering* v3.1.0 (refers to Sections B2.1.2, B2.1.4 (both), and B2.1.6 of the COP))
  - form of output to data logger, e.g. flow rate or pulse, including details of any signal conversion applied (see Section 1.2 of NEMS *Water Metering* v3.1.0 (refers to Sections B1.1.2, B2.1.1 and B2.2.1 of the COP))
  - date, laboratory, and identifier for the wet lab certification (see Section 1.2 of NEMS *Water Metering* v3.1.0 (refers to Sections B1.1.2, B2.1.1 and B2.2.1 of the COP))
  - date of installation and name of installer (see Section 3.4.3 of NEMS *Water Metering* v3.1.0 (refers to Section B2.3.4, B2.1.1 and B2.2.1 of the COP))
  - date and time, verifier, method, and result of each verification (see Section 4.1 of NEMS *Water Metering* v3.1.0 (refers to Section B2.4 of the COP)), and
  - date, time, and reason for any change of, or to, the meter (see Section 3.4.11 of NEMS *Water Metering* v3.1.0 (refers to Section B2.3.10 of the COP) and Sections B2.1.8 and B2.1.9 of the COP)

- relevant regulatory and planning context:
  - type of take, e.g. surface or groundwater
  - use type, e.g. crop irrigation, public water supply, snow making
  - consent number, decision, and conditions
  - service agreements with third party providers

    Note: Third party providers are intermediaries between the consent holder and consenting authority that may design, install and/or verify abstraction and/or metering systems and/or collect and/or host water meter and/or flow measurement data.

  - regional rules, e.g. minimum flow restrictions
  - water allocation designation and/or water management zone and/or plan

  - whether seasonal monitoring is permitted, i.e. the data logger is switched off in the off-season
  - any provisions for temporary exemptions from abstraction controls and records of those exemptions.
- deployment details:
  - installation report, including as-built diagram and photographs, (see Section 3.4.9 of NEMS *Water Metering* v3.1.0 (refers to Section B2.3.11 of the COP))
  - applicable flow rates (i.e. Q1, Q2, Q3 and Q4 as described in the NEMS *Glossary*) and whether variable rate of take is possible
  - measurement type, e.g. flow, volume, pulse count, or meter reading
  - units, resolution, recording interval, and time zone of the logged data
  - inspection and maintenance records (see Section 3.4.11 of NEMS *Water Metering* v3.1.0 (refers to Section B2.3.10 of the COP))
  - meter location by GPS, and with respect to point of abstraction (see Section 2.1 of NEMS *Water Metering* v3.1.0 (refers to Sections B1.2.1 and B2.3.6 of the COP))
  - details of other takes and/or meters on the same distribution network (see Section 2.1 of NEMS *Water Metering* v3.1.0 (refers to Sections B1.2.1 and B2.3.6 of the COP))
  - description of any issues potentially affecting accuracy of recording, e.g. water quality, nearby electrical equipment (see Section 3.4.1, of NEMS *Water Metering* v3.1.0 and Sections B2.2, B2.3.5, B2.3.12, D1.3.1, and Appendices of the COP)
  - date, time, and reason for any change to the installation, including location of the meter or configuration of pipework (see Section 3.4.11 of NEMS *Water Metering* v3.1.0 (refers to Section B2.3.10 of the COP) and Sections B2.1.8 and B2.1.9 of the COP)
  - details of any backup, secondary and/or supplementary data logged, e.g. site status flags, tamper flag, site power supply, portable pump GPS location, rainfall, soil moisture, bore water level, pump run hours, and/or pump electricity records
- verification of data collection:
  - method(s) used for data verification readings, including who reads the totaliser at what frequency and how and where the readings are provided and stored

- all records of inspections as detailed in Section 4.2.2 of NEMS *Water Metering* v3.1.0 (refers to Section B2.4.7 of the COP)
- all results of performance tests described in Section 4.2.3 of NEMS *Water Metering* v3.1.0.

These metadata must be verified and permanently archived with all other metadata as described in Section 6.

2.2 Plots and comparisons

2.2.1 Fixed interval totals

Use 15-minute volumes, or volumes at the recording interval if fixed and greater than 15 minutes, to check for anomalies such as:

- spuriously high values indicative of flow instability or interference (see Section F 3.3)
- inconsistent patterns of use indicative of possible unmarked gaps in the data (see Section F 3.8)
- out of range values, including negative values (see Section F 3.3).

Note: If the time-series manager censors bar plots to positive increments use a different method to check for negative values.

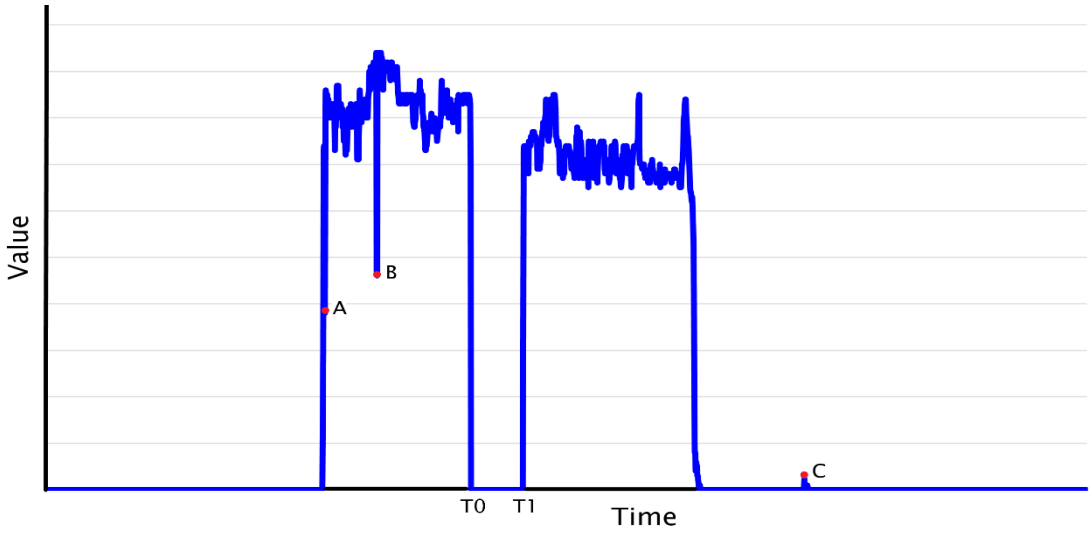


Figure F 2 – An example plot of hourly values in a 3-month period showing values at A and B that are half their adjacent values (data elements are missing and because of the incremental interpolating data type the next logged value is averaged over a two-hour interval), values of zero between T0 and T1 that may be missing pulses, and very small values at C that may be noise.

Use interval(s) consistent with consented limits, e.g. hourly, daily and/or weekly maximum take, to review periods of apparent non-compliance for possible data recording anomalies.

2.2.2 Cumulative totals

Plots of cumulative totals allow rapid visual assessment of anomalous patterns and timing of apparent use and/or trends that require further investigation, especially if pump cycles are frequent and/or irregular (see Figure F 3).

A multi-year plot, for example over the duration of the consent, annotated with the date and time of each verification of the installation and/or any change in, or of, the meter or its installation, assists with identifying:

- any stationarity of record issues arising from meter and/or installation changes
- whether drift, if any, was gradual over the period between verifications
- when drift became significant if it was not gradual for the entire period.

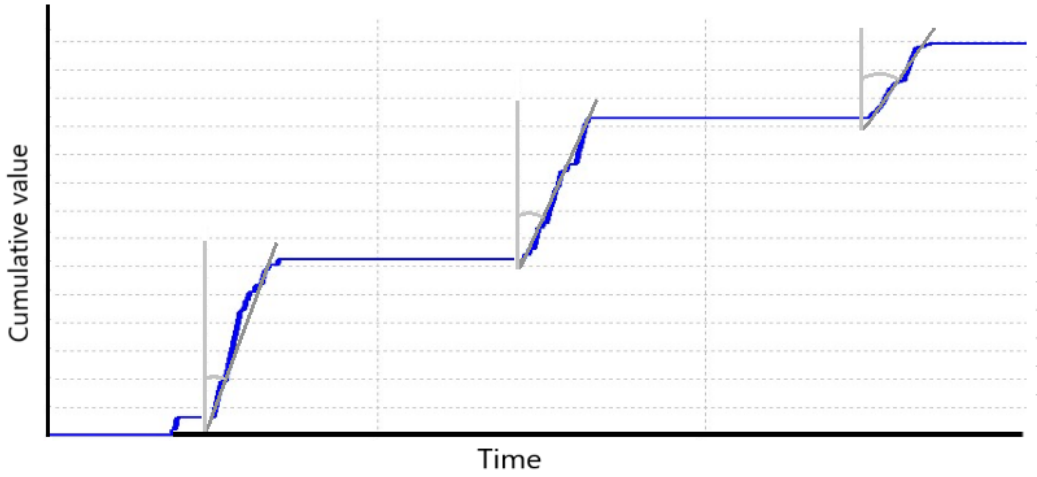


Figure F 3 – An example cumulative plot of three water years showing an apparent 'false start' to the first season and declining water use. Slope of the trace represents rate of use. Average rate per season (grey sloping lines) declines with volume each year and should be investigated and confirmed to not be due to deteriorating metering equipment.

2.2.3 Comparisons

- Use comparisons to:
  - cross-check the data for anomalies, and
  - confirm editing and adjustments have been properly carried out.
- Use fixed interval and cumulative totals to check for anomalies. Compare the logged data with:
  - any backup, secondary or supplementary data from the same site (see Section F 2.1) that may confirm a common data quality issue, e.g. power supply or data logger failure, or identify issues of timing, scale, or tampering
  - a reliable and representative record from another site (see Section F 2.2.4).

- Use a common totalling interval that is at least as long as the longest recording interval of the data to be plotted.

  For example, if comparing an 'on-event' water use record with standard daily rainfall, use a totalling interval of 24 hours from 9 a.m. or the daily rainfall data will be apportioned and thus misrepresented.

- If using a backup record for comparison, there should be no difference in scale or event timing other than due to resolution and/or recording interval differences.
- When comparing with other sites, proportions, patterns, and timing of use should be consistent with how the various elements of the abstraction and metering configuration interact.
- Compare the entire water year (to date if not yet ended) with previous years and investigate any magnitude, timing, and patterns of use inconsistent with earlier record.
- Use cumulative plots and/or period totals to confirm editing and adjustments. Compare the data before and after:
  - editing applied, and/or
  - infill of missing record (Figures F 4 and F 5), and/or
  - rescaling of the data applied to correct for configuration (set-up) errors (Figure F 5).

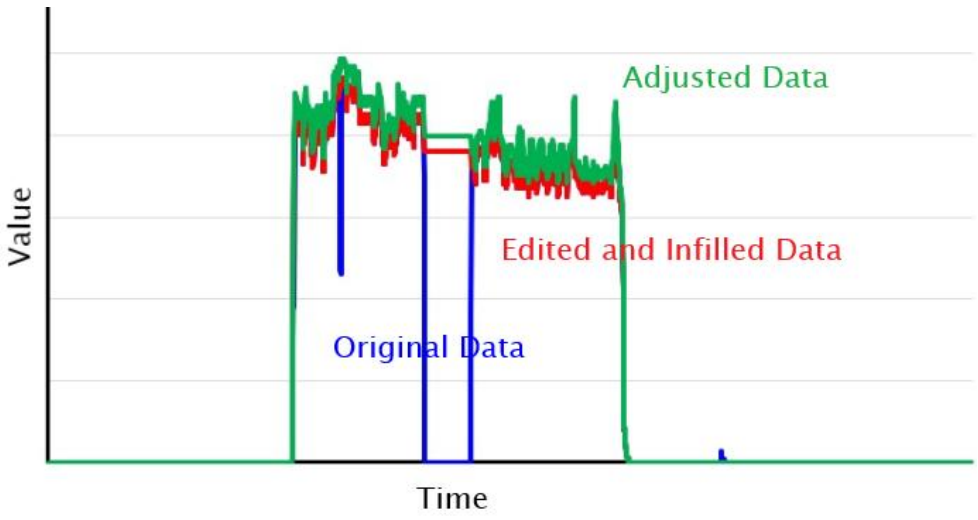


Figure F 4 – An example of a comparison plot of hourly volumes before and after removal of off-season noise and infilling of missing record, followed by a scaling adjustment that compensates for the meter under-reading as revealed by later verification.

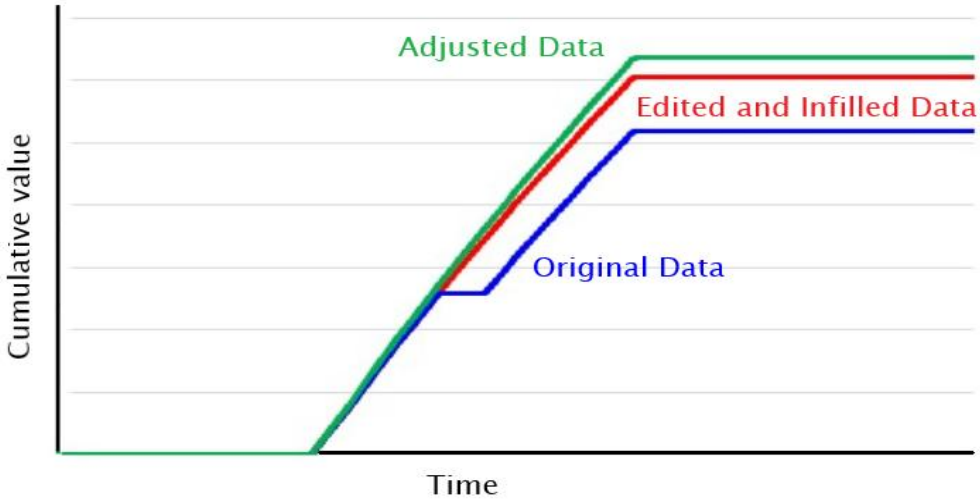


Figure F 5 – The cumulative version of Figure F 4, showing cumulative volume before and after removal of off-season noise and infilling of missing data, followed by a scaling adjustment that compensates for the meter under-reading revealed by later verification.

2.2.4 Between-station comparisons

- Criteria for selecting a suitable water use comparison site are similar to those for selecting a suitable infill record donor site (see Appendix F.1 Section 2.5). In any case, the comparison site(s) for any assessment of recorded volumes must be part of the same metered distribution network.
- Use between-station comparisons to:
  - check for transient problems that may occur and resolve between site visits, such as interference
  - identify when a problem detected during a site visit arose, e.g. loss of pulses to the data logger
  - investigate problems that develop gradually and may not be apparent from a single inspection, such as deterioration of the meter or leaks.
- Initial identification of timing issues, e.g. commencement of a seasonal take or periods of restricted take, may be assisted by comparing with other takes in the vicinity, or local rainfall, soil moisture, groundwater levels and/or source stream flows but these comparisons cannot be used to assess recorded volumes.

2.2.5 Portable pumps

- Use mapping services to check that GPS location data collected from portable pumps are feasible (e.g. aligns with consented abstraction locations, does not plot in the ocean if supplying fresh water).
- If a pump has been used in multiple locations, confirm:
  - water use data associated with each location has been filed to the correct site, and
  - no water use data have been lost, and

- all water use recorded is associated with a recognised and authorised abstraction location.

2.3 Verification

2.3.1 Verification of installation

Requirements are set out in NEMS *Water Metering* v3.1.0 Section 4.1 (refers to Sections B1.1.2 and B2.4 of the COP).

Verification of the installation must be carried out by a suitably qualified accredited person to confirm the metering system meets the accuracy required by the Regulations:

- on commissioning, and
- after a change to or of the meter and/or installation, and
- at intervals or on events as required by the conditions of consent, or
- otherwise at no more than five-yearly intervals.

For quality coding purposes, verification of the installation is assessed in terms of currency, i.e. if the last verification has 'expired' because more than five years has elapsed (or less if consent requires), or the installation has been altered, all data recorded between expiry date and the next installation verification must be quality coded QC 0 (non verified).

However, if an overdue installation verification is completed no later than twelve months after expiry and before the next irrigation season, and the meter is found compliant, quality code of the QC 0 data may then be upgraded as if verification had been completed within the required time.

When determining the result of an installation verification, uncertainty of the method is taken into account (see Section B2.4.10 of the COP).

For example: If uncertainty of the independent reference reading is ±2% (accounting for all error sources) and the installed service meter total differs from this reference by 3% then the meter complies with the ±5% accuracy requirement of the Regulations. If the service meter total differs by 4% compliance is uncertain; it must differ from the reference reading by more than ±7% (2% + 5%) to be assessed as non-compliant.

Results of each verification, including assessed difference and uncertainty regardless of compliance, must be summarised in an Operational Comment (see Sections 6.2.4.5, F 3.1.1, and F 5.2.3) filed at the time of each verification.

Data from a compliant meter can be quality coded QC 600 provided all other QC 600 criteria are met.

Independent reference readings obtained during installation verifications must be reported and considered with their uncertainty in any time-series data quality control checks, e.g. control charts, tabulations, and deviation tests (see Section F 2.4).

Logged data and totaliser readings from the service meter, including those obtained for verification of data collection (see Section F 2.3.2), may under limited circumstances be retrospectively rescaled following an installation verification.

- If the difference between service meter and independent reference readings is within the uncertainty of the reference reading, there is no justification to adjust values from the service meter.
- If the service meter is verified compliant with the accuracy requirement of the Regulations, data recorded from it are not to be adjusted.
- If the service meter is not verified compliant with the accuracy requirement of the Regulations (i.e. includes non-compliant and inconclusive results), the data from it may be retrospectively rescaled provided the discrepancy is traced to a configuration error at set-up, for example, an incorrect multiplier.
  - Quality code rescaled data as QC 400 (significant modification).
  - Quality code data not verified compliant, but not rescaled, as QC 200 (no quality).

2.3.2 Verification of data collection

Requirements are set out in NEMS *Water Metering* v3.1.0 Section 4.2 (refers to Section B2.4.7 of the COP).

Service meter totaliser readings are periodically compared with the cumulative total recorded in the corresponding period(s) between totaliser readings. Provided the installation verification is current, if there is no more than 1% difference between the totaliser and logger totals the corresponding record may be quality coded at least QC 500.

Note: Totaliser readings are the difference between current and previous values read from the meter's display. Pulse count data logging is usually independent of the meter's display such that if cumulative totals are logged, values stored will not be those displayed by the meter, but differences calculated over the same period of time should match.

To achieve QC 600 all other requirements of the site inspection (see Section 4.2.2 of NEMS *Water Metering* v3.1.0 (refers to Section B2.4.7 of the COP)) must also be met, which would normally preclude record checked against totaliser readings supplied by the consent holder from achieving QC 600.

While abstraction is occurring the meter display may be changing rapidly. The time of the reading becomes a critical factor in determining agreement with the volume logged. Ideally the totaliser should be read when the abstraction is not operating, but if not, the logger time must also be checked and clocks synchronised before the totaliser is read or the reading may be deemed unreliable for data quality control purposes.

Off-season totaliser readings may be regarded as reliable with only the date supplied if there is separate confirmation that there has been no water use in that day. These

readings may then be filed with a nominal time of 12:00:00 NZST but must be accompanied by an Operational Comment stating that the time of the reading is nominal.

In terms of timeliness, a water meter record cannot be fully verified without a totaliser reading at the start and end of the record period. For seasonal takes this would ideally be at the start and end of the abstraction season; however, a mid-season reading is also desirable to catch data quality issues that would otherwise impact an entire water year's data.

QC 600 data requires a totaliser reading in each water year and with no more than 12 months between readings. Until a reliable 'period end' totaliser reading is obtained, recorded data can only be assigned QC 0 (non verified), or QC 100 if a gap. Once the necessary totaliser reading has been obtained the quality code can be reassessed as follows:

- QC 500 applies, if:
  - QC 600 cannot be achieved, and
  - the logged total is no more than 1% different from the corresponding volume recorded by the totaliser, or
  - the logged total is more than 1% different from the corresponding volume recorded by the totaliser but the pulse output has been tested and confirmed to be operating correctly and one or more gaps are identified and marked that (are assumed to) account for any shortfall beyond the 1% tolerance.
- Otherwise, QC 400 applies, provided the record can still be regarded as representative of the actual water use, albeit somewhat compromised.

Recorded data that are not representative must be deleted and treated as a gap. Data are not representative if they:

- are demonstrably false (e.g. implies negative water use, or exceeds maximum possible pump rate), or
- have under-registered by more than 5% compared with corresponding reliable totaliser volume(s) and the difference cannot be attributed to known or assumed gaps in the data, or
- have over-registered by more than 5% compared with corresponding reliable totaliser volume(s) and the difference cannot be attributed to wrong recording scale and/or units.

2.3.3 Pulse output tests

Pulse output may be observed and assessed for signal strength and reliability using an oscilloscope with the abstraction system running at its usual flow rate. This may be referred to as a 'rate test' and is intended to ensure that the meter's electronic output corresponds with the recording device (see Sections 4.2.3 and 3.4.8 of NEMS *Water Metering* v3.1.0 (refers to Section B2.3.9 of the COP)).

Some meters offer a simulation mode that allows test pulses to be generated.

- These will appear on the data logger but not on the totaliser and must be accounted for when assessing verification differences (see Sections F 2.3.1 and F 2.3.2) and ultimately removed from the record.
- Total the recorded data before and after removing the test pulses and reconcile the totals with the number of test pulses intended to be removed. Quality code is unchanged by the editing of test pulses, but a Data Processing Comment is required, and the reconciliation must be stored permanently with the data processing records.

2.3.4 Status checks

If abstraction is periodic, systems that record pulse by pulse (i.e. 'on event' or 'heartbeat' data) are often set up to log and/or send a zero value and timestamp at regular intervals independent of the water meter, to indicate the site is still operating.

Because the data are stored as an interpolating data type, these extra data elements alter the apparent start time and rate of accumulation of the next increment of volume logged, influencing how the record is interpreted, and may alter reported rates of water use (see Section F 1.3). The extra data elements should be filtered from the record, but this may not be practical unless they are stored at the same time each day.

A Data Comment must be filed that describes the frequency of any status data generated, its effect with respect to data type, and whether the status data elements remain in the processed record or have been filtered out. If filtered, reconcile the data before and after to ensure nothing else has been removed. The total volume recorded in the period should be unchanged. Filtering to remove status data elements has no effect on quality code.

2.4 Deviation tests

Track data collection verification results using a control chart (Figure F 6) or other suitable multi-period collation, analysis, and record of deviations.

- Test pulses must be deducted from the logger total before calculating deviation from the totaliser reading (see Section F 2.3.3).
- Deviations calculated from totaliser readings deemed unreliable should be included but labelled or tagged as 'unreliable'.
- If using a chart, plot outliers along the top or bottom of the chart rather than rescaling the chart to incorporate them to avoid loss of plot resolution.

Intervals between installation verifications are too long to be useful on their own for data processing decisions, however:

- all installation verification reports (see Section B2.4.8 of the COP) must be permanently stored in the site file or station history

- an Operational Comment must be filed at the time of each installation verification that includes sufficient detail to quantify any bias in the data (see Section F 3.1.1)
- a summary of results should be collated and maintained for easy reference, tracking and scheduling (see Sections F 2.3.1, F 2.4.1, and Table F 1), and
- outcomes can be incorporated in sequence with the data collection verifications to aid data processing decisions (Figure F 6).

Use a deviation with time test to investigate time-dependent issues such as leakage or gradual deterioration of metering equipment.

A scatterplot of totaliser readings versus corresponding logger totals (net of test pulses) can be useful to identify data totalling errors, totaliser reading errors, and scaling issues arising from a mismatch of measurement units.

Tests may be configured to update automatically with new data from the field.

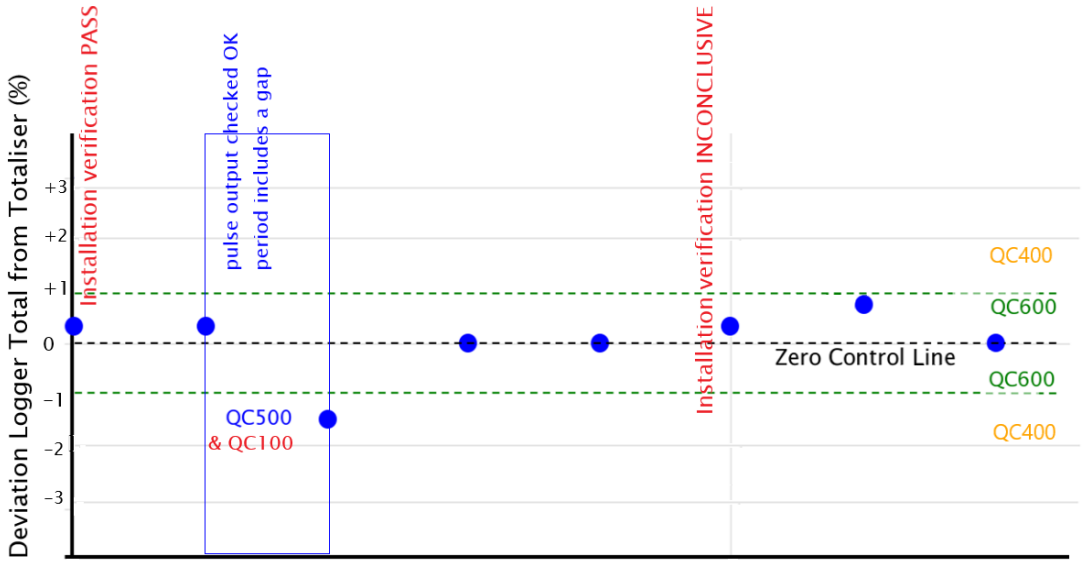


Figure F 6 – An example of a control chart used to track verification status and quality coding decisions for water meter data.

2.4.1 Interpretation of installation verification results

Percent deviation of the service meter volume from the independent reference volume (i.e. $((meter - reference)/reference) \times 100$), plus the determined uncertainty of the reference measurement:

- must not exceed ± 5% for the meter to be compliant with the accuracy requirement of the Regulations, or
- must lie wholly outside ± 5% for the meter to be non-compliant with the accuracy requirement of the Regulations, and
- is inconclusive in terms of compliance if neither of the above apply because the extent of uncertainty traverses the accuracy threshold.

Refer to Section F 2.3.1, and Section B2.4.11 of the COP, for more explanation.

Table F 1 – Example of a Summary of Installation Verification Results.

Date	Meter	Volumes (m^3)		Diff.	Tolerance	Result	Verifier
	Serial #	Reference	Meter	%	%		
10.01.05	123	20.0 ± 1.2%	19.3	-3.5	-4.7 to -2.3	PASS	ABC Ltd
20.12.09	123	31.3 ± 1.5%	30.0	-4.1	-5.6 to -2.6	INCONCL.	ABC Ltd
08.12.14	123	25.3 ± 2.2%	23.4	-7.5	-9.7 to -5.3	FAIL	XYZ Inc.
15.12.14	4442	32.0 ± 2.0%	32.6	1.8	-0.2 to 3.8	PASS	XYZ Inc.
30.11.19	4442	27.5 ± 2.1%	28.4	3.3	1.2 to 5.4	INCONCL.	XYZ Inc.

3 Potential Errors and Recommended Editing

This section describes common problems specific to water meter data, and guides selection of an appropriate method for data repair, including what metadata are then required to be applied and filed.

3.1 Sources of errors

- Site factors (see Section 2 of NEMS *Water Metering* v3.1.0 (refers to Sections B1.2.1, B2.3.6 and B2.3.7 of the COP)).
- Instrument installation, physical condition, and function (e.g. pipe configuration, failure to generate and/or log a pulse, damage to or deterioration of the meter, restriction of the meter's moving parts, vibration, and power supply issues leading to poor or loss of recording) (see Section 3 of NEMS *Water Metering* v3.1.0 (refers to Section B2.3 of the COP)).
- Environmental conditions that adversely affect meter performance and/or recording (e.g. water quality, interference, poor hydraulic conditions, temperature extremes, and inundation) (see Section 3 of NEMS *Water Metering* v3.1.0 (refers to Section B2.3 of the COP)).
- Issues of calibration and performance identified by verification (see Section 4 of NEMS Water Metering v3.1.0 (refers to Section B2.4 of the COP)).
- Data transfer from providers and between systems (see Sections 5.1 and 5.2 of NEMS *Water Metering* v3.1.0 (refers to Sections D2.2, D2.3 and D2.4 of the COP)).

Issues with data capture are not always identifiable from a site visit alone. Some problems such as cavitation, electrical interference, or failure to generate a pulse may

be transient and occur and resolve between visits. Gradual deterioration of performance may not be apparent from a single visit. Interpretation of data plots and comparisons (see Section F 2.2) and deviation tests (see Section F 2.4) are necessary for these cases.

3.1.1 Systematic error

Because logged data are not routinely adjusted to the results of installation verifications (see Section F 2.3.1) and there can be a relatively long interval between those verifications, a small bias may persist in a water use record for a considerable period of time.

Quality code does not compensate for bias in the data and the quality code assigned is not exclusive to presence of bias. It is therefore essential that data users are made aware of potential bias in the data via adequate reference in Operational Comments to the results of all installation verifications and not only those that are compromised or identify significant calibration issues (see Sections 6.2.4.5, F 2.3.1, and F 5.2.3).

3.2 False calculated rate of take

When rate of take is calculated by dividing each stored volume increment by its preceding timestep false rates can result. Causes are:

- additional zero value data elements added to the record by sources unrelated to the meter, e.g. status checks (see Section F 2.3.4) and some time-series CSV imports
- additional pulses logged while meter testing under simulation mode (see Section F 2.3.3)
- fixed interval data logging too frequent with respect to the measurement resolution of metered volume
- no mechanism or algorithm to identify periods of no water use.

The issue is more one of how the data are collected, stored, and interpreted than errors in the data per se. Solutions are, as applicable:

- remove from the record any additional data elements (i.e. values and timestamps) arising from status or simulation mode meter checks or the importing of data (see Sections F 2.3.3 and F 2.3.4)
- select a fixed data logging interval that returns a rate close to the normal operating flow rate of the abstraction when divided into the volume increment
- aggregate pulse count data into a reasonable fixed interval before dividing by that interval to determine the apparent rate of take
- implement documented assumptions about the likely interval of accumulation of each pulse, e.g. Hilltop Software's 'Thirty minute Rainfall' data type (see Section F 1.3).

3.3 Spikes

Spikes in water meter data may be caused by:

- the sudden onset of flow ('first rush') and consequent acceleration of the meter, possibly with cavitation
- shockwaves ('water hammer') due to sudden flow variation, e.g. when a pump shuts off
- backflow causing dials to go backwards, logged as negative increments
- electronic transients and electrical interference from electric fences, overhead power lines, or other nearby electrical equipment
- a missing data element (next value is apportioned over two timesteps)
- pulse counters that have reset to zero on a fault, which may then trip a 'round the clock' algorithm in some software, e.g. Hilltop Software's Meter Reading data type, or result in a negative stored volume.

Treatment of spikes and outcome of that treatment depends on the combination of:

- cause of the spike
- whether increments of volume or accumulating volume are stored
- the software and data type used to store the values, and
- whether interpolation is allowed to apply.

If using a time-series manager and data type that does not count an incremental value if its interval is undefined, the simplest way to eliminate the influence of a spike is to insert a gap marker immediately prior to the spurious value, i.e. prevent interpolation from defining its interval.

Note: The spurious value is still present in the series, but it is not included in any plot or aggregated total because it is effectively nulled by not having an interval associated with it. The start of the next interval is defined by the timestamp of the spike, so the subsequent value is counted as normal.

Note: For Hilltop Software's Meter Reading data type, inserting this gap element (marker) also usefully stops the 'round the clock' algorithm from causing a spurious increment if a pulse count has reset to zero on a fault.

If the times-series manager and data type does count every value stored whether its interval is defined or not, the spurious data element (i.e. the value and its timestamp) must be deleted and the consequent gap marked.

Resulting gaps are then treated as missing data (see Section F 3.8).

Spike removal method and its consequent effect on the stored data must be understood. The wrong approach for the time series and data type may result in reliable values that

follow the spurious being ignored or spread across more than one recording interval leading to under-reporting of volumes and/or rates of water use.

If spiking is frequent, persistent, and affecting consecutive values, treatment as noise is necessary (see Section F 3.4)

Table F 2 – Guidance for resolving spikes in the data

Guidance for resolving spikes in the data		see Section(s)
Issue(s)	Spurious implausible values recorded.	F 3.3
Evidence	Value significantly different from adjacent values. Observable in a bar plot of the data at its recording interval, or at 15-minute intervals if logging 'on-event'. Confirmation by close inspection of values logged, and by field investigation and elimination of cause, if possible.	Fig. F 2 F 2.2.1 F 3.1 F 2 3.6
Solution(s)	Insert a gap marker immediately prior OR delete the spurious data element(s) and replace with a gap marker, depending on the time-series software and data type employed. Apply missing data processes to the resulting gaps. If spiking is frequent, persistent, and affecting consecutive values, treatment as noise is necessary.	F 3.3 4.11 4.16 F 3.8 F 3.4
Metadata	QC 100 for gaps and a Data Comment explaining reason for the gap. Revise these if the gap is subsequently infilled. Refer to missing data or noise treatment guidance as applicable. Comments may be aggregated if frequent and repetitive.	6.2.3 F 5.2.4 6.2.4.6 F 3.8 F 3.4

3.4 Noisy data

The most common causes of noisy water meter data are electrical interference, mechanical meter bounce, and deficient 'empty pipe' settings. All arise directly from issues at site, which should be investigated and addressed to eliminate the problem wherever possible.

Electrical interference and mechanical meter bounce (rapid multiple switch closures instead of a single clean pulse) cause over-registering. Occurrence can be detected in the data as:

- unexpected or unusually high rates of abstraction
- anomalies in the timing of abstraction.

Initial identification of the problem is therefore usually by way of consent non-compliance alerts, but cause should then be confirmed by:

- a pulse output test ('rate test'), and/or
- an installation verification with focus on possible causes of interference and over-registering.

Affected data must be assessed for representativeness. If not adequately representative of the actual volumes of water through the meter the affected period(s) must be deleted and treated as missing record (see Section F 3.8). Filtering or rescaling shall not be applied because the interference is unlikely to be either entirely random, or consistent and proportional in effect.

If not discarded the affected data must be quality coded QC 400 (representative but compromised). Data Comments must be filed to explain the reason(s) for the reduced quality code, why the affected data have not been discarded, and any limitations on use of the data.

Noise due to deficient 'empty pipe' settings adds apparent use to the record when the take is not operating. With portable pumps it may be due to wind acting on exposed pipes. The possibility of actual use must be investigated and discounted. Verified periods of no abstraction can be set to zero with quality code QC 500. Otherwise, assess and treat affected periods as for the other forms of interference described above.

Table F 3 – Guidance for resolving noisy data

Guidance for resolving noisy data		see Section(s)
Issue(s)	Pulse fluctuations compromise accurate determination of water use. Over-registering of volumes and rates.	F 3.4
Evidence	Timing and rate of abstraction anomalies. Apparent non-compliance with consent limits and/or off-season use. Field investigations, including pulse output tests and installation verification results. Problem resolves after cause is addressed.	F 3.4 F 2 3.6
Solution(s)	Assess representativeness of the data. Downgrade the quality code of compromised data. Discard periods not representative and mark as a gap. Set verified periods of no abstraction to zero. Apply missing data processes to the resulting gaps.	F 3.4 4.12 4.16 F 3.8
Metadata	QC 500 for verified no abstraction set to zero. QC 400 for compromised data. QC 100 for gaps. Data Comment(s) explaining reason(s) for downgraded quality codes or gap. Revise quality code and comments for gaps subsequently infilled. Refer to missing data guidance as applicable.	F 3.4 6.2.3 F 5.2.4 6.2.4.6 F 3.4 F 3.8

3.5 Loss of calibration

Loss of calibration may be due to:

- poor meter operating conditions, e.g. temperature variations, hydraulic disturbances, or lack of particles or particle size variations affecting Doppler instruments, that may be transient or persistent, or
- declining meter performance due to poor water quality, e.g. chemical properties or suspended sediment and grit causing wear, clogging, and/or corrosion.

Commissioning tests followed by installation verifications at intervals of no more than five years are intended to minimise these problems.

Quality code of the data depends on the outcome of these verifications (see Section F 2.3.1).

An Operational Comment that describes extent and cause of calibration loss must be filed for periods assessed as affected, which may be a more general statement for the site if all data are potentially affected.

Adjusting data to compensate for loss of calibration is not permitted.

Affected data must be assessed for representativeness. What constitutes representative in this context must be determined by the recording agency on a site-by-site basis. If not adequately representative of the actual volumes of water through the meter, affected period(s) should be removed from the record and treated as missing (see Section F 3.8).

Table F 4 – Guidance for data affected by loss of calibration

Guidance for data affected by loss of calibration		see Section(s)
Issue(s)	Inaccurate measurement of volumes and rates of abstraction.	F 3.5
Evidence	Results of commissioning tests and periodic verifications of the installation.	F 3.5 F 2.3.1
Solution(s)	Remove data that are not representative and mark as a gap. Apply missing data processes to the resulting gaps.	F 3.5 F 3.8
Metadata	Quality code as determined from results of verifications. Operational Comment(s) describing extent and cause. Revise quality code and comments for gaps subsequently infilled. Refer to missing data guidance as applicable.	F 3.5 F 2.3.1 6.2.3 F 5.2.3 6.2.4.5 F 3.8

3.6 Incorrect scaling

Incorrect scaling means volume increments stored are wrong by some factor. The problem may arise from:

- wrong measurement units, including a misplaced decimal point
- incorrect logger configuration, e.g. a wrong multiplier, or
- a mismatch between totaliser and pulse count increments.

The problem is detected by verifications and/or pulse output tests (see Section F 2.3) and may be identified by apparent non-compliance with consent limits if the error results in increments that are too large.

For affected data to be rescaled, cause must be traceable to an error during set-up from which the adjustment(s) needed are obtained by calculation. It may be necessary to reverse the applied configuration then apply the correct configuration.

Assign a quality code of QC 400 to rescaled data and explain the adjustment in a Transformation Comment.

Rescaled data must only be stored in the fully processed time series (see Section F 6).

Table F 5 – Guidance for resolving incorrect scaling

Guidance for resolving incorrect scaling		see Section(s)
Issue(s)	Scale of the stored data is wrong.	F 3.6
Evidence	Results of periodic verifications and/or pulse output tests. Apparent non-compliance with consent limits.	F 2.3
Solution(s)	In the fully processed series, apply linear transformations to change the data increments to their correct volume.	F 3.6 4.8 F 6
Metadata	QC 400 for rescaled data. Transformation Comment(s) explaining the adjustment(s).	F 3.6 F 2.3.1 6.2.3 F 5.2.6 6.2.4.8

3.7 Time faults

A time shift may be needed to obtain data in NZST or to correct for an incorrectly configured or defaulted logger (see Section 4.3).

If the time fault caused existing data to be overwritten or conflicting new data elements to be discarded, some missing record at period start if shifted forward, or period end if shifted back, is also a consequence that must be addressed (see Section F 3.8).

A time drift adjustment alters the accumulation interval of each volume increment and therefore changes the apparent rate of take calculated from these data. Determining whether a clock drifted or stopped is therefore important (see Figure F 7).

Data logging may also have stopped when the clock stopped, or all subsequent pulses may be tallied into a single stored value at clock restart, depending on how data collection is configured. A period of missing record is a consequence of either, but a pulse tally captures all volume since the clock stopped allowing the gap to be infilled (see Appendix F.1 Section 2.1).

Time-series processing software often combines data adjustment tools so that it is possible to unintentionally alter time and introduce time errors. Errors in fixed interval data can be identified by analysing the timesteps or inspecting the timestamps but can only be detected in 'on-event' data by comparing the processed data with the original as in Figures F 4 and F 5.

3.7.1 Supervisory Control and Data Acquisition (SCADA) systems

Clock drift

Clocks in SCADA system remote devices (i.e. the programmable logic controllers or PLCs) often drift. To minimise the drift, some SCADA systems synchronise all PLCs with the base clock once per day, usually at midnight. The PLCs may have drifted enough over the preceding day that they are pulled forward or pushed back by more than the data logging interval, so they may skip an interval or overwrite data previously collected. Under-reporting results if the data overwritten were not zero values.

Daily tallies

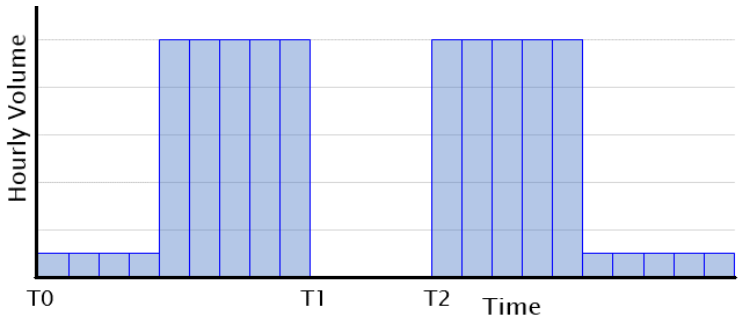
Daily tallies are usually logged at a SCADA base at midnight then the tally register cleared for the new day. If the PLC and base clocks are not synchronised:

- counts may be assigned to the wrong day, or
- 'late' counts may be wiped when the register is cleared without being included in the day's tally but no longer exist to be included in the next day's tally either, leading to under-reporting.

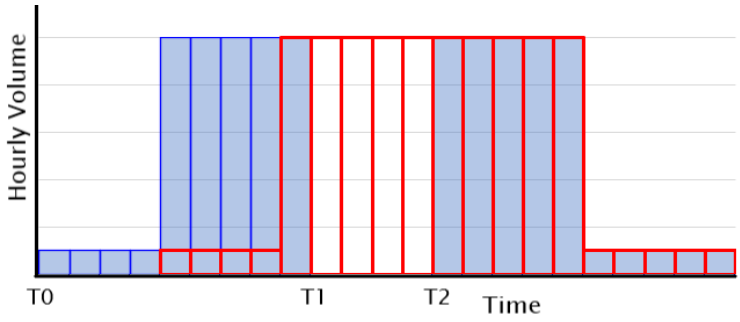
Under-reporting from these systems is not recoverable other than by comparing with an independent non-resetting meter reading.

The remedy for both situations is a combination of:

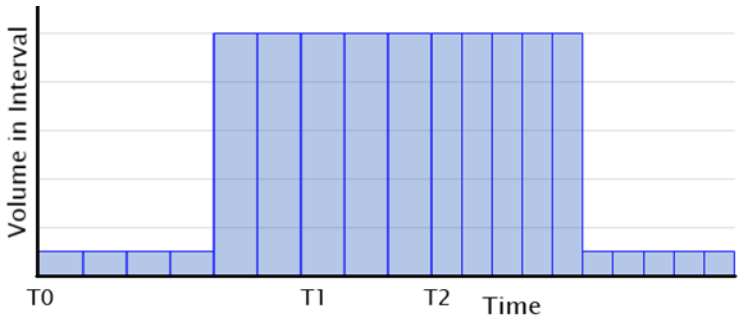
- reconciling with independent non-resetting meter readings
- intimate knowledge of the SCADA system's data collection methods and clock operations
- tedious and meticulous inspection of the data either side of the time the system performs synchronisation and/or resets its tallies
- repair of the data where possible or marking as a gap if not.



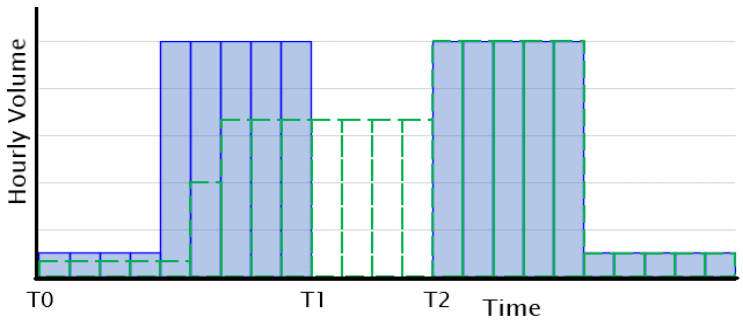
A record of hourly volumes with a gap of 4 hours between T1 and T2.



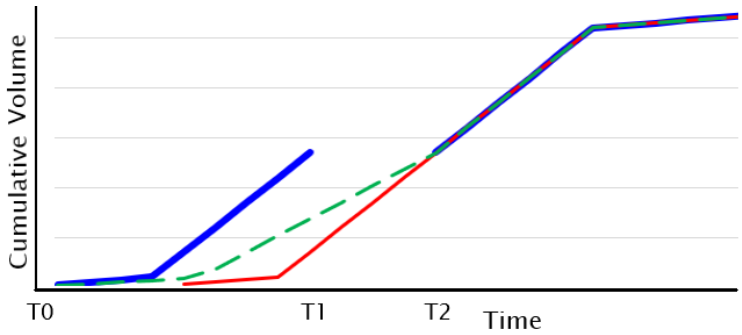
Example 1: At T2, start time T0 is found wrongly set 4 hours back. Data from T0 to T1 is shifted forward 4 hours, closing the gap between T1 and T2.



Example 2: At T2, logger time is T1, 4 hours slow. Hourly timesteps between T0 and T1 are 'stretched' to compensate for the drift, closing the gap between T1 and T2.



The 'stretched' data reapportioned to hourly intervals.



Example 3: Cumulative plot showing original data (blue) with the time shifted (red) and the time drift adjusted (green dashed). Slope of each line indicates apparent flow rate.

Figure F 7 – A comparison between time shift and time drift adjustments in a period of hourly water meter data stored as an interpolating incremental data type.

Table F 6 – Guidance for resolving time faults

Guidance for resolving time faults		see Section(s)
Issue(s)	Timing and/or temporal distribution of recorded data is wrong, and/or data are missing.	F 3.7
Evidence	Logger date/time is different from actual at inspection. Investigation finds configuration error or reset, and/or event timing and/or temporal distribution anomalies are apparent when compared with other available and relevant data.	F 3.7 Fig. F 7 F 2 3.6
Solution(s)	If wrong time zone, apply time shift then address any missing record created at the start (or end) by the shift. If clock is slow or fast apply time drift adjustment. If a clock fault and/or has stopped, treat period until restart as missing record.	4.3 or 4.6 Fig. F 7 and/or F 3.8
Metadata	If a time shift is fully traceable, quality code is unaffected, but a Data Processing Comment is required explaining identified cause and details of the shift applied. QC 100 if missing, or QC 300 if infilled, and a Data Comment. Otherwise, 'minor' or 'significant' modification criteria apply and a Data Processing Comment explaining identified cause and details of the amount and period of adjustment is required.	F 5.2.5 6.2.4.7 F 5.2.4 6.2.4.6 6.2.3

3.8 Missing data

When data are stored as incremental totals of interpolating data type, a gap created by missing data must either be closed, infilled, or marked to prevent interpolation through the period of the gap.

The clean data series is stored with all verified gaps marked but not filled. Gaps in the fully processed time series must be filled wherever possible (see Section F 6). This series is more useful for scientific analysis over long time periods, for which gaps in the record are problematic.

When considering the treatment and associated metadata requirements for missing water meter data the following broad descriptions are helpful:

- a brief period is a few recording intervals, but never more than a day
- a short duration is no more than 3 days
- a longer period may be up to two weeks
- an extended period is two weeks or more.

On power loss, no data are logged but the meter totaliser should continue to register water use and can be read at intervals to provide a substitute record. However, certain meters can get stuck such that the meter totaliser also fails to register.

If pulse generation fails, depending on the measurement system, values of zero may be logged when water may have been abstracted, e.g. status checks (see Section F 2.3.4). Verification of data collection (see Section F 2.3.2) and pulse output tests (see Section F 2.3.3) identify and confirm the problem. Unless zero take can be corroborated by other data and observations the zero values must be stripped from the record and the period(s) marked and treated as a gap.

3.8.1 Seasonal recording

Water meter data may be seasonal. Some consenting authorities allow data logging to be switched off with the pump in the off-season, creating annual gaps of several months duration in the record.

If the meter reading at the start of the next season matches the reading at the end of the previous season the off-season gap may be infilled with nil take (see Appendix F.1 Section 2.4).

If the meter has incremented between seasons the volume recorded must be added to the record as off-season take using the method described in Appendix F.1 Section 2.2.

If the meter was not read at either of the end of the previous or start of the current season the off-season period must be marked as a gap and treated accordingly.

Note: It should not be assumed that because there is no irrigation there is no water take in the off-season. Land occupiers may use the water for a variety of purposes. Some knowledge of these other purposes is helpful when verifying the recorded data.

Data may be missed at season start if the measurement and recording devices can be isolated from the pump (and therefore do not meet COP section B1.1.4) and the recording equipment is not powered up when the pump is turned back on.

A data collection verification should detect the problem if not noted sooner (see Section F 2.3.2.).

A pulse output test confirms that otherwise, pulse recording is reliable (see Section F 2.3.3).

Comparison with pump run time records confirms when the pump was switched on (see Section F 2.2.3).

The off-season, and the period up to data collection resuming, are marked as gaps to subsequently be infilled where possible (refer to Appendix F.1).

3.8.2 Closing gaps in incremental interpolating data

Closing a gap by removing the gap marker or flag in an incremental interpolating data series results in the next stored total being spread at a constant rate through what was the duration of the gap (see Section F 1.3).

Where this is not a reasonable representation of the actual water use, the temporal distribution of the data can be altered by inserting additional data elements to redefine the interval(s) associated with the value(s), in the same way that status checks (see Section F 2.3.2) create a problem.

3.8.3 Methods for infilling gaps

For details on specific methods for infilling gaps in water meter data, see Appendix F.1 of this Annex.

Table F 7 – Guidance for resolving missing data

Guidance for resolving missing data		see Section(s)
Issue(s)	Data are missing, or values of zero are generated and logged in place of actual measurements.	F 3.8
Evidence	Expected timestamps are not present in original fixed interval data. A gap marker may or may not be present depending on data collection method. Logged volume is short compared with totaliser. Cumulative plot shows unexpected flat periods of trace. Comparison plots show expected event(s) and/or volume missing. Investigation confirms data were not logged and/or not collected.	F 3.8 4.16 F 2 3.6
Solution(s)	Mark the gap in the clean data series. In the fully processed series apply one or more methods from Appendix F.1 as appropriate to the available supporting data.	4.16 to 4.20 incl. App. F.1 5.4 & 5.5
Metadata	QC 300 if infilled with synthetic data or an accumulated total. QC 100 if left as missing. Data Comments are required explaining identified cause and providing details of decisions made and methods applied, including the resolution and expected reliability of any synthesised infill.	F 5.1 6.2.3 F 5.2.4 6.2.4.6

3.9 Data transfer

Operational systems such as SCADA that collect then transfer water use data may log service meter reading, independent pulse count, or volume in interval calculated from either, or a measured flow rate. These consent holders and third-party providers may, by agreement, provide a different measurement or data in a different form to that stored by the recording agency.

What is being sent must be agreed and fully documented to ensure data are received, stored, and ultimately interpreted appropriately. Record of the site setup(s) and data transfer protocols must be collated and maintained and provided to the recording agency to incorporate in their site/station history/file and summarise in the site metadata.

Procedure must be developed, documented, and implemented to ensure:

- data transfer between agencies is controlled and traceable, and
- data types are aligned, or suitable tested, controlled, and traceable transformations are applied, and
- data subsequently changed are reported back to the collector.

4 Adjusting Data to Verification Results

Installation verifications provide independent measurements of volume through the meter. The verification device must have the same or better accuracy than the meter being verified.

If a verification does not unequivocally confirm compliance with the accuracy requirement of the Regulations (see Section F 2.4.1) the recorded data may be adjusted to compensate for the identified bias, but only if the origin of the bias is traceable to a configuration error.

The adjustment is implemented retrospectively by rescaling the data (see Section F 3.6). For data captured by pulse count this means changing the volume increment of each pulse and therefore changing the apparent resolution of the data (see Section 4.8).

The adjustment is applied after all other data processing has been completed, including any infilling of missing record. Adjusted data are therefore only to be stored in the fully processed time series (see Section F 6).

5 Metadata

5.1 Quality coding

Quality code for water meter data is set by the performance objectives in the quality coding flowchart in NEMS *Water Metering (Measurement, Processing and Archiving of Water Meter Data)*. The flowchart is also available in NEMS *National Quality Code Schema*.

5.2 Data processing actions and adjustments

The quality code of any data collected may be affected by subsequent actions on and adjustments made to the data. Minor modifications reduce quality code to QC 500. Significant modifications reduce quality code further to QC 400. Refer to Section 6.2.3 for definitions of 'minor' and 'significant'.

Further guidance on how and when quality code must change as a consequence of data processing is provided in Section F 3 of this Annex.

5.3 Example water meter data comments

The following are templated examples of comments for water metering sites.

Every comment must be assigned a fully specified timestamp and be associated with the relevant data (the time series of water use) via some form of 'Site' and 'Measurement' key combination. These 'database keys' are usually specified in some form of record header not shown here.

5.3.1 Site/Initial Comments

Type: Site
Measurement: Water Take
Initial comment for the water meter *<meter-ID>* (at *<site, property, or locality name>*)
Located at *<map co-ordinates and type*[23]*>* drawing water from the *<river name>* River, river number *<river number>*[24] (or *<aquifer name>* aquifer, or *<name of water body>* as applicable) under resource consent *<auth_number>* (or permitted use) for *<intended use e.g. pasture irrigation>*
Data are recorded as *<x>*m^3 *(or* L*)* pulses logged as they occur *(or* total volume (m^3) *(or* L*)* in *<x>* minute intervals*) (*by *<name of supplier>) (*transferred *<time interval e.g. daily, weekly, annually, or periodically to the recording authority by <method of data transfer>*
Additional information: *<site purpose, anything relevant to general interpretation of the record e.g. seasonal recording, additional location information if part of a distribution network, abstraction scheme or allocation plan, water source properties that may affect meter performance, verification frequency> <Some (or All) quality control (and/or data editing) is automated; refer to the relevant Data Processing Comments>*.
The following is also measured at this site: *<list variables, including any backup record or supplementary data, whether permanently stored or not>*
The local recording authority is: *<name of recording and/or archiving agency(ies)>*

5.3.2 Equipment Comment examples

Type: Equipment
Measurement: Water Take
Meter *<make, model and serial number>* installed on *<dd-mm-yyyy hhmmss>* is a *<state type (see Table 2 of the COP)>* meter with accuracy *<state accuracy and/or standard and accuracy class and date of wet lab certification>*, display resolution of *<increment and units>* and dials range of *<maximum dials reading and units>*. The meter is installed in *<describe main features of the pipe configuration e.g. length of straight pipe of diameter x, or vertical etc.>*, *<relevant location if not at the water abstraction point, and/or in relation to other fixtures, inputs or draw-offs>* (or is portable). Meter calibration is valid for *<calibration period>*. The meter and installation is independently verified every *<installation verification frequency>*. Data (and location) is logged to a *<describe main logger features e.g. how powered, compact (or otherwise e.g. PLC), multi- or single input, programmable etc.>* data logger, recording *<describe logging and sampling regime e.g. each increment of volume as it occurs, or, total volume in fixed intervals of x-minutes>*.
Data are collected by *<whom, and method and frequency e.g. twice daily telemetry polling and occasional manual download>*, verified *<data collection verification frequency>* by *<whom and method e.g. recording authority inspection or consent holder submission>*.

[23] state the co-ordinate system: NZTopo50 or NZGD 2000 preferred (latitude/longitude to 6 decimal places)
[24] from *Catchments of New Zealand* (SCRCC, 1956).

5.3.3 Operational Comment examples

Type: Operational
Measurement: Water Take
Pipework reconfigured on *<dd-mm-yyyy hhmmss>* to/because of *<provide reason>*. The meter is now installed in *<describe main features of the pipe configuration e.g. length of straight pipe of diameter x, or vertical etc.>*, *<relevant location if not at the water abstraction point, and/or in relation to other fixtures, inputs or draw-offs>*.

Type: Operational
Measurement: Water Take
Meter *<serial no.>* replaced on *<dd-mm-yyyy hhmmss>* to/because of *<provide reason>*. Installation is otherwise unchanged (or Installation was also modified to/because of *<provide reason>*. The meter is now installed in *<describe main features of the pipe configuration e.g. length of straight pipe of diameter x, or vertical etc.>*, *<relevant location if not at the water abstraction point, and/or in relation to other fixtures, inputs or draw-offs>*). Refer to the associated Equipment Comment for details of the new meter.

When a meter is replaced, a corresponding Equipment Comment is required (see Section F 5.2.2) for the new meter. If the installation is also modified a Stationarity Comment alerting and explaining the change is also required (see Section F 5.2.7).

Type: Operational
Measurement: Water Take
Installation verification on *<dd-mm-yyyy hhmmss>* was inconclusive with deviation of meter from reference of *<(-) or (+) x %>*. Reference uncertainty was +/-*<x %>*.

Type: Operational
Measurement: Water Take
Installation verification passed on *<dd-mm-yyyy hhmmss>* with deviation of meter from reference of *<(-) or (+) x %>*. Reference uncertainty was +/-*<x %>*.

Type: Operational
Measurement: Water Take
Installation verification failed on *<dd-mm-yyyy hhmmss>* with deviation of meter from reference of *<(-) or (+) x %>* because of *<provide reason>*. Reference uncertainty was +/-*<x %>*. Raw readings from *<dd-mm-yyyy hhmmss>* to *<dd-mm-yyyy hhmmss>* are considered to under (or over) register water use by *<verification difference>*. Meter was repaired (or replaced) on *<dd-mm-yyyy hhmmss>* (with same type (or a *<state type>* if different). Refer to the associated Equipment Comment for details of the new meter).

Routine comment of all verification results is recommended for water meter data because assignment of a lower quality code is not exclusive to evidence of bias in the record, and data are not routinely rescaled to the results of verifications to mitigate the bias. If the data are rescaled there must be a corresponding Transformation Comment (see Section F 5.2.6).

5.3.4 Data Comment examples

Type: Data
Measurement: Water Take
Missing record from *<dd-mm-yyyy hhmmss>* to *<dd-mm-yyyy hhmmss>* due to *<identified cause of recording failure>*. The gap is not filled because *<state reason(s)>*.

Type: Data
Measurement: Water Take
Gap from *<dd-mm-yyyy hhmmss>* to *<dd-mm-yyyy hhmmss>* due to *<identified cause of recording failure>* filled with zero water use verified by pump run time (or electricity) records.

Type: Data
Measurement: Water Take
Gap from *<dd-mm-yyyy hhmmss>* to *<dd-mm-yyyy hhmmss>* due to *<identified cause of recording failure>* filled with zero water use inferred from no movement in the totaliser over the period as evidenced by *<type of evidence e.g. timestamped photos supplied by the consent holder>*.

Type: Data
Measurement: Water Take
Data capture method changed on *<dd-mm-yyyy hhmmss>* to *<describe new method e.g. event data, where each volume increment generates a pulse that is timestamped as it occurs>*. (A zero-value status check is also generated on the logger every *<describe frequency e.g. hour, or day at a certain time>*.) Data was previously logged as *<describe previous method e.g. total volume in fixed intervals of x-minutes>*.

Type: Data
Measurement: Water Take
Data may be compromised by *<reason e.g. sediments, temperature, air entrapment>* from *<dd-mm-yyyy hhmmss>* to *<dd-mm-yyyy hhmmss>*. Record is not adjusted.

Type: Data
Measurement: Water Take
Synthetic record from *<dd-mm-yyyy hhmmss>* to *<dd-mm-yyyy hhmmss>* due to *<identified cause of recording failure>*. Totaliser readings are not available. Record was generated from *<provide or describe the relation e.g. state the regression equation>* obtained by *<method e.g. least squares or multiple regression or rainfall-runoff model algorithm, etc.>* with input data of *<list measurements and periods used>*. *<Add indication of reliability e.g. regression coefficient or standard error and analysis sample size, or some other assessment of uncertainty etc.>*, *<Add limitations on usefulness e.g. daily values only, or not recommended for daily water balances, irrigation application analysis etc.>*

Type: Data
Measurement: Water Take
Synthetic record from *<dd-mm-yyyy hhmmss>* to *<dd-mm-yyyy hhmmss>* due to *<identified cause of recording failure>*. Record was calculated as the sum of (difference of) meters *<meterID-1>* and *<meterID-2>* on the same distribution network. Calculated total in the period is x m^3. Corresponding volume by totaliser is y m^3.

Type: Data
Measurement: Water Take
Synthetic record from *<dd-mm-yyyy hhmmss>* to *<dd-mm-yyyy hhmmss>* due to *<identified cause of recording failure>*. Total take in the period is filed as a single value at *<dd-mm-yyyy hhmmss>* being the recorded backup pulse tally (or assessed as *<x>* m^3 from a reading of *<y>* m^3 for the period *<dd-mm-yyyy hhmmss>* to *<dd-mm-yyyy hhmmss>*). (Record from *<dd-mm-yyyy hhmmss>* to *<dd-mm-yyyy hhmmss>* is filled with zero water use verified by *<method>*).

5.3.5 Data Processing Comment examples

Type: Data Processing
Measurement: Water Take
Values deleted (or edited to zero) from *<dd-mm-yyyy hhmmss>* to *<dd-mm-yyyy hhmmss>* to remove false (or test) data due to *<identified cause e.g. interference or verification check>*. Edited by *<name>* on *<date of processing>*.

Type: Data Processing
Measurement: Water Take
Data filtered from *<dd-mm-yyyy hhmmss>* to *<dd-mm-yyyy hhmmss>* to remove zero values generated as *<frequency e.g. hourly, or daily (at hhmmss)>* site status checks. Edited by *<name>* on *<date of processing>*.

Type: Data Processing
Measurement: Water Take
Data adjusted from *<dd-mm-yyyy hhmmss>* to *<dd-mm-yyyy hhmmss>* by (or for) *<method and parameters e.g. time drift (or shift) of x (hours, minutes etc.)>* to compensate for *<identified cause e.g. clock running slow (or fast), or wrong logger time at setup etc.>*. Edited by *<name>* on *<date of processing>*.

Type: Data Processing
Measurement: Water Take
From *<dd-mm-yyyy hhmmss>* (to *<dd-mm-yyyy hhmmss>*) automated quality control (and/or editing) is applied to this data. Actions include: *<briefly describe each action in specific terms e.g. Range Test: negative volumes removed and gapped; Over-range Test: Values exceeding pump capacity of x m^3/hr not accepted; Gap Test: error flagged if timestep* > 24 hrs; etc.> (or Actions are documented in *<provide reference to processing system documentation that contains specific detail of the tests applied to this data e.g. the site file, quality management system etc.>*), applied *<describe where in the process, with respect to what is original data, e.g. on the data logger (or telemetry system, etc.) prior to archiving as original data, or, after original data have been preserved but before near real-time web publication etc.>*, using *<provide name(s) of software and version and briefly describe how the actions are specified and/or configured in the system, and/or provide reference to where the code is permanently preserved, configuration files or screenshots are retained or similar>*.

Similar 'automation' comments must be provided each time any relevant detail changes, from change to an action threshold through to a change of organisational procedure and/or software. Cross-reference relevant Equipment and Operational Comments as required to avoid unnecessary duplication. File a corresponding Stationarity Comment if change of methods potentially disrupts stationarity of the data.

The level of detail required in 'automation' comments depends on the extent to which the comments are necessary to ensure traceability of changes made to the raw measurements (see Sections 3.1.1 and 8.2).

5.3.6 Transformation Comment examples

Type: Transformation
Measurement: Water Take
Data and totaliser readings from *<dd-mm-yyyy hhmmss>* to *<dd-mm-yyyy hhmmss>* are rescaled by *<factor applied>* to compensate for the under (or over) registering of water use identified by verification on *<date of installation verification>*. Edited by *<name>* on *<date of processing>*.

5.3.7 Stationarity Comment examples

Type: Stationarity
Measurement: Water Take
Meter replaced by *<new type>* (and/or relocated to *<new location>* and/or reinstalled at/in *<new pipe configuration>*) on *<dd-mm-yyyy hhmmss>*. *<Add relevant before and after details and reason for change>*.

Type: Stationarity
Measurement: Water Take
Pipework reconfigured on *<dd-mm-yyyy hhmmss>* to/because of *<provide reason>*. The meter is now installed in *<describe main features of the pipe configuration e.g. length of straight pipe of diameter x, or vertical etc.>*, *<relevant location if not at the water abstraction point, and/or in relation to other fixtures, inputs or draw-offs>*.

Stationarity Comments can also be used to capture and collate information about historical methods and data. A common change to be identified in a Stationarity Comment is date and time of a change in data recording method, e.g. from fixed interval to 'on-event' logging (see Section F 1.3).

Type: Stationarity
Measurement: Water Take
Data capture method changed on *<dd-mm-yyyy hhmmss>* to *<describe new method e.g. event data, where each volume increment generates a pulse that is timestamped as it occurs>*. (A zero-value status check is also generated on the logger every *<describe frequency e.g. hour, or day at a certain time>*.) Data was previously logged as *<describe previous method e.g. total volume in fixed intervals of x-minutes>*.

6 Preservation of Record

For water meter data, in addition to the requirements of Sections 6 and 8 of this Standard, the recording agency must store and retain indefinitely and, if electronic, back up regularly:

- all verification reports, totaliser readings, and results
- all site inspection observations and notes
- the original 'as recorded' data
- the verified edited and quality coded record with all gaps marked, i.e. the clean data
- the fully processed time series, i.e. the clean data, rescaled to the installation verification results if required, and with any missing record filled wherever possible, and quality codes revised as applicable, and
- all required associated metadata for each of the above.

7 References

Soil Conservation and Rivers Control Council (SCRCC). 1956. *Catchments of New Zealand.* SCRCC, Wellington.

Appendix F.1 Methods for Infilling Gaps

1 Information Requirements

The method chosen to infill a gap (i.e. a period of missing record) will depend on:

- the duration requiring infilling
- the likelihood of no water use during the period missing
- the likelihood of variable water use during the period missing
- whether other meters in the same distribution network also measure the take in part, or in combination with other metered use
- availability of supplementary data and supporting observations such as:
- totaliser readings
- pump on/off and/or run time records
- records of pump electricity use
- observations of abstraction occurring, including anecdotal, or a nearby downstream stream flow record or water levels recorded in an affected well
- prior knowledge of the likely pattern of abstraction
- the existence of models that can predict likely abstraction.

2 Recommended Methods

The following methods are candidates for infilling gaps in water metering records:

- inserting all, or an assessed part, of a totaliser reading
- inserting values of zero for known and verified periods of no water use
- calculating by sum and/or difference from records obtained from other meters in the same distribution network that measure some or all of the same take
- synthesising a record.

Synthetic infill can be created using one or more of the following methods:

- apportioning all or part of a totaliser reading to the temporal distribution of available supplementary data
- regression with available supplementary data
- estimates generated by models.

A combination of the above methods may improve results. For example, modifying a regression or model to account for known and verified periods of no water use.

Infilling of missing data is only required to be attempted for the fully processed time series (see Section F 6).

If reliable totaliser and/or independent reference readings exist, the corresponding record period(s) that include synthetic data generated by any method must sum to the relevant totaliser or independent reading.

2.1 Using a pulse tally or totaliser readings to infill a gap

When data logging has failed a pulse tally may be maintained that is recorded when data logging resumes.

When pulse generation and/or data logging fails, totaliser readings may still be available from the meter display. The consent holder may be required to supply regular readings until data logging resumes, or the volume difference since the totaliser was last read may pertain to a longer interval, in which case the portion relevant to the missing period must be assessed (see Appendix F.1 Section 2.2).

Manual readings supplied by the consent holder that are used to infill missing data are quality coded QC 300 to allow all periods of filled missing record to be identified and separated on the basis of quality code if desired. (A record of self-monitored water meter data would otherwise be quality coded QC 0 'non verified').

Totaliser readings may need to be interpreted before they can be manually entered into the record at the date and time of the reading. For example, they may be:

- converted between volume in interval and cumulative volume or pulse count and vice versa, and/or
- rescaled as described in Appendix F.1 Section 2.2 if the average of prior relevant data collection verifications shows consistent bias > ±1% between logged and totaliser volumes.

With the gap marker removed the interpolation engine spreads the tallied or derived volume evenly through the interval from the previous data element in the series, except if the data are stored using Hilltop Software's 'Thirty minute Rainfall' data type where it is spread only through the previous thirty minutes.

Temporal distribution of the infilled record may be improved by combining with infilling periods of no water use (see Appendix F.1 Section 2.4).

2.2 Assessing a totaliser reading to infill a gap

If a totaliser reading relates to a period longer than the period of missing data, the portion applicable to the period missing must be assessed.

If the clean recorded data are otherwise reliable and have been in good agreement with the totaliser (deviation ≤ ±1%), determine the total volume logged in the interval of the totaliser reading then deduct it from the volume obtained from the totaliser reading.

The remainder is the assessed portion of the totaliser reading to be used to infill the gap.

If there has not been good agreement with the totaliser (i.e. deviations > ±1%) the assessed portion must be rescaled by the average of deviations observed for the same meter and installation configuration.

For example:

Totaliser on 1-Mar-2020 12:00:00 reads 13000 m^3 and on 1-Apr-2020 12:00:00 reads 14000 m^3.

Period of record missing is 20-Mar-2020 12:00:00 to 1-Apr-2020 12:00:00.

Recorded volume from 1-Mar-2020 12:00:00 to 20-Mar-2020 12:00:00 is 653 m^3.

Average of all data collection verifications for same meter and installation to date of gap is -1.8% (i.e. logged volumes are less than those from the totaliser).

Total volume expected to have been logged between 1-Mar-2020 12:00:00 and 1-Apr-2020 12:00:00 is (1+(-1.8/100)) * (14000-13000) = 982 m^3

Volume estimated would have been logged between 20-Mar-2020 12:00:00 and 1-Apr-2020 12:00:00 is 982 – 653 = 329 m^3 to be applied to infill the gap

2.3 Estimating a totaliser reading to infill a gap

- If the meter itself has failed, temporal distribution and estimates of volumes of water abstracted can be obtained from pump and/or electricity records and the pump specification.
- Appropriate relations to estimate volumes of water used may be developed:
- directly from the pump specification and run hours, and/or
- by regression analysis with simultaneous good quality logged record from the water meter, and the pump and/or electricity records (see Appendix F.1 Section 2.6).

2.4 Infilling periods of no water take

- A gap in the record may not have missed any water take. Periods of no water use may be:
- known from documented independent observation at site
- inferred from no movement in the totaliser, or
- deduced by calculation from other meters on the same distribution network if they measure all or part of the same take (see Appendix F.1 Section 2.5).
- Deleting the gap marker is not sufficient on its own to substitute a period of no water take because the system will then interpolate between the adjacent values, which may be non-zero.

- A record of nil take can be created in the time series by deleting the gap marker (if any) and entering values of zero at the start and end of the nil take period. However, because of the incremental interpolating data type the effective period of no take begins from the last non-zero value stored prior to the zero now filed at the start of the infill period.
- If the period of nil take is known, or inferred from totaliser readings, quality code may be carried forward from the adjacent series, but a Data Comment is required to explain that there was a gap in the record, no take occurred, and how this is known or was inferred (see Section F 5.2.4).
- If the period of nil take is deduced from other records it is synthetic data, QC 300 applies, and an appropriate Data Comment explaining method etc. is required (see Section F 5.2.4).

2.5 Calculating infill record from other meters

- In some cases, the meter may be one of two or more in a water distribution network supplied from the same abstraction point or be one party to a shared allocation from an aquifer or catchment. It may be possible to calculate infill record for the meter of interest from the records of other meters in the network or scheme (the 'donor' sites).
- Before 'donor' site data are used in the calculation of infill record:
- they must be verified as free of error
- some repacking of the data may be needed to align data intervals (see Section 4.13), depending on recording method at the 'donor' site(s).

  Note: Repacking incremental data alters its resolution.

- The infilled record should be checked against a subsequent totaliser reading.
- The infilled record is synthetic data, QC 300 applies, and an appropriate Data Comment explaining method etc. is required (see Section F 5.2.4).
- A diagram, plan or map of the distribution network or scheme that identifies each meter used in the calculation and its relation to the others must be stored with the data processing records and referred to from the Data Comment.

2.6 Infilling by regression analysis

- Regression analysis can be used to estimate water use if there is no record of water use available or able to be calculated (see Appendix F.1 Section 2.5) but records of pump operation such as run time and/or electricity usage, are available.

- General procedure is described in Appendix 2 to the main document.
- Analyse as long a period as possible within the period of the same meter and installation configuration and installation verification interval.
- Decide a suitable data interval for analysis and acceptable timestep of the infill, taking into account the extent of the gap and the quality of the relationship(s) (see Section F 3.8 and 6.2.5).
- The derived relation may introduce a constant that predicts negative values or water use when the pump is not operating unless one of the following options is utilised:
- Calculate the regression equation only when the pump is operating and apply it only to those times to generate the infill record.
- Force the regression through the origin (0,0). This tends to inflate R^2.
- The infilled record is synthetic data, QC 300 applies, and an appropriate Data Comment explaining method etc. is required (see Section F 5.2.4).

2.7 Infilling from models

Choice, availability, and degree of sophistication of a suitable predictive model depends on what the abstracted water is used for, and the availability and reliability of the necessary input data. For example:

- models that predict daily irrigation requirements from climate, soil and crop factors are reasonably common but will not necessarily reflect actual application of water
- simple but coarse models to estimate water take for public supply are easily constructed from population or connections data
- simple routing models or relatively complex rainfall–runoff models might be used to estimate natural stream flow from which a water take may be estimated by difference from actual recorded stream flow, but timing issues usually limit estimates to daily averages at best.

If a model already exists or is simple to create then it may be a viable source of infill data; however, if time consuming to set up, difficult to replicate, and/or accuracy and/or resolution is poor, models may be difficult to justify for the sole purpose of generating infill record.

Infill from this source is synthetic data, QC 300 applies, and an appropriate Data Comment explaining method etc. is required (see Section F 5.2.4).

3 Other Considerations

Infilled record is not intended, and must not be used, for assessment of compliance with any legal obligation of the consent holder. Its purpose is to facilitate water balance calculations and the naturalising of stream flows for scientific and water management planning activities.

Annex G Soil Moisture Data Processing

1 General Overview

1.1 Normative references

This Annex shall be read in conjunction with the following references:

- NEMS Soil Moisture Measurement – Measurement of water held within soils

Where reference is made from this Annex to specific sections of the above NEMS document, the title is abbreviated, and version stated, i.e. 'NEMS *Soil Moisture* v2.0.0'. Where requirements and/or procedure in this Annex duplicate and possibly conflict, this Annex shall prevail.

1.2 Scope of this annex

NEMS *Soil Moisture Measurement* includes, and references, information about measuring soil water potential but excludes doing so from scope. This Annex therefore does not address data measured by tensiometers, resistance blocks, or psychrometers. Also excluded from scope is the sampling of random sites using handheld or portable sensors, as is used to assess areal variations in soil moisture.

While focus of this Annex is on continuously sensed data logged to a device, manual measurements are used to verify the in-situ measurement system, and the processing guidance contained in this Annex is applicable to a continuous or quasi-continuous time series of at-point soil moisture, regardless of whether measurements are manual or automatic.

1.3 Units of measurement

The terms soil moisture and soil water (content) are used interchangeably in NEMS *Soil Moisture* v2.0.0 and in this Annex to refer to the amount of water in a soil, either as a mass (i.e. gravimetric measure) or a volume. Neither should be confused with soil water potential, which is the force (tension) holding water in a soil that a plant must overcome to extract that water, usually expressed in kilopascals (kPa).

Water content expressed as a proportion or percentage is not dimensionless because the ratio is of water to soil. This is important if solving mass balance or continuity equations for water.

NEMS *Soil Moisture Measurement* requires time-series measurements as % volume of water per unit volume of soil, and/or as mm of water per unit depth of soil. However, primary reference measurements are recommended to be gravimetric water content unless impractical. In any case, primary reference measurements used for calibration and validation must be in the same units as the sensor delivers, and for data verification must be in the units of the logged data and the consequent time series.

The following example illustrates the relationship between the various units.

An 80 cm^3 sample of soil, of surface area 16 cm^2 and depth 5 cm, is weighed (m_{wet}), dried, then weighed again (m_{dry}).

The gravimetric water content, θ_g, is given by:

$$\theta_g = \frac{m_{water}}{m_{dry\ soil}} = \frac{m_{wet} - m_{dry}}{m_{dry}} = \frac{105-93}{93} = 0.129\ g\ g^{-1} \text{ or } 12.9\%$$

The bulk density of the soil, ρ_b, is given by:

$$\rho_b = \frac{m_{dry}}{V_{sample}} = \frac{93}{80} = 1.1625\ g\ cm^{-3}$$

The volumetric water content, θ_v, is given by:

$$\theta_v = \theta_g \times \frac{\rho_b}{\rho_w} = 0.129 \times 1.1625 = 0.15 \text{ or } 15\%$$

where ρ_w is the density of water, close to 1 g cm^{-3}, and is usually ignored.

The volumetric water content, θ_v, is also given by:

$$\theta_v = \frac{V_{water}}{V_{sample}} \text{ rearranged } V_{water} = \theta_v \times V_{sample} = 0.15 \times 80 = 12\ cm^3$$

where V_{sample} is the total volume of dry soil + air + water in the sample.

The equivalent depth of water is therefore $12 \div 16 = 0.75\ cm$ in 5 cm, or 150 mm per metre of soil, i.e. 15% of the unit depth of soil.

Note: 1 cm^3 = 1 mL and 1 g cm^{-3} = 1000 kg m^{-3}

1.4 Supplementary variables

Dielectric sensors are sensitive to soil temperature and conductivity. If soil moisture is measured using a dielectric sensor that is susceptible to these effects but lacks on-board compensation, concurrent measurement as supplementary data, and subsequent compensation during data processing for the following, is required:

- soil temperature (see NEMS *Soil Moisture* v2.0.0: Sections 2.2.11 and 3.4),
- conductivity if a significantly saline soil, which may be encountered in areas of low rainfall, e.g. central Otago, or that receive wastewater (see Section 3.5 of NEMS *Soil Moisture* v2.0.0).

Organisations may choose to permanently store supplementary data as a supplementary rather than primary time series and therefore not apply all procedures in this Standard to those data.

However, as a minimum, supplementary data must be:

- identified in the soil moisture Site/Initial Comment (see Sections 6.2.4.3 and G 5.2.1)
- described in the archived soil moisture time-series Data Comments (see Sections 6.2.4.6 and G 5.2.4).
- inspected and edited for gross errors
- quality coded QC 200 if edited from the original and/or quality reviewed (see Sections 3.1 and 7.2), otherwise retain QC 0, and
- accompanied by Data Processing Comment(s) if editing was applied (see Section 6.2.4.7).

Note: At date of publication of this Annex there are no NEMS Standards for the processing of soil temperature or conductivity data, and therefore no mechanism to assign a quality code higher than QC 200 to these supplementary data.

If supplementary data are edited it may change dependent soil moisture values, therefore:

- processing inter-dependent time series together is strongly recommended
- the impact on the soil moisture record of editing necessary supplementary data must be assessed, which will normally require the supplementary data to be reviewed and/or processed first
- inconsistent adjustments between supplementary data and dependent soil moisture record must be avoided
- editing of necessary supplementary data must be described and explained in a Data Processing Comment attached to the soil moisture time series.

1.5 Complementary measurements

Measurements listed in Section 3.6 of NEMS *Soil Moisture* v2.0.0 are not required supplementary data (see Section G 1.4) but are useful metadata and records for comparison with soil moisture data for quality control.

2 Quality Control

2.1 Additional metadata required

General requirements for metadata are set out in Section 6.1. The following additional metadata, as applicable to the site, instrument(s), and deployment, are required to be available when verifying soil moisture data:

- site and location details, including:
- purpose of the monitoring and consequent specification or expectations of accuracy and precision of the data

- description of the local topography, including slope, aspect, and presence of any humps and hollows near the sensor(s) and/or access tubes (see Section 1.3.2 of NEMS *Soil Moisture* v2.0.0)
- presence of any natural and man-made features in proximity and clearances from any larger obstacles (see Section 1.3.3 of NEMS *Soil Moisture* v2.0.0)
- information about the soil type(s), soil profile, and bulk densities if available (see Section 1.3.1 of NEMS *Soil Moisture* v2.0.0)
- details of land cover, land use, irrigation applied, and any other on-farm activities that influence soil moisture, including any changes noted within the record period (see NEMS *Soil Moisture* v2.0.0: Sections 1.3 and 3.6)
- information about presence of and changes to relevant drainage features that influence sub-surface hydraulic gradient at and around the sensor, e.g. seasonal water table variations, depth of any sub-surface drains, proximity and invert level of nearby surface drains, drainage pump activity, bed level and associated elevation of the water surface in nearby water bodies
- estimates of field capacity and permanent wilting point for the soil and ground cover, pasture, or crop present in the record period
- sensor and deployment details, including:
- descriptions of all sensors installed, including on-board soil temperature and conductivity compensation capability, range of measurement, and their replacement history (see Section 4.1.3 of NEMS *Soil Moisture* v2.0.0)
- details of the instrument(s) and methods used, and facilities provided for obtaining field calibration and verification measurements
- GPS location data, plans, and photographs of the site and soil pit showing the soil horizons and relative (x,y,z) locations of the in-situ sensor(s) and access tubes (see Section 4.1.2 of NEMS *Soil Moisture* v2.0.0) and any identification markers (see Section 2.1 of NEMS *Soil Moisture* v2.0.0)
- calibration and validation records for all instruments used at site (see NEMS *Soil Moisture* v2.0.0: Sections 3.3, 4.1.4 and 4.1.5).
- Site visit information, including:
- observations of settling around the sensor(s) and any remediation
- observations of other changes to the sensor environs (ground cover, crop type and stage, obstructions, irrigation activity, land clearance, construction, stock movements etc.)
- details of neutron probe readings (e.g. locations, depths, measurement times, calibrations, uncertainties)
- verification results, and
- relevant completed quality coding matrix assessments.

These metadata must be verified and permanently archived with all other metadata as described in Section 6.

2.2 Plots and comparisons

- Check around the time of each site visit for anomalies introduced by inspection, sampling, and maintenance activities, and to identify steps in the data introduced by site remediation, or replacing or reconfiguring the sensor, data logger, and/or altering the installation.
- Check for inconsistencies or trends in the values of significant thresholds deduced from the data such as field capacity and stress point.
- Identify any loss of expected patterns in the data such as the daily steps associated with plant transpiration and surface evaporation (see Figure G 1).

2.2.1 Comparisons

- Use comparisons to:
- cross-check data for anomalies, and
- confirm editing and adjustments have been properly carried out.
- Compare the recorded data with:
- record collected from other sensors at different depths, or within the same site, if any, provided they are not affected by the same data quality issue
- other associated variables recorded at the site, e.g. relevant supplementary variables (see Section G 1.4), and complementary measurements (see Section G 1.5), especially rainfall and/or irrigation depths as applicable
- verification measurements, and validation results, if any.

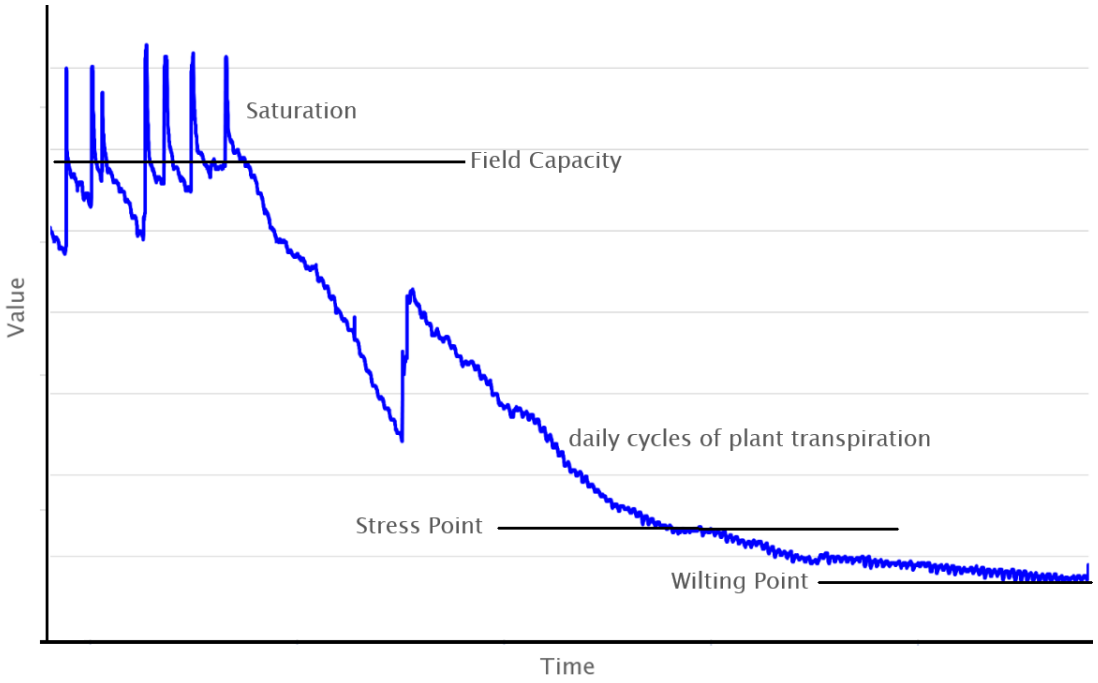


Figure G 1 – An example of a period of soil moisture data showing the typical features of saturation, field capacity (below which daily transpiration is apparent), stress point (where the trace levels out), and wilting point (where daily transpiration ceases).

2.2.2 Between-station comparisons

In areas where soils and catchment characteristics are reasonably homogenous and irrigation is not taking place there may be a consistent relationship between sites that are up to a few kilometres apart, sufficient to verify pattern and range of the data.

Records of rainfall at a nearby location may be used to confirm occurrence and timing of increases and decreases in soil moisture.

Other climate variables may help distinguish the effects of evaporation and transpiration from discontinuities or noise caused by recording faults.

In addition to cross-checking specific features in the data, use comparisons, including between-station comparisons, to identify:

- possible failure of on-board temperature and/or conductivity compensation in dielectric sensors
- trend indicative of in-situ sensor calibration drift
- change in and/or disruption of:
- diel and seasonal patterns
- shape and pattern of response to rainfall, dry spells, and/or growth stage of ground cover
- relative timing of daily maxima and minima
- inferred values of field capacity and stress point
- the annual range of the recorded data, which may be indicative of a calibration shift or loss of sensor span.

Note: The above may be difficult to distinguish from effects of hydraulic gradient change without additional verification measurements and knowledge of surrounding drainage systems.

Do not discount the possibility that problems may be transient and occur (and resolve) between site visits.

2.3 Calibration, validation, and verification

2.3.1 Field calibration and verification of in-situ dielectric sensors

While most in-situ dielectric sensors are capable of precise measurement provided compensation for soil temperature and conductivity is functional or not required (see Section G 1.4 and NEMS *Soil Moisture* v2.0.0: Sections 3.4 and 3.5), they must be field calibrated to provide accurate values of soil moisture so that installation effects, and soil type and organic matter content, may be accounted for.

Note: Some brands of dielectric sensor may give repeatable but implausible readings for the soil type unless field calibrated.

Reference values are used to establish and maintain the field calibration of the in-situ sensor (see Section G 4) and to verify that the measurement system in general is operating correctly, but they are not used directly to adjust for sensor drift (see Section G 3.3).

Ideally, the reference values, i.e. independent readings of soil moisture, are obtained by taking soil samples near the sensor and analysing them gravimetrically in a laboratory, but collection of the samples disturbs the sensor environment so use of a calibrated and validated neutron probe (see Section G 2.3.2) is preferred (see Section 3.3 of NEMS *Soil Moisture* v2.0.0).

- The neutron probe is deployed via suitably located permanently installed access tubes at depths consistent with depth(s) of the in-situ sensor(s).
- For strip (ribbon or tape) sensors a reference value is the average of a minimum of two near-simultaneous independent readings, one at each end of the strip.
- Reference values obtained at site over a relatively short timeframe are used for field calibration of the in-situ sensor (see Section G 4).
- Reference values obtained at site at least every twelve (12) months, but preferably every six (6) months (see Section G 2.3.3), are used to verify system performance in general and detect drift from an established field calibration.
- Verification tolerance is ± 1% (soil water content) plus the uncertainty of the reference value.

For example: Verification tolerance for a soil water content of 35% and reference uncertainty of 1.5% is 32.5% to 37.5%.

Note: The uncertainty of a reference value obtained by neutron probe is the greater of the manufacturer's stated instrument accuracy or the prediction interval of the reference instrument's field calibration.

Note: For soil moisture measurement accuracy to be within ± 3% of the true soil moisture value, uncertainty of the reference value must be no more than ± 2%. This is usually achievable for both neutron probes and gravimetric samples.

- If the check differs beyond verification tolerance from the current field calibration, drift is a possible cause (see Sections G 3.3 and G 4). The in-situ sensor's field calibration must then be reassessed unless a further check within six months is within tolerance, in which case the first check may be regarded as an anomaly, and if so, must then be noted and explained in an Operational Comment (see Section G 5.2.3).

Soil matric potential and water retention curves

Tensiometer readings in conjunction with water retention (pF) curves (soil matric potential vs. %w/w or %v/v soil moisture for various soil types) may be useful to:

- extend field calibration relationships to field capacity and wilting point (which is difficult to measure under irrigation), or
- act as a sanity check on soil moisture values obtained by measurement.
- However, they cannot be considered verification reference readings when assessing quality code using the quality coding matrix, either with respect to the range of the field calibration obtained, or the elapsed time between reference readings.

2.3.2 Calibration and validation of reference neutron probes

For a neutron probe to be used as a reference instrument it must be calibrated to gravimetrically determined values, i.e. results of samples analysed in a laboratory. A minimum of fifty samples is recommended. Linear relationships "of ± 1.5% over the representative normal range of the soils that will be measured" are required for reference measurements to be considered reliable (see Section 3.3.2.1 of NEMS *Soil Moisture* v2.0.0).

Note: ± 1.5% is units of soil moisture not proportion of value, i.e. 30% ± 1.5% expands to 28.5% to 31.5%.

The soil samples for calibration can be drawn from a variety of locations, including various sections of a sample core, and therefore include a range of soil types and soil moisture values; however, samples must be obtained from each site and soil horizon for which bulk density is required to be known.

The linear relationships should be derived from simple ordinary least squares regression, not forced through zero (allows for an 'instrument offset'), with the required tolerance of ± 1.5% determined as the root mean square error (RMSE).

Note: RMSE is the average deviation from the trendline. It is easy to calculate and available in most statistical applications including Excel and R. Additional samples should continue to reduce RMSE even if some residuals remained outside ± 1.5% of the fitted trendline. RMSE is a readily understood and interpreted single value aggregated measure that is easily incorporated into the time-series metadata filed comments.

Annual validation of neutron probes is by way of stable reference standards, i.e. sealed drums of various materials of known water contents. The known water content in each drum is established using a calibrated neutron probe. It does not matter what the drum water content values are provided the annual validation readings remain within ± 0.5% of those values (see NEMS *Soil Moisture* v2.0.0: Sections 3.3.2.2 and 3.3.2.3).

2.3.3 Reliability of reference values

When using reference values, the following should be considered and assessed:

- the units of measurement of the in-situ and reference sensors, and the supplementary measurements and conversions necessary to achieve compatibility (see Section 3.1 of NEMS *Soil Moisture* v2.0.0 and Section G 1.3)
- the need for compensation for soil temperature and/or conductivity (see NEMS *Soil Moisture* v2.0.0: Sections 3.4 and 3.5 and Section G 1.4)
- timing of the reference measurement or collection of each sample with respect to in-situ sensor readings

  Note: The data-logger reading immediately before any disturbance caused by sampling should be used.

- reference measurement stability and location, or sample location(s) relative to the sensor (see NEMS *Soil Moisture* v2.0.0: Sections 3.3.1.1 and 3.3.1.2)

  Note: Location includes depth in the soil profile. Reference readings are taken near each end of a ribbon sensor then averaged. If cable stops are used to position a neutron probe, its depth is sensitive to elevation of the top of the access tube. If a neutron probe is used too close to the surface it will underread because neutrons escape from the soil and are not reflected back to the probe's detector. Neutron probe sampling radius decreases with increasing soil moisture.

- records of calibration and validation of the neutron probe(s) used (see Section G 2.3.2)

  Note: Laboratory instruments are subject to the calibration and validation requirements of the laboratory method of analysis.

- integrity of sample(s) collected (see Annex C of NEMS *Soil Moisture* v2.0.0)
- precision and accuracy of the reference readings or sample results

Note: Sample drying temperature may result in loss of organic matter as well as water content (Birendra et al, 2016). Results for stony soils may need adjusting for stone content.

- stability of the in-situ sensor electronically, and with respect to settling after installation (see Section 2.2.9 of NEMS *Soil Moisture* v2.0.0).

  Note: Buried sensors may take up to two years to settle.

A reference reading is unreliable, and must be identified as such in any field calibration analysis if:

- it is outside the calibrated range of the reference probe (see Section G 2.3.2)
- the reference probe field calibration is yet to achieve a minimum of fifty samples and an RMSE ≤ 1.5% (see Section G 2.3.2), or
- the reference probe fails its next validation check (see Section G 2.3.2).

The field calibration relationship of the in-situ sensor must not be changed solely on the basis of an unreliable reference reading.

If more than six (6) months has elapsed since the most recent verification visit (i.e. site inspection during which one or more reference readings were obtained), data from that period cannot be quality coded QC 600. Data recorded more than twelve (12) months on from the most recent verification visit cannot be quality coded higher than QC 400 (see Section 2.2.9 of NEMS *Soil Moisture* v2.0.0).

If a verification check is disregarded as unreliable:

- an Operational Comment is required giving reason(s), and
- date of the disregarded visit cannot be used to determine the verification frequency for quality coding purposes.

2.3.4 Laboratory results

Laboratory results must be supplied as the raw unrounded measurement value with its associated uncertainty of measurement (UoM) to be useful for:

- field calibration of instruments, and
- verifying the continuous data collected.

Note: For laboratories this may be a departure from their standard practice and will require prior arrangement.

Laboratory results are subject to extensive quality processes but errors, usually of human origin, may still arise. Agencies making use of laboratory results must ensure procedures exist and are implemented to ensure any error found is identified, and corrected wherever possible, at every instance of the result being stored, including at the source laboratory, to prevent future transfers of results reintroducing the error.

2.4 Deviation tests

Monitoring deviations over time, e.g. by control or run charts or similar, is largely redundant for quality control of soil moisture data. The information provided can be incorporated into the field calibration analysis (see Section G 4).

Deviation with range (see Section 3.6.4.5, Figure 13) may also be useful to investigate any non-linearity of the field calibration relation but may be indistinguishable from calibration drift until the installation has fully settled.

3 Potential Errors and Recommended Editing

This section describes common problems specific to soil moisture data and guides selection of an appropriate method for data repair, including what metadata are then required to be applied and filed.

3.1 Sources of errors

- The site environs, with respect to undocumented and/or unknown variations and/or changes in:
- drainage, and associated depth to the water table
- land use
- irrigation practice, application and/or methods
- crop type and stage and/or other ground cover, and
- proximity to undesirable features (see Section 1.3.3 of NEMS *Soil Moisture* v2.0.0).
- Site factors:
- variations in soil type through the profile (see Sections 2.2.3.1 and 2.2.3.2 of NEMS *Soil Moisture* v2.0.0), and
- relative locations of the sensor and gravimetric sampling locations and/or reference probe access tubes.
- Instrument deployment:
- orientation of the sensor (see NEMS *Soil Moisture* v2.0.0: Sections 2.2.4, 2.2.5 and 2.2.7)
- degree of disturbance of the soil profile (see Section 2.2.9 of NEMS *Soil Moisture* v2.0.0), and
- voids around the sensor and/or access tubes.

  Note: Stony and shrink-swell clay soils are prone to this problem (Birendra et al, 2016).

- Interference, deterioration, and damage caused by:
- installation (sensor prongs bent and/or not parallel)
- stock and/or machinery (e.g. trampled, mowed, ploughed etc.)

- unintentional wetting of and/or ponding over the sensor
- soil compaction (e.g. from human, animal, or irrigator traffic)
- excavation
- vandalism
- static discharges to the wave guides, and
- nearby electrical or radio equipment (e.g. electric fences),

  Note: TDR and some TDT sensors are not subject to electrical errors because they use time and not current or voltage to measure the soil dielectric, while capacitance sensors are very susceptible (Birendra et al, 2016).

- Instrument performance:
- maintenance of calibration
- over-ranging
- electronic transients. and
- sensitivity to soil temperature and/or conductivity (see Sections 3.4 and 3.5 of NEMS *Soil Moisture* v2.0.0).

3.2 Steps in the data

Steps in soil moisture data may be real, in response to plant transpiration, or erroneous due to recording problems.

Daily cycles associated with plant transpiration may appear as steps if recording resolution is close to the range of the cycle (see Figure G 1). They will be apparent when soil moisture is between field capacity and permanent wilting point and plants are present and growing. Values step down around the middle of the day from a daily maximum in the very early morning.

Erroneous steps may result from:

- sensor replacement (soil moisture and/or supplementary variables) (see Sections G 3.2.1 and G 1.4)
- disturbance around the sensor, e.g. the taking of reference samples (see Section G 2.3.1)
- a sensor and/or logger configuration error (usually confined to analogue sensors outputting current or voltage) (see Sections G 3.2.2 & G 3.9)
- a fault with the sensor(s), including those measuring the supplementary data used for temperature and/or conductivity compensation (see Sections G 3.2.2 and G 1.4).

Cause of the step dictates which data should be repaired and how.

Adjustments applied to the recorded data must reflect assumptions made about the nature, timing, duration, and magnitude of the error.

3.2.1 Instrument replacement and disturbance

Describe an instrument replacement and/or relocation in an Operational Comment (see Section G 5.2.3). If the replacement instrument is a different type, brand, or model, include its details in a corresponding Equipment Comment (see Section G 5.2.2).

Record when and where soil samples are taken from near the sensor in an Operational Comment (see Section G 5.2.3).

A new field calibration relation is required for a new soil moisture sensor and/or installation (see Section G 4). The new relation applies from the time of the instrument replacement or relocation without any gradual transition. Another period of settling is likely during which field calibration may drift, so subsequent revisions to the field calibration must be made until it is again stable.

If the data collected after replacement, relocation, or sampling remains offset from data previously collected despite reliable and stable field calibrations, leave the bias in the data, but identify and explain it in a Stationarity Comment (see Section G 5.2.7) filed at the time of the instrument replacement or disturbance that initiated the change.

3.2.2 Offset errors

Offset errors may be due to sensor and/or logger configuration errors or to unexplained electronic glitches. Offset errors in soil moisture data must be identified and the bias removed before field calibration is attempted. Offset errors in required supplementary data must be identified where possible and the bias removed then compensation revised if the bias has affected recorded soil moisture values (see Section G 1.4).

Note: It is possible for the offset error to occur when supplementary values are logged rather than when measured, in which case, depending on the recording system, compensation may be unaffected by the error.

A configuration error will be coincident with a site visit or remote update of a logger program. Remove the incorrect offset from the affected data then reapply the correct one (see section G 3.9.2).

Electronic glitches may occur at any time and may remedy themselves, reversing the initial step. They can be difficult to detect. Visible bias such as a shift in the value of a key threshold, e.g. field capacity, and/or recession discontinuity in a plot of the data may be the only clue (see Figure G 2). Comparison plots, and reference readings if available, help confirm which period either side of a step is correct, and which is offset and requires adjustment to remove the bias.

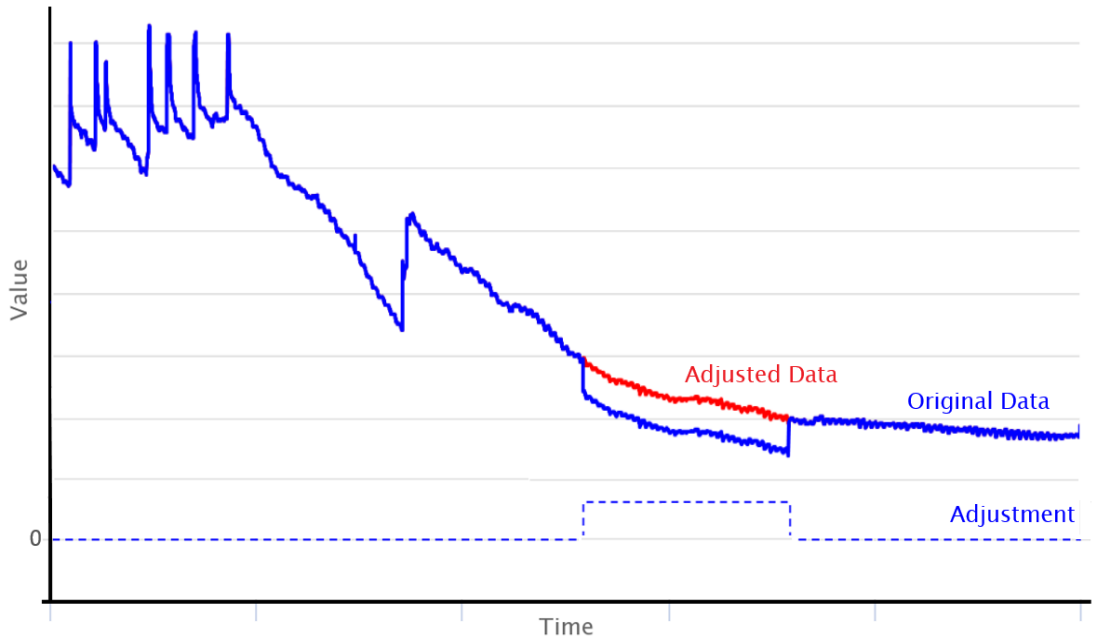


Figure G 2 – An example of part of a recession offset by a constant or near-constant amount (blue line) with the adjusted data (red line) and showing the offset shift adjustment applied (blue dotted line).

Table G 1 – Guidance for resolving steps in the data

Guidance for resolving steps in the data		see Section(s)
Issue(s)	Sudden change in soil moisture between successive readings that disrupts continuity of pattern in the data, especially of a recession or values of key thresholds, e.g. field capacity.	G 3.2
Evidence	Physical cause is identified (observed or verified at site, or consequence of an event known to have occurred). Trace of data when plotted steps unexpectedly up (and/or down). May be other evidence of bias (reference values and comparison plots).	Fig. G 2 G 2 3.6
Solution(s)	No adjustment if due to different instrument type or change of location (stationarity is disrupted). Rescale if instrument configuration was wrong. Apply an offset shift to the biased period if an offset error.	G 3.2.1 G 3.9 G 3.2.2 4.2
Metadata	Operational Comment required for change of instrument or location. Equipment Comment also required if instrument type or specification changed. Stationarity Comment required at step. If offset shift or rescaling is fully traceable, quality code is unaffected, but a Transformation Comment is required. Otherwise, 'minor' or 'significant' modification criteria apply and a Data Processing Comment explaining identified cause and details of the adjustment(s) applied (amount, type, and period of adjustment) is required.	G 5.2.3 G 5.2.2 G 5.2.7 G 3.2.2 G 3.9 & G 5.2.6 G 5.1 6.2.3 G 5.2.5 6.2.4

3.3 Drift

Drift apparent in soil moisture data from in-situ instruments is most likely associated with calibration drift as the installation settles or is a consequence of drift in the supplementary sensor(s), which, unless those measurements are logged separately and field checked, may be extremely difficult to detect.

In any case, elapsed time before drift is detected and confirmed depends on verification frequency and rate of drift.

Drift in soil moisture data is recommended to be addressed as part of the maintenance of the field calibration (see Section G 4). Drift adjustment as described in Sections 4.4 and 4.5 should not be used.

3.4 Spikes

Soil moisture measurements may spike to higher or lower values depending on the instrument and cause. Spikes in a record from a sensor below the root zone may be real and indicate a drainage event.

Spiking to spurious values must be edited. In many cases they are due to electronic transients and may become more frequent prior to a sensor failing completely. Spurious values may also be due to electrical interference, or surface water entering voids around the sensor.

Isolated spurious values may be deleted or replaced. If deleted, the interpolation engine can be left to interpolate between the remaining adjacent values unless regular interval data are required.

Intermittent spurious values may be deleted manually or discarded using a numerical filter. A track minimum or maximum (as applicable) or a rate of change filter may be more successful than a threshold filter if there is frequent spiking to values within the range of the reliable data.

If only one or two successive values are removed at each occurrence the interpolation engine can be left to interpolate between the remaining adjacent values unless regular interval data are required. If more than a few successive values are removed gap processes are then required (see Sections 4.16 to 4.19, and G 3.11).

If spurious values are frequent, persistent, and affecting consecutive values, treatment as noise is necessary (see Section G 3.5).

Table G 2 – Guidance for resolving spikes in the data

Guidance for resolving spikes in the data		see Section(s)
Issue(s)	Spurious values recorded.	G 3.4
Evidence	Value significantly different from adjacent values. Observable in a plot of the data. Confirmation by comparison plots and field investigation, and elimination of cause if possible.	Fig. 32 G 2 3.6
Solution(s)	Delete or replace spurious values. If more than a few consecutive values are removed, missing data processes are also then required. If spurious values are frequent, persistent, and affecting consecutive values, treatment as noise is necessary.	4.11 or G 3.11 or G 3.5
Metadata	QC 500 and Data Processing Comment required explaining identified cause and whether values are deleted or replaced, OR Refer to missing data or noise treatment guidance as applicable. Comments may be aggregated if frequent and repetitive.	G 5.1 6.2.3 G 5.2.5 6.2.4.7 or G 3.11 or G 3.5

3.5 Noisy data

Noise in soil moisture data may be due to:

- frequent persistent interference
- loss or lack of on-board soil temperature and/or conductivity compensation
- imminent failure of the sensor electronics
- erratic measurements due to the presence of air gaps around sensors and access tubes.

Noise within expected precision of the sensor need not be edited. Excessive noise may be filtered out manually or by machine algorithm.

If the noise appears to be randomly distributed about the expected true value an averaging, moving mean, or median of values filter may be used. The averaging window should not be so long as to induce hysteresis in the data.

If the noise appears biased toward higher (or lower) values, use a track minimum (or track maximum) filter. Carefully assess the edited data to confirm that the values retained are not also biased.

If insufficient values are retained to reliably represent the measured soil moisture, treat the period as missing data (see Section G 3.11).

Table G 3 – Guidance for resolving noisy data

Guidance for resolving noisy data		see Section(s)
Issue(s)	Noise obscures representative signal. Range of fluctuations compromises precision.	G 3.5
Evidence	Noise not seen in independent observations. Trace when data are plotted is 'fuzzy'. Variation between adjacent values is larger than is normal or expected from resolution of the instrument. Noise is absent after cause is addressed.	Fig. 7 Fig. 33 G 2 3.6
Solution(s)	Resample, or 'smooth' manually or by applying a statistical filter. Filter choice is determined by whether noise is apparently random or biased. Some cautions apply.	G 3.5 Fig. 33 4.12
Metadata	QC 500 or QC 400 depending on 'minor' or 'significant' data modification, and Data Processing Comment explaining identified cause and method applied, OR Refer to missing data guidance as applicable.	G 5.1 6.2.3 G 5.2.5 6.2.4.7 or G 3.11

3.6 Over-ranging

Over-ranging occurs when measurements exceed the manufacturer's stated range for the sensor, including range for supplementary measurements made by the sensor that are used for on-board compensation. Values returned when a range is exceeded are brand dependent and may be an error code.

Data loggers and some sensors may prevent recording of values and create a gap or a flag when measurement range is exceeded. Others may continue to output values. If not flagged by the instrument, over-ranging of measurements used for on-board compensation may be difficult to detect unless the supplementary measurements are also logged and reviewed.

When processing soil moisture data it is important to identify when over-ranging may be an issue and be alert to the possibility of consequent false values or data loss.

False values must be removed from the record, then treat as for missing data.

Table G 4 – Guidance for resolving over-ranging

Guidance for resolving over-ranging		see Section(s)
Issue(s)	No data, or false values may be recorded.	G 3.6
Evidence	Gaps or error flags in the record when adjacent values are near the limits of manufacturer's stated range.	4.16 G 3.6 G 2

	Recorded values exceed manufacturer's stated range for the variable (primary and/or supplementary measurements affecting primary values).	3.6 G 1.4
Solution(s)	Remove false values and error flags. Treat all consequent gaps as missing data. Some infilling of gaps may be feasible, but cautions apply.	G 3.6 4.16 to 4.19 incl.
Metadata	Refer to missing data guidance.	G 3.11

3.7 Saturation bias

For soil moisture, saturation is a real phenomenon that occurs when water content exceeds field capacity of the soil. If surface ponding occurs over the sensor due to surface depressions, the measured soil moisture will be elevated and misrepresent the site.

Surface depressions over the sensor may form as the installation settles or the area is traversed, and their presence should be monitored. Any depression found should be noted and remedied (see Section 2.2.10 of NEMS *Soil Moisture* v2.0.0).

If a surface depression over the sensor is observed, review the prior data for possible bias. Comparison with rainfall and/or irrigation records may reveal more frequent and/or prolonged periods of saturation. Suspected periods of bias may be retained in the record but must be quality coded as QC 400 (compromised) and a Data Comment filed alerting to the possibility of bias, the reason for the bias, and the date and time of site remediation.

Table G 5 – Guidance for resolving saturation bias

Guidance for resolving saturation bias		see Section(s)
Issue(s)	Periods of high moisture content and saturation may be over-represented.	G 3.7
Evidence	Surface depressions noted over the sensor. Comparison plots may indicate more frequent and/or prolonged saturation events compared to rainfall and/or irrigation depth.	G 3.7 G 2.2 3.6
Solution(s)	Downgrade the quality code of periods suspected to be biased.	G 3.7 6.2.3
Metadata	QC 400 and a Data Comment explaining the downgraded quality code.	G 3.7 G 5.1 6.2.3 G 5.2.4 6.2.4.6

3.8 Sensor exposure

A sensor may become exposed inadvertently if the soil around it falls away due to erosion, slumping or pit wall collapse, or by deliberate removal, legitimate or otherwise. Cause should be evident from site inspection or may be advised by the land occupier.

Measurements after exposure will not be representative, may be offset, and possibly erratic.

Remove affected data from the record and treat the period as missing data (see Section G 3.11).

Table G 6 – Guidance for resolving sensor exposure

Guidance for resolving sensor exposure		see Section(s)
Issue(s)	False values are recorded.	G 3.8
Evidence	Physical cause is known or identified (observed or verified at site, or consequence of an event known to have occurred). Recorded values are not representative and may be erratic.	G 3.8 G 2 3.6
Solution(s)	Remove false data and treat as missing.	4.16 to 4.19 incl. G 3.11
Metadata	QC 300 if replaced with synthetic infill, or QC 100 if left missing. Data Comments are required explaining identified cause and providing details of decisions made and methods applied.	G 5.1 6.2.3 G 5.2.4 6.2.4.6

3.9 Incorrect scaling

Incorrect scaling means that the range of the data is wrong by some factor. The problem usually arises from:

- wrong measurement units, or
- incorrect sensor and/or logger configuration.

3.9.1 Wrong measurement units

Data in the wrong measurement units are recoverable without impacting data quality if all necessary information is available to explicitly convert values (see Section G 1.3).

- Metadata must state the units of measurement, and the conversion applied and units in which the data are stored when different (see Sections G 5.2.2 and G 5.2.6).

- Any change to the density values used to convert between units (see Section G 1.3) must be noted in a Stationarity Comment (see Section G 5.2.7).
- Verification data must be in the same measurement units as the continuous data collected to be directly comparable.
- Field calibration relations should be derived in the units required for archiving the data, so associated uncertainty and goodness of fit relates to the data in its final form.

3.9.2 Wrong instrument configuration

Analogue sensors that output a current or voltage require a multiplier and offset to be applied by the data logger to convert sensor signal to measurement units. If the multiplier is incorrect a scaling error arises that will show as differences in subsequent verification checks that vary in proportion to the logged value and/or unrealistic values for the soil type and conditions. If the configuration was changed part way through a continuous record, there may be a step in the data at the time of the change.

To correct the data, remove any offset applied, then divide by the incorrect scaling multiplier to obtain raw signal, then multiply the raw signal by the correct scaling multiplier, then apply an appropriate revised offset (i.e. recalculated using the raw signal and its correct multiplier).

If the necessary transformations are fully traceable and do not compromise precision, there is no effect on quality code.

Table G 7 – Guidance for resolving incorrect scaling

Guidance for resolving incorrect scaling		see Section(s)
Issue(s)	Scale and/or units of the data is/are wrong.	G 3.9
Evidence	Differences between reference and logged values are variable and often large. Data inconsistent with expected range. A step-change occurs at time of configuration change.	G 3.9 G 2 3.6
Solution(s)	Apply conversion equations, to equivalent precision, if measurements are in the wrong units. For instrument configuration errors, apply transformations reversing the applied instrument configuration parameters to obtain raw signal, then apply the correct configuration parameters to the recovered raw signal.	G 3.9.1 G 1.3 G 3.9.2 4.7
Metadata	If the correction required is fully traceable, quality code is unaffected, but a Transformation Comment is required. Otherwise, 'minor' or 'significant' modification criteria apply and a Data Processing Comment explaining identified cause and details of the amount and period of adjustment is required.	G 3.9 G 5.2.6 G 5.1 6.2.3 G 5.2.5 6.2.4

3.10 Time faults

A time shift may be needed to obtain data in NZST or to correct for an incorrectly configured or defaulted logger (see Section 4.3).

If the time fault caused existing data to be overwritten or conflicting new data elements to be discarded, some missing record at period start if shifted forward, or period end if shifted back, is also a consequence that must be addressed (see Section G 3.11).

Time drift adjustment is rarely needed with modern electronic loggers (see Section 4.6). If logger date/time does not agree with actual date/time it is more likely the logger has stopped and there is a gap in the record, possibly unmarked, needing to be identified and addressed.

Most time-series management software has the ability to make time adjustments simultaneously with value adjustments. There is risk when using drift adjustment tools that time is unintentionally adjusted and time faults are introduced into the processed data. This is relatively easy to detect in fixed interval data by analysing the timesteps or inspecting the timestamps.

Table G 8 – Guidance for resolving time faults

Guidance for resolving time faults		see Section(s)
Issue(s)	Temporal distribution of recorded data is wrong and/or data are missing.	G 3.10
Evidence	Logger date/time is different from actual at inspection. Investigation finds configuration error or reset, and/or temporal anomalies are apparent when compared with data from a nearby rain gauge or similar soil moisture site.	Fig. 18 Fig. 26 G 2 3.6
Solution(s)	If wrong time zone, apply time shift then address any missing record created at the start (or end) by the shift. If clock is slow or fast, apply time drift adjustment, OR if clock stopped, treat period until restart as missing record.	4.3 or 4.6 Fig. 19 Fig. 27 and/or G 3.11
Metadata	If the time shift is fully traceable, quality code is unaffected, but a Data Processing Comment is required explaining identified cause and details of the shift applied. QC 100 if missing, or QC 300 if infilled, and a Data Comment. Some cautions apply. Otherwise, 'minor' or 'significant' modification criteria apply and a Data Processing Comment explaining identified cause and details of the amount and period of adjustment is required.	4.3.3 G 5.2.5 6.2.4.7 G 5.1 6.2.3 G 5.2.4 G 5.2.5 6.2.4

3.11 Missing data

When considering the treatment and associated metadata requirements for missing continuous soil moisture data the following broad descriptions of duration are helpful:

- a brief period is a few recording intervals up to an hour
- short duration is between adjacent peaks and troughs of the diel transpiration cycle, or of runoff events, i.e. within the rising or falling side of the cycle or event, but not over the peak or trough
- a longer period may be one or more days up to one week
- an extended period may be a week or more.

Soil moisture can be strongly influenced by local factors and large seasonal differences in variability, so similarity between nearby sites is rarely adequate to synthesise data to infill a gap from record at a donor site.

Backup instrumentation is not usually installed at soil moisture sites but there may be multiple sensors installed through the soil profile. Depending on the fault that has caused the missing data, record from a sensor at another depth may be available to assist with filling a gap at another, by confirming the presence or absence, and pattern and timing, of features and events in the data.

- A brief gap may usually be closed and left to interpolate (see Section 4.17).

Note: Slight truncation of a runoff peak may result but is of minimal consequence for most users of soil moisture data.

- Fill a short period with reference readings if available (see Section 4.18) or by manually adding values to complete the curve (see Section 4.19).
- Adjust the reference readings by the inverse of the field calibration relation before adding into the in-situ record if the gap is infilled before the field calibration is applied.
- A longer period may be filled if soil moisture is in recession and no rainfall or irrigation occurred during the gap.
- Copy in a piece of similar record from another time period, but preferably the same season, at the same site, or from a nearby site that shows similar daily patterns within a similar recession.
- Some offset adjustment, or slight drift adjustment at start and/or end of the infill, may be needed to avoid creating a step in the recipient data.
- The end result must reflect the range and timing of the adjacent recorded diel cycles if present and not create a discontinuity in the overall recession of the recipient data.
- Infill of an extended period is not recommended.

Table G 9 – Guidance for resolving missing data

Guidance for resolving missing data		see Section(s)
Issue(s)	Data are missing.	G 3.11
Evidence	Expected timestamps are not present in the original data. A gap marker may or may not be present depending on data collection method. Comparison plot shows entire, or parts of cycles or events are missing. Investigation confirms data were not logged and/or not collected. Data have been intentionally removed.	4.16 Fig. 9 G 2 3.6
Solution(s)	Use verification readings where available, and/or: if brief, interpolate across gap if short period, interpolate across gap, or manually infill with a curve, but not over a peak or trough for longer periods, in recessions only, copy in a piece of similar trace from same or nearby similar site otherwise mark the gap or note a temporary site closure.	G.3.11 4.16 to 4.19 incl. 5.4 & 5.5
Metadata	QC 500 if brief and interpolated. Otherwise, QC 300, or QC 100 if left as missing. Data Comments are required explaining identified cause and providing details of decisions made and methods applied, and reliability of the infill.	G 5.1 6.2.3 G 5.2.4 6.2.4.6

4 Field Calibration

4.1 Field calibration data

Field calibration requires clean continuous in-situ data (see Section G 3) and reliable reference values (see Section G 2.3.3).

Reference values collected over as wide a range of moisture content as possible in a relatively narrow timeframe are preferred to avoid the influence of calibration drift.

Ideally, the reference values are obtained by taking samples of the soil near the sensor and analysing them gravimetrically in a laboratory, but collection of the samples disturbs the sensor environment we are attempting to calibrate, so use of a suitably calibrated and validated neutron probe (see Section G 2.3.2) is preferred.

Reference values are obtained with the neutron probe via suitably located permanently installed access tubes at depths consistent with depth(s) of the in-situ sensor(s) or, in the case of strip (ribbon or tape) sensors, from the average of the probe readings at both ends of the strip.

A minimum of three, and ideally up to seven, calibration points over a wide range of values between field capacity and wilting point are required to confirm linearity of the relation.

4.2 Deriving the field calibration relation

Deriving the field calibration relation is a modelling exercise. As such it requires:

- analysis of the available data, and
- consideration of alternatives within the context of:
- robustness of the relation
- linearity of the relation
- likelihood that the relation slope and constant differ significantly from 1 and 0 respectively (i.e. sensor scale and offset are significantly different from 1:1 and zero)
- the possibility of calibration drift
- the nature of the drift (e.g. linear or non-linear, episodic or gradual, range of values affected etc.), and
- overall reliability of the result of calibration as reflected in the quality code(s) assigned to the calibrated time series.

Use one or more scatter plots (see Section 3.6.4.1, Figure 10) to develop and maintain the field calibration relationship(s).

- Reference readings must be the y-values in the scatterplot if fitting trendlines to obtain a regression equation(s) from the calibration that will be used to transform the in-situ values (see Appendix 2).
- Label each x-y pair in the scatter plot chronologically to assist assessment of any calibration drift with time.
- If using a time-series manager rating development toolbox:
- reference readings and calibrated values are the 'rated' data and the uncalibrated in-situ sensor values are the 'unrated'
- gap ratings may be used to halt application of any calibration relationship for a specified period
- synthetic ratings are not acceptable.

The field calibration relationship may change over time as soil profile disturbance from installation, and initial sampling to calibrate the neutron probe, settles (see Section G 2.3.2).

As new calibration points (i.e. verification data) are collected, assess whether their deviation from the current relation is outside the verification tolerance (see Section G 2.3.1).

- If not, revisit the quality code matrix assessment if the new data extend the calibrated range.
- If so, consider whether the existing relation should be modified, or a new relation developed (see Section G 2.3.1).
- If a new relation is decided, additional calibration points will be required to support it (see Section G 4.1).

- If deviation exceeds tolerance but a new relation cannot be justified, quality code is reduced as determined by the Quality Code Matrix (see Section 4.2 of NEMS *Soil Moisture* v2.0.0).

4.2.1 Example

Figures G 3, G 4, and G 5 show three interpretations of the same field calibration data.

In Figure G 3, beginning with the blue data, a new relation is derived when two consecutive checks are outside tolerance of the existing relation. The red relation technically has sufficient calibration points but two are close together, so linearity of that relation is inconclusive. The other two relations fit their calibration data, but both have slope and constant significantly different from 1 and 0.

In Figure G 4 the red data from Figure G 3 are used to modify the initial blue relation resulting in a slope and constant much closer to 1 and 0, but one calibration point that participates in determining the trendline is outside tolerance of the relation derived.

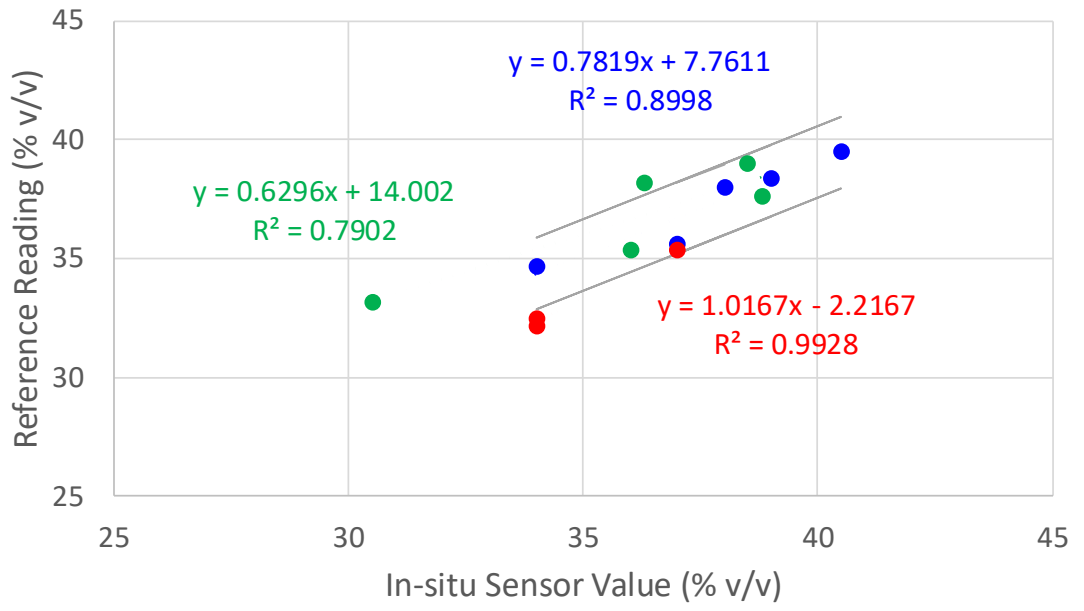


Figure G 3 – An example of a soil moisture sensor field calibration where dots are the calibration data, dotted lines are the trendlines for each of three derived relations over time (blue, red, and green) with their corresponding linear equations shown similarly colour coded. The grey lines are the tolerance of ± 1.5% v/v for the blue relation.

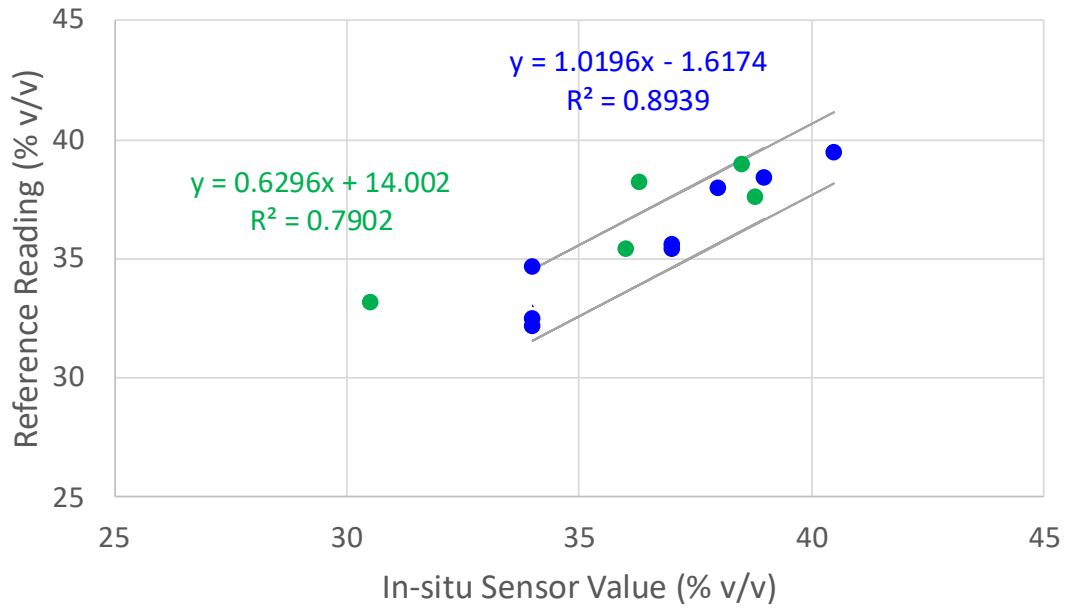


Figure G 4 – An example of a soil moisture sensor field calibration where dots are the calibration data, dotted lines are the trendlines for each of two derived relations over time (blue and green) with their corresponding linear equations shown similarly colour coded. The grey lines are the tolerance of ±1.5% v/v for the blue relation.

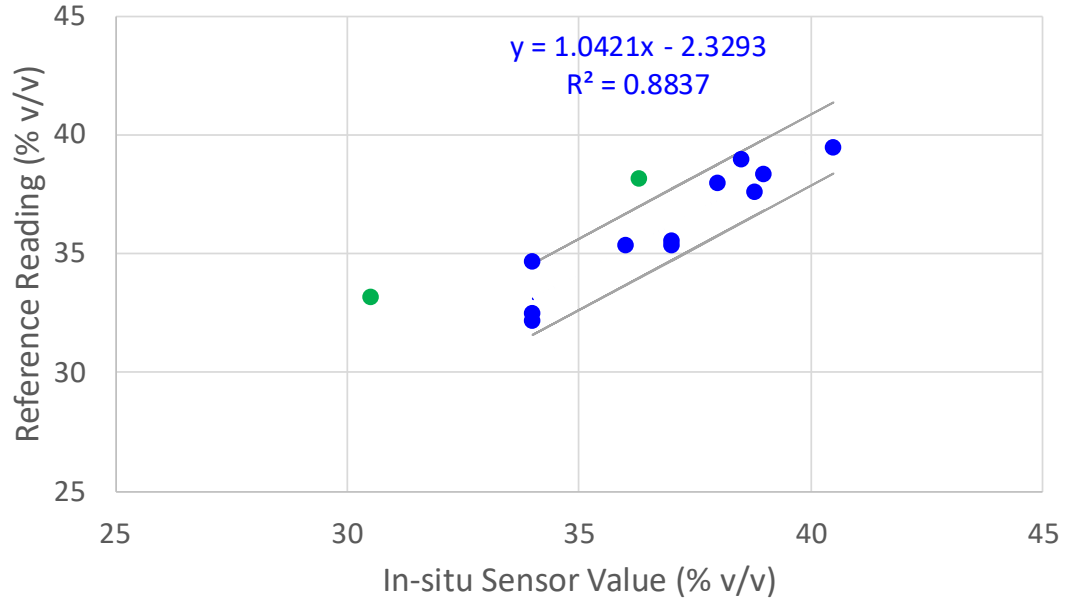


Figure G 5 – An example of a soil moisture sensor field calibration where dots are the calibration data, the dotted line is the trendline fitted to the blue data with its corresponding linear equation shown. Green dots are outliers not used to derive the trendline. The grey lines are the tolerance of ± 1.5% v/v for the blue relation.

In Figure G 5 the later green data from Figure G 4 are noted as being close to the initial blue relation so the first two green calibration points have been set aside as outliers and the blue relation revised using all other data. The change to the relation from that shown in Figure G 4 is of little real consequence in terms of accuracy of the data and the

occurrence of outliers so revising the relation as in Figure G 5, and regenerating the derived calibrated data, is probably not justified.

For this example, regardless of the chosen interpretation of the calibration data, the calibrated range is too small (< 70% of the range between field capacity and permanent wilting point) for the resulting field calibrated time series to achieve QC 600. Other factors in the quality coding matrix determine whether each field-calibrated period can achieve QC 500.

4.3 Field calibration metadata

Where field calibration is undertaken, a field calibration history must be maintained, preserved, and be accessible.

Note: Suitable repositories are the site file, a calibration database (with the manufacturer's calibration information), or an asset management system.

The history must contain the following:

- the definition of each relation (e.g. the equation, lookup function, or rating point pairs)
- range and period of applicability of each calibration
- the calibration data, including their uncertainties and provenance (method of reference measurement, validation etc.)
- the method used to develop the relation(s)
- explanation of assumptions
- assessment of outliers
- observations and descriptions of any unusual or exceptional conditions impacting the relation(s)
- explanation of extrapolations beyond the calibrated range, if any
- the method used to apply the relation(s)
- the method used to transition between successive relations
- assessment of uncertainty of the relation(s) (see Section G 4.5)
- any other known or suspected limitations of the relation(s) that may affect use of the calibrated soil moisture data.

A Data Comment must be filed for any period of final record that is not field calibrated, explaining why a field calibration has not been applied.

4.4 Applying the field calibration

Apply the field calibration relation(s) to clean soil moisture data, after all other data processing operations have been completed.

Field calibration relations may be applied by one of the following methods:

- explicit transformation processes that write the transformed data to a new time series

- via the time-series manager's rating engine (transformed data are virtual; calculated as and when the data are accessed and not written to file), or
- using modelling facilities (transformed data may be 'virtual' or written to file depending on the facility).
- Different methods may be used for different sites, but method must be the same for the duration of any individual time series.

Unless there is an associated step in the uncalibrated data, transitions between successive field calibration relations must be gradual, pro-rated with time over the period of suspected calibration drift between each relation.

Retrospectively modifying field calibration relations (see Section G 4.2), maintaining their history (see Section G 4.3), and transitioning between successive relations is easier to implement using rating facilities; however, there are risks when exchanging or migrating rating definitions between time-series management systems (see Section 4.10.2).

4.5 Uncertainty of the field calibration relation

Uncertainty of a field calibration relation may be difficult to quantify; however, its component uncertainties must be described, either in the Transformation Comment (see Section G 5.2.6) or Rating Model Comment (see NEMS Rating Curves Section 1.2.2) as applicable, as follows:

- number of calibration points supporting the relation
- range of the calibration points
- time period over which the calibration points were collected
- uncertainties associated with the calibration points, if known
- range of the data calibrated by the relation
- tolerances applied when developing the relation (e.g. maximum acceptable deviation, number of permissible outliers etc.)
- outliers to the relation, their inclusion or exclusion when developing the relation, and their deviation from the adopted relation
- goodness of fit statistics, if obtainable (e.g. R^2 if the relation was derived by regression).

Note: Quality codes for soil moisture data include assessment against some of the above criteria but are affected by a range of other factors. The quality code ultimately assigned to the data is an indicator of its reliability and usability but does not directly quantify or convey its expected uncertainty.

5 Metadata

5.1 Quality coding

Quality code for soil moisture data is set by four different but related sets of criteria:

- the quality coding flowchart
- the quality coding matrix
- blanket provisions, and
- data editing actions and adjustments.

The quality coding flowchart and quality coding matrix may be found in NEMS Soil Moisture Measurement (Measurement of water held within soils) version 2.0.0.

Note: At date of publication of this Annex the quality coding flowchart available in NEMS National Quality Code Schema is the previous version 1.0.

5.1.1 The Quality Coding Matrix

The Quality Coding Matrix uses information about the site, installation, instruments, and field calibration range to differentiate between a maximum possible quality code of QC 400, QC 500, or QC 600 for the period of data to which each field calibration relation applies.

- Quality codes above QC 400 cannot be assigned before the field calibration relation is determined.
- Quality code may change retrospectively as new field calibration data are obtained.

Compensation for soil temperature and/or conductivity are not regarded as data editing but are included in the Quality Coding Matrix assessment.

5.1.2 Blanket provisions

The following provisions apply to soil moisture data in addition to the generic application of quality codes as set out in the quality coding flowchart descriptions:

- data suspected of saturation bias are limited to a quality code of QC 400 (see section G 3.5)
- supplementary data required to be permanently stored (see Section G 6) that are not verified and processed according to their relevant NEMS, or for which no NEMS Standard exists (see Section G 1.4) shall:
- retain quality code of QC 0 if the data are original (see Section 3.1.1) and not quality reviewed (see Section 7.2)
- be assigned QC 200 if quality reviewed (see Section 7.2) with or without verification data, or if edited from the original.
- maximum possible quality code of soil moisture values that are compensated for soil temperature, and/or conductivity using supplementary data during soil moisture data processing is the lesser of:
- the soil moisture quality coding matrix result (see Section 4.2 of NEMS Soil Moisture v2.0.0), and the final quality code assigned to the supplementary data if verified and processed to NEMS

- QC 500, and the soil moisture quality coding matrix result if the supplementary data are not processed to NEMS but are reviewed, and edited if necessary for gross error
- QC 400, and the soil moisture quality coding matrix result if the supplementary data are original as recorded and applied without their review.
- maximum possible quality code of soil moisture values that require compensation for soil temperature and/or conductivity but are not compensated is QC 400
- a period of record overdue its six-monthly verification cannot be quality coded QC 600. If verification is more than three months overdue the data since last verification cannot be quality coded higher than QC 400 (see Section G 2.3.3).

5.1.3 Data editing actions and adjustments

The quality code of any data collected may be affected by subsequent editing actions and adjustments made to the data. Minor modifications reduce quality code to QC 500. Significant modifications reduce quality code further to QC 400. Refer to Section 6.2.3 for definitions of 'minor' and 'significant'.

Compensation for soil temperature and conductivity, conversion between units of measurement, and application of the field calibration, has no additional effect on the quality code, i.e. these actions are effectively exempt from the quality coding flowchart data modification test.

Further guidance on how and when quality code must change as a consequence of data processing is provided in Section G 3 of this Annex.

5.2 Example soil moisture comments

The following are templated examples of comments for soil moisture stations.

Every comment must be assigned a fully specified timestamp and be associated with the relevant data (the time series of soil moisture measurements) via some form of 'Site' and 'Measurement' database key combination. The database keys are usually specified in some form of record header not shown here.

5.2.1 Site/Initial Comments

Type: Site
Measurement: Soil Moisture
Initial comment for soil moisture at *<site, property, or locality name>*
Site number *<network number, ID or code>* located at *<map co-ordinates and type[25]>*
In the catchment of the *<river name>* River, *<river number>*[26] (or *<name of water body>* as applicable) and is monitored for *<site purpose and target characteristics>*.
Soil type is *<provide brief description>* and land use is *<state predominant use>*.
Water content is monitored at *<depth(s) & units>* and *<not>* field calibrated.
Site plan and evaluation, and soil profile are available from *<reference>.*
Additional information: *<anything relevant to general interpretation of the record e.g. seasonal recording, compensation for conductivity, presence of obstructions, stock, artificial drainage and/or irrigation, verification frequency and method, adjacent sites>*.
<Some (or All) quality control (and/or data editing) is automated; refer to the relevant Data Processing Comments>.

The following is also measured at this site: *<list variables, including any sensors at other depths, and supplementary data, whether permanently stored or not>*.

The local recording authority is: *<name of recording and/or archiving agency>*

5.2.2 Equipment Comment examples

Type: Equipment
Measurement: Soil Moisture
Recorder installed on *<dd-mm-yyyy hhmmss>* is a *<describe main logger features e.g. how powered, compact (or otherwise e.g. PLC), on-board, multi- or single input, programmable etc.>* data logger recording *<describe logging and sampling regime e.g. instantaneous readings at fixed intervals of x-minutes>*. The sensor is a *<type and form e.g. dielectric TDR ribbon, TDT or capacitance probe, etc.>*, *<brief description of deployment method e.g. driven from the surface, inserted in a pit wall, laid in a backfilled trench, via access tube etc.>* and measures *<list relevant on-board measurements & their units, including any supplementary variables>* in the *<zone or layer description e.g. near-surface, root zone, topsoil, subsoil etc.>* at *<depth & units>* below ground surface.
Sensor range is *<range and units>* with resolution of *<resolution>* and nominal accuracy of *<accuracy specification>*. (Sensor output is converted to logged % water content by *<details of any transformation applied at the time of data capture or collection e.g. scaling multiplier and/or offset for an analogue sensor>*). Site is inspected *<verification frequency>*. Data are collected by *<method e.g. telemetry or manual download>*. Logged values are *<not>* field calibrated *<by method and frequency e.g. biannual neutron probe measurement or gravimetric sampling>*.

Explanation of sensor types, including abbreviations used, may be found in Annex B of NEMS *Soil Moisture* v2.0.0.

[25] state the co-ordinate system: NZTopo50 or NZGD 2000 preferred (latitude/longitude to 6 decimal places)
[26] from *Catchments of New Zealand* (SCRCC, 1956).

Type: Equipment
Measurement: Soil Moisture
Verification (and field calibration) reference data are obtained *<state frequency>* by *<describe method(s) and instrument(s) used e.g. gravimetric analysis of individual samples or sections of a core extracted from locations x to y metres from the sensor, and/or manual readings from a field calibrated neutron probe via access tube(s) placed x metres from the sensor etc.>*. *<Add other relevant information such as range, units, serial number, calibrated range, and validation frequency of the neutron probe, bulk density, and/or cross-reference to laboratory results and sample metadata; how the reference data are supplied (e.g. collected at each agency site visit, or via paper, email, or electronic transfer from the land occupier or a third party); and where the reference data are stored>*.

To avoid comments becoming too long and complex, create similar but separate comments for:

- each sensor at the site if multiple sensors are deployed at different depths, and/or
- sensor replacements if previously described details change as a consequence. Include confirmation that all other details have not changed. For example:

Type: Equipment
Measurement: Soil Moisture
Replacement soil moisture sensor is a *<type and form e.g. dielectric TDR ribbon, TDT or capacitance probe etc.>* installed on *<dd-mm-yyyy hhmmss>* at *<describe where in relation to replaced sensor>*. New sensor range is *<range and units>* with resolution of *<resolution>* and nominal accuracy of *<accuracy specification>* and is *<not>* field calibrated. Sensor output, calibration frequency and method, site visit frequency, and data collection method are unchanged.

5.2.3 Operational Comment examples

Type: Operational
Measurement: Soil Moisture
Sensor replaced on *<dd-mm-yyyy hhmmss>* because *<provide reason>*. *<Replacement sensor is a different type (or model) (or range) (or deployment). Refer to the associated Equipment Comment for sensor specification and/or deployment details.>*

Type: Operational
Measurement: Soil Moisture
Sensor relocated on *<dd-mm-yyyy hhmmss>* to *<where in relation to previous>* because *<provide reason for relocation e.g. instrument replaced, to avoid interference or obstruction, land use change etc.>*. New location is *<describe new environment>*. New sensor position is in the *<zone or layer description e.g. near-surface, root zone, topsoil, subsoil etc.>* at *<depth & units>* below ground surface.

If a sensor is relocated a Stationarity Comment is also required (see Section G 5.2.7). If a sensor is replaced and relocated, the above two comments can be combined.

Type: Operational
Measurement: Soil Moisture
Soil sample for gravimetric analysis collected on *<dd-mm-yyyy hhmmss>* at depth *<depth from ground surface>* from *<distance and compass direction or bearing>* of the sensor for the purpose of verification (and and field calibration) of the sensor (and/or the reference neutron probe).

Type: Operational
Measurement: Soil Moisture
Verification reference reading on *<dd-mm-yyyy hhmmss>* is unreliable because *<give reason> <and is excluded from field calibration of the sensor>*.

A comment for every verification reference reading assessed as unreliable is recommended in a soil moisture record because reference readings are infrequent but crucial to field calibrating the sensor and identifying and quantifying sensor drift. There is no other way to calibrate a soil moisture record for site variations and installation effects, or to validate the performance of an in-situ sensor while it is installed.

5.2.4 Data Comment examples

Type: Data
Measurement: Soil Moisture
Missing record from *<dd-mm-yyyy hhmmss>* to *<dd-mm-yyyy hhmmss>* due to *<identified cause of recording failure>* (or values removed because of *<describe recording fault>*). *<Gap is for an extended period so is not filled.> <Add any other relevant information such as why the gap has not been filled if not an extended period>*.

Type: Data
Measurement: Soil Moisture
Data from *<dd-mm-yyyy hhmmss>* to *<dd-mm-yyyy hhmmss>* are measurements obtained by *<method>* that replace record affected by *<identified cause of recording fault or failure>*. *<Add any other relevant information e.g. who took the measurements, instrument or sample ID details etc.>*.

Type: Data
Measurement: Soil Moisture
Synthetic record from *<dd-mm-yyyy hhmmss>* to *<dd-mm-yyyy hhmmss>* due to *<identified cause of recording failure>* (or replaces data affected by *<describe recording fault>*). Record generated by inserting points to complete the curve (or inserting record from *<site, sensor depth, and date/time range> <adjusted by <method>* to merge with adjacent record>). *<Add description of any limitations on reliability or usefulness>*.

Type: Data
Measurement: Soil Moisture
Soil temperature from the soil moisture sensor (or an independent sensor at site) is logged at *<state recording interval>* intervals. Refer to the relevant Equipment Comment for sensor details. The data are used to compensate soil moisture readings on-board the sensor (or on the logger) (or during soil moisture data processing). The soil temperature data are reviewed and edited for gross errors but not verified prior to use and is archived as supplementary data (or is verified, processed, and archived as primary data at *<relevant site, time series and metadata identifiers>*).

Type: Data
Measurement: Soil Moisture
Change of datalogging interval on *<dd-mm-yyyy hhmmss>* from *<previous interval>* to *<new interval>*.

Type: Data
Measurement: Soil Moisture
Data may be compromised from *<dd-mm-yyyy hhmmss>* to *<dd-mm-yyyy hhmmss>* due to *<describe cause e.g. suspected or known interference or disturbance, sensor exposure, ponding in surface depressions over sensor, low power, suspected calibration drift, possible failure or range exceedance of supplementary sensor etc.>*. *<Add any other relevant information such as corroborating evidence, cautions on use of the data, and any mitigation subsequently applied such as a new field calibration or installation of an independent supplementary variable sensor including the date/time it is effective from>*

5.2.5 Data Processing Comment examples

Type: Data Processing
Measurement: Soil Moisture
Values deleted and record interpolates from *<dd-mm-yyyy hhmmss>* to *<dd-mm-yyyy hhmmss>* to remove spikes caused by *<identified cause>*. Edited by *<name>* on *<date of processing>*.

Type: Data Processing
Measurement: Soil Moisture
Values replaced from *<dd-mm-yyyy hhmmss>* to *<dd-mm-yyyy hhmmss>* to remove spikes caused by *<identified cause>*. Edited by *<name>* on *<date of processing>*.

Type: Data Processing
Measurement: Soil Moisture
Time shift of -1 hour is applied to convert period logged in NZDT from *<dd-mm-yyyy hhmmss>* to *<dd-mm-yyyy hhmmss>* to NZST. Error due to *<give reason e.g. incorrect clock reset at logger restart>*. Edited by *<name>* on *<date of processing>*.

Type: Data Processing
Measurement: Soil Moisture
Data adjusted from *<dd-mm-yyyy hhmmss>* to *<dd-mm-yyyy hhmmss>* by *<method and parameters e.g. offset shift of x % (or mm)>* to compensate for *<identified cause e.g. configuration error>*. Edited by *<name>* on *<date of processing>*.

Type: Data Processing
Measurement: Soil Moisture
Data smoothed using a *<time interval or number of values>* centred moving mean from *<dd-mm-yyyy hhmmss>* to *<dd-mm-yyyy hhmmss>* to minimise random noise caused by *<identified cause>*. Edited by *<name>* on *<date of processing>*.

Type: Data Processing
Measurement: Soil Moisture
From *<dd-mm-yyyy hhmmss>* (to *<dd-mm-yyyy hhmmss>*) automated quality control (and/or editing) is applied to this data. Actions include: *<briefly describe each action in specific terms e.g. Range Test: values < x mm or > x'* mm not accepted (or, removed (and gapped)); Flat Line Test: error flagged if n consecutive values are same; etc.> (or Actions are documented in *<provide reference to processing system documentation that contains specific detail of the tests applied to this data e.g. the site file, quality management system etc.>*), applied *<describe where in the process, with respect to what is original data, e.g. on the data logger (or telemetry system, etc.) prior to archiving as original data, or, after original data have been preserved but before near real-time web publication etc.>*, using *<provide name(s) of software and version and briefly describe how the actions are specified and/or configured in the system, and/or provide reference to where the code is permanently preserved, configuration files or screenshots are retained or similar>*.

Similar 'automation' comments must be provided each time any relevant detail changes, from change to an action threshold through to a change of organisational procedure and/or software. Cross-reference relevant Equipment and Operational Comments as required to avoid unnecessary duplication. File a corresponding Stationarity Comment if change of methods potentially disrupts stationarity of the data.

The level of detail required in 'automation' comments depends on the extent to which the comments are necessary to ensure traceability of changes made to the raw measurements (see Sections 3.1.1 and 8.2).

5.2.6 Transformation Comment examples

Transformations applied prior to archiving a soil moisture record are included here. Transformations of archived records to other forms of the variable, or to other variables of interest, for analysis or modelling are outside scope (see Section 6.2.4.8).

Field calibration transformations developed and applied using a TSM's rating engine must be commented as for rating curves. Refer to NEMS *Rating Curves* (Sections 1.2.1 to 1.2.5 inclusive and Annex L) for requirements, substituting uncalibrated soil moisture

for ‘recorded stage’, reference values for ‘gauged flows’ or ‘gaugings’, field calibrated soil moisture for ‘rated’, ‘derived’ or ‘recorded’ flows, and ± 1% for the deviation tolerance.

The first example needs only to be filed once at the start of the relevant archive record, not repeated for each period of data processed.

Type: Transformation
Measurement: Soil Moisture
Soil moisture is archived in millimetres of water per metre of soil transformed from sensor readings in % volumetric water content using the relation, depth = % v/v x10.

Type: Transformation
Measurement: Soil Moisture
Archived soil moisture is field calibrated from *<dd-mm-yyyy hhmmss>* to *<dd-mm-yyyy hhmmss>* by transformation using the linear (or nonlinear) relation *<provide equation>* derived by *<method>*. The calibration data comprises *<x>* samples (or neutron probe readings) obtained between *<dd-mm-yyyy hhmmss>* and *<dd-mm-yyyy hhmmss>* with range *<range & units of reference values>* and maximum deviation from the derived relation of *<deviation & units>*. Range of the calibrated data is *<range & units>*. *<Add other goodness of fit statistics as applicable e.g. regression coefficient R^2>*. *<A gradual transition pro-rated with time is applied from <dd-mm-yyyy hhmmss>* to *<dd-mm-yyyy hhmmss>* being the period of suspected drift between the previous and this field calibration>. Applied by *<name>* on *<date of processing>*.

Type: Transformation
Measurement: Soil Moisture
Data from *<dd-mm-yyyy hhmmss>* to *<dd-mm-yyyy hhmmss>* is transformed by Y' = [(Y – *<C>*) x (*<m'/m>*)] + *<C'>* to correct a scaling error. Logger parameters applied from *<dd-mm-yyyy hhmmss>* were multiplier *<m>* and offset *<C>*. Correct logger parameters are multiplier *<m'>* and offset *<C'>* applied on the logger from *<dd-mm-yyyy hhmmss>*. Edited by *<name>* on *<date of processing>*.

Type: Transformation
Measurement: Soil Moisture
Compensation for soil conductivity is applied from *<dd-mm-yyyy hhmmss>* to *<dd-mm-yyyy hhmmss>* by *<describe method, including equations or reference to them e.g. a manufacturer’s manual>* using *<frequency e.g. hourly or daily or simultaneous etc.>* soil conductivity readings (or estimates) from *<source of conductivity data or estimates>*. *<Add other relevant information e.g. description and limitations of assumptions, if any>*

5.2.7 Stationarity Comment examples

Type: Stationarity
Measurement: Soil Moisture
Sensor moved on *<dd-mm-yyyy hhmmss>* to *<where in relation to previous>* because *<provide reason for relocation e.g. instrument replaced, to avoid interference or obstruction, land use change etc.>*. Measurement of the target characteristics may be affected. Location and position details are available from the relevant Operational Comment. *<A new field calibration is effective from this date>*.

Type: Stationarity
Measurement: Soil Moisture
Step-change in data from *<dd-mm-yyyy hhmmss>* is coincident with change of sensor type (or location), (and/or deployment). Sensor and deployment details are available from the relevant Equipment Comments. Location details are available from the relevant Operational Comments. *<A new field calibration is effective from this date>*.

Type: Stationarity
Measurement: Soil Moisture
A change in land use (or irrigation practice) (or drainage) from *<description of previous>* to *<description of new>* effective from *<dd-mm-yyyy hhmmss>* at (or within) *<location relative to sensor e.g. x m (or km) upslope (or radius) etc.>* may affect soil moisture values recorded at this site after this date. *<Add references to other relevant information such as maps, farm plans, water use records, drainage plans etc.>*

Type: Stationarity
Measurement: Soil Moisture
Method to field calibrate the in-situ sensor is changed from *<dd-mm-yyyy hhmmss>*. Refer to the relevant Transformation Comments for method details.

Type: Stationarity
Measurement: Soil Moisture
Bulk density was resampled on *<dd-mm-yyyy hhmmss>* and the new value of 1.1832 g/m^3 applies from that date when calculating reference values of volumetric water content from the gravimetric water content results of gravimetric analysis.

Stationarity Comments can also be used to capture and collate information about historical methods and data.

6 Preservation of Record

For soil moisture sites, in addition to the requirements of Section 6 and 8 of this Standard, the recording agency must store and retain indefinitely, and, if electronic, back up regularly:

- the original data as defined (see Section 3.1.1), which may include on-board (the instrument) compensation for soil temperature and/or conductivity
- as supplementary data, soil temperature and/or conductivity that are not compensated for in the original soil moisture data collected, but for which compensation is necessary
- the time series of clean (compensated, verified and edited) uncalibrated soil moisture data
- if applicable:
- the field calibration history (see Section G 4.3), and
- the field calibration relations stored and implemented via the TSM's rating engine, or
- the field-calibrated time series as transformed by applying the field calibration relations to the clean data series, and
- the field calibration metadata.

7 References

Birendra KC, Breneger S, Curtis A. 2016. *Soil Moisture Monitoring – Book 11.* Irrigation New Zealand. Christchurch, New Zealand. Retrieved from https://www.irrigationnz.co.nz/Members%20Only/good%20management%20practice/Book11-SoilMM.pdf (21 April 2021).

Soil Conservation and Rivers Control Council (SCRCC). 1956. *Catchments of New Zealand.* SCRCC, Wellington.

Annex H Dissolved Oxygen Data Processing

1 General Overview

This Annex contains further processing guidance specific to continuous dissolved oxygen (DO) data measured using in-situ optical sensors and stored as data type instantaneous (continuous) (see Section 1.1.1).

The general principles also apply to a time-series record of DO compiled from discrete measurements (see Section 1.1.2) obtained using a hand-held optical instrument.

1.1 Normative references

This Annex shall be read in conjunction with the following references:

- NEMS Dissolved Oxygen – Continuous Measurements of Dissolved Oxygen for Environmental Monitoring Purposes
- NEMS Water Quality
  - *Part 1 of 4: Discrete Sampling and Measurement of Groundwater Quality for Environmental Monitoring Purposes*
  - *Part 2 of 4: Discrete Sampling and Measurement of River Water Quality for Environmental Monitoring Purposes*
  - *Part 3 of 4: Discrete Sampling and Measurement of Lake Water Quality for Environmental Monitoring Purposes*
  - *Part 4 of 4: Discrete Sampling and Measurement of Coastal Water Quality for Environmental Monitoring Purposes*

Where reference is made from this Annex to specific sections of the above documents, the title is abbreviated and version stated, e.g. 'NEMS *Dissolved Oxygen* v3.0.0'. Where requirements and/or procedure in this Annex duplicate and possibly conflict, the NEMS document with the most recent publication date shall prevail.

1.2 Measurement

All optical DO sensors and meters measure the partial pressure of oxygen (see Section 2.2.1, NEMS *Dissolved Oxygen* v3.0.0). Raw sensor values are therefore usually DO% saturation, from which DO concentration may be calculated. However, some optical sensors convert to DO concentration on-board by default so that their raw values are concentrations.

DO% saturation measurements may be:

- referenced to equilibrium 100% saturation at standard atmospheric pressure of one atmosphere at sea level (1013.25 hPa), known as DO% raw, uncorrected DO%, or DO% reference (DO% ref), or

- in terms of equilibrium 100% saturation for the barometric pressure at the site at the time of the measurement, known as corrected DO% or DO% local.

DO% raw (i.e. DO% reference) should not be confused with raw sensor values. They may or may not be the same data depending on the sensor's configuration.

Corrected DO% (i.e. DO% local) should not be confused with edited DO% data. Corrected here means the effect of local barometric pressure is removed, which may be done on-board the DO sensor if it has a built-in barometer.

Some DO sensors without a built-in barometer allow altitude or current local barometric pressure to be entered as part of their configuration, which is then used in an on-board correction that allows raw sensor values of (an approximation to) DO% local to be obtained.

Both normative references (see Section H 1.1) allow measurements of DO as % saturation or concentrations (mg/L). A continuous time-series of DO in either of these units, and as any form of % saturation, may be permanently archived as the primary verified dataset (see Section 3.3.2 of NEMS *Dissolved Oxygen* v3.0.0). In most cases, DO as concentrations and/or as corrected DO% (i.e. DO% local) are preferred.

Conversion between DO units and/or the various forms of % saturation each requires concurrent values of one or more of the supplementary variables (see Section H 1.3).

Note: DO% saturation in any form is unaffected by salinity. Direct conversion between corrected DO% (i.e. DO% local) and DO as concentrations is not possible.

An example illustrating the relationship between DO concentration, and uncorrected and corrected DO% saturation is provided in Annex D of NEMS *Dissolved Oxygen* v3.0.0.

1.3 Supplementary variables

Measurement of DO requires concurrent measurement of:

- water temperature at all times
- local true barometric pressure, when at-site atmospheric pressure must be known
- altitude, if not at sea level and local true barometric pressure is unknown, and
- salinity when 8 parts per thousand or more, or varying.

Supplementary variables may be measured using:

- additional sensors within the same in-situ instrument with the compensations for and/or conversions between the various forms of DO performed automatically by the instrument and/or its proprietary data retrieval software, or
- separately deployed sensors to the DO instrument with the compensations for and/or conversions between the various forms of

DO subsequently performed on a user-programmed data logger or during data processing.

Organisations may choose to permanently store logged supplementary data as a supplementary rather than primary time series and therefore not apply all procedures in this Standard to that data. However, as a minimum, supplementary data must be:

- identified in the DO Site/Initial Comment (see Sections 6.2.4.3 and H 4.2.1)
- described in the archived DO time-series Data Comments (see Sections 6.2.4.6 and H 4.2.4), and
- quality coded as either QC 0 or QC 200 if not fully processed (see Section H 4.1.2).

Requirements for the measurement and recording of continuous supplementary data, including calibration and validation of the sensors, and verification of the logged supplementary data are included in NEMS *Dissolved Oxygen* v3.0.0 and incorporated into the Quality Coding Matrix assessment for DO.

Verification differences and quality code of the required supplementary data are additional factors in deciding a final quality code for the dependent DO records (see Section H 4.1).

If supplementary data are edited it may change dependent DO values, therefore:

- processing inter-dependent time series together is strongly recommended
- the impact on a DO record of editing one or more supplementary data series must be assessed, which will normally require the supplementary data be reviewed and/or processed first
- inconsistent adjustments between supplementary data and dependent DO record must be avoided, and
- editing of necessary supplementary data must be described and explained in a Data Processing Comment (see Section 6.2.4.7) attached to the DO time series.

1.4 Complementary measurements

An at-site or nearby concurrent record of stage (water level to known datum) and/or flow is recommended if DO measurements are significantly affected by variation in either, for example, in estuaries. An at-site concurrent record of stage is recommended where there is some foreseeable risk of sensor exposure, e.g. in a degrading mobile gravel-bed river.

Local air temperature records may also be useful to identify sensor exposure events.

2 Quality Control

2.1 Additional metadata required

General requirements for metadata are set out in Section 6.1. The following additional metadata, as applicable to the site and deployment, are required to be available when verifying DO data:

- site details:
  - type of environment (river, lake, or coastal water)
  - the site purpose, measurement objective(s), and target characteristic(s) to be measured
  - a record documenting the site selection process and its evaluation (see Sections 1.3 and 1.4 of NEMS *Dissolved Oxygen* v3.0.0)
  - location (in GPS co-ordinates and WGS84 datum), and altitude (in MASL) if not at sea level (see Section 1.4 of NEMS *Dissolved Oxygen* v3.0.0), and
  - location (in GPS co-ordinates and WGS84 datum), and altitude (in MASL) if not at sea level, of any supplementary measurements not co-located (e.g. barometric pressure)
- instrument details (in-situ sensor and reference instrument):
  - sensor type, model, manufacturer, and serial number
  - sensor accuracy, resolution, and response time, as specified by the manufacturer
  - the units of primary measurement, and other units available (concentration (mg/L) and/or % saturation, and if % saturation, DO% reference and/or DO% local)
  - the sensor range, as deployed in the units of primary measurement
  - details of any on-board compensation for temperature, salinity, and/or barometric pressure
  - characteristics of any on-board anti-fouling mechanism
  - date, laboratory, and identifier for each calibration
  - the calibration relation(s), if and when supplied; these are essential if applied on the data logger by the user
  - date and results of any validations (i.e. checks on the calibration of the sensor other than by verification during field visits), and
  - date and time of each deployment
- sensor deployment details as applicable to the water body:
  - sampling method and data-logging interval
  - details of data logged as backup, secondary, and/or supplementary
  - method(s) used for verification of sensor readings

    - photos of the deployment showing mounting/housing detail and location context, including distance from margins and presence of structures or machinery that may aerate the water
    - characteristics of the water environment and installation that may impact data quality (see NEMS *Dissolved Oxygen* v3.0.0: Sections 1.3, 2.3, 3.3.3 and 3.3.4)
    - any other known influences on DO at the site (e.g. potential for super-saturation due to algal blooms or high macrophyte biomass)
    - the level of the sensor(s) with respect to:
        - the water level gauge, where co-located
        - the water surface
        - the riverbed or lakebed
        - likely temperature and/or salinity gradients or stratification
    - date, time, and reason(s) for any relocation of the sensor
    - any changes over time in the measurement environment
- reference readings, including:
    - instrument used
    - uncertainty in the result, and/or
    - information about when, where, and how each reading was obtained (e.g. proximity to the in-situ sensor).

These metadata must be verified and permanently archived with all other metadata as described in Section 6.

2.2 Plots and comparisons

- Check around the time of each site visit for anomalies introduced by inspection, sampling, and maintenance activities, and to identify steps in the data introduced by cleaning, or replacing or reconfiguring the sensor, data logger, and/or the installation.
- Check continuity of the daily sine curve and that each daily maximum and minimum occurs at a plausible time.

2.2.1 Comparisons

- Use comparisons to:
    - cross-check data for anomalies, and
    - confirm editing and adjustments have been properly carried out.
- Compare the recorded data with:
    - other associated variables recorded at the site, e.g. relevant supplementary variables

- complementary measurements of water level or flow at site or from a site within the same river system, and/or air temperature at site or from a nearby site
- a backup instrument at the same site, provided it is not also affected by the same data quality issue(s)
- an auxiliary instrument at the same site, e.g. a multi-variable instrument that may be recording over a different range, accuracy and/or resolution, provided it is not also affected by the same data quality issue(s)
- verification measurements, and validation results, if any.

2.2.2 Between-station comparisons

Unless there are substantially different inputs or physical characteristics, DO recorded at distant sites within the same river system can be sufficient to verify diel variation and weekly cycles.

Records of flow or water level at sites either upstream or downstream are useful to confirm occurrence and timing of relatively sudden reductions in the daily range of DO.

For example: A fresh may slough periphyton from a riverbed that was causing large diel variations due to photosynthesis and respiration. Diel variation may gradually increase again after the event as the periphyton re-establishes.

Note: You may need to allow for the time of travel of an increase in flow between sites.

Records of air and water temperature at nearby sites can also be useful for identifying if a sensor is out of the water.

In addition to cross-checking specific features in the data, use comparisons, including between-station comparisons, to identify:

- sensor exposure due to low water levels or dry channel or bed, and
- change in and/or disruption of:
- diel and seasonal patterns
- expected correspondence with supplementary variables (water temperature, salinity and/or barometric pressure as applicable)
- shape and pattern of response to level and/or flow variations
- relative timing of daily maxima and minima
- daily DO range, especially possible gradual loss of span.

Do not discount the possibility that problems may be transient and occur (and resolve) between site visits.

2.3 Reliability of reference values

Reference values used to verify a DO record from an in-situ device are obtained directly using an independent reference sensor (see Section 2.4.1 of NEMS *Dissolved Oxygen* v3.0.0).

When using reference values to verify or to adjust recorded DO the following should be considered and assessed:

- the form and units of measurement of the in-situ and reference sensors, and the supplementary measurements and conversions necessary to achieve compatibility (see Sections 7.2 of NEMS Dissolved Oxygen v3.0.0 and Section H 3.9)
- calibration records and validation results for the reference sensor (see Section H 2.3.1) and the in-situ sensor (see Section H 2.3.2)
- measurement stability and location relative to the in-situ sensor (see NEMS Dissolved Oxygen v3.0.0: Section 7.5.4)
- timing of the reference measurement with respect to in-situ sensor readings (see Section 7.5.4 of NEMS Dissolved Oxygen v3.0.0)

  Note: Simultaneous readings are the most reliable for data verification, especially when conditions are changing rapidly.

- precision and accuracy of the reference reading (see Sections 2.2.1.1 and 7.5.5.2 of NEMS Dissolved Oxygen v3.0.0).

A reference reading is unreliable, and must be identified as such on quality plots, if:

- it is outside the calibrated range of the reference sensor as stated or implied by the manufacturer (see Section H 2.3.1)
- its uncertainty exceeds the verification tolerance (see NEMS Dissolved Oxygen v3.0.0 Section 7.5)
- the sensor cap or foil on the reference sensor used is expired (see NEMS Dissolved Oxygen v3.0.0 Section 6.2.2
- the reference sensor used was not appropriately or acceptably calibrated or successfully validated at the time (see NEMS Dissolved Oxygen v3.0.0 Sections 4.3 and 5.3), or
- the reference sensor fails its end of day validation and is not then successfully recalibrated (see NEMS *Dissolved Oxygen* v3.0.0 Section 5.3).

If successfully recalibrated after a failed end of day validation, the reference readings for that day can be used provided the amount of calibration adjustment is added to the uncertainty of the reference readings (see NEMS *Dissolved Oxygen* v3.0.0 Section 5.3.4.1), however they may still be unreliable if total uncertainty then exceeds the verification tolerance.

A DO record should not be adjusted to any unreliable reference value unless there is other corroborating evidence of faulty recording. If adjusted, the adjustment(s) should be reviewed when reliable reference readings resume. In any case the period of data associated with the unreliable reference cannot be quality coded higher than QC 400.

If a verification check is disregarded as unreliable:

- an Operational Comment is required giving reason(s), and

- the date of the disregarded visit cannot be used to determine the elapsed time between verifications for quality coding purposes, i.e. the initial quality code assigned (see section 9.4 and Annex A of NEMS Dissolved Oxygen v3.0.0) may need to be reviewed and possibly reduced.

2.3.1 Calibration and validation of reference sensors

Manufacturers of optical DO instruments may state a measurement range, a calibrated range, or both. When both are stated the instrument's calibrated range is usually less than its measurement range, i.e. values can be obtained from the sensor that are outside its calibrated range. When only a measurement range is stated, it is assumed under this Standard that the manufacturer has adequately calibrated the sensor over that range. Certificates of manufacturer calibration are not routinely available or supplied.

Instead, confirmation of the accuracy and serviceability of DO sensors, and any required supplementary sensors, relies on calibrations and validations performed by, or on behalf of, the monitoring agency. It is these (user) calibrations and validations that are discussed in the remainder of this Annex.

Requirements and methods for calibration and validation of reference sensors are set out in the NEMS *Dissolved Oxygen* v3.0.0 and the NEMS *Water Quality Parts 1 to 4* v2.0.

If an otherwise serviceable reference sensor or meter fails to validate to within the allowable tolerance (see NEMS *Dissolved Oxygen* v3.0.0 Section 5.3.4) it may be presumed to be due to sensor calibration drift. Review all reference readings with that instrument since its last successful validation and add the apparent calibration drift to the uncertainty of those readings.

Calibration of an optical DO instrument involves adjusting the sensor or meter to known values at zero and/or full saturation. Because the necessary methods are impractical, NEMS *Dissolved Oxygen* v3.0.0 does not require monitoring agencies to validate linearity through the sensor range to full saturation or linearity of response beyond full saturation. Indication of possible loss of linearity is instead reliant on the results of verifications (see NEMS *Dissolved Oxygen* v3.0.0 section 7.5). If sufficient verifications are performed, testing for range-dependent bias (see Section 3.6.4.5) can reveal loss of linearity in either the reference or in situ sensor. It remains then to determine which sensor is affected, replace it, and review the relevant data already collected from it. In the super-saturated range linearity is assumed to be satisfactorily maintained if one or more verifications are performed in that range and the deviations are within the verification tolerance specified in the NEMS *Dissolved Oxygen* v3.0.0.

2.3.2 Calibration and validation of in-situ sensors

Requirements and methods for (user) calibration and validation of in situ DO sensors are set out in the NEMS *Dissolved Oxygen* v3.0.0.

An in-situ sensor that fails validation should be calibrated before redeployment. A sensor that fails to calibrate successfully should have its sensor cap or foil replaced or not be deployed. In either case, use comparisons (see Section 2.2) to review all data

collected since the last successful validation for any unexpected range, unreliable values, and evidence of drift.

Any data collected with an expired sensor cap or foil must be discarded as unreliable and treated as missing record (see Section H 3.11) unless there is corroborating evidence, e.g. comparisons with other sites and/or related variables, that demonstrate the data can be trusted. Data retained shall be assigned no higher than QC 400 and a Data Comment (see Section H 4.2.4) noting the cap or foil expiry date and summarising the evidence shall be filed in the time-series metadata.

In-situ sensor performance over time is also checked by routine verifications, plus additional visits as needed to confirm any apparent non-conformances and prevent data loss (see Section 7.5, NEMS *Dissolved Oxygen* v3.0.0).

2.4 Deviation tests

NEMS *Dissolved Oxygen* v3.0.0 verification tolerances vary with the reference value. Performance can still be monitored graphically using a control chart or deviation with time plot, but the tolerances must be calculated from each reference value at the same time as each deviation (Figure H 1).

The verification tolerances required to determine the thresholds for the deviation tests are obtained from the verification tolerance row of the Visit matrix in Annex A of NEMS *Dissolved Oxygen* v3.0.0.

Note: Annex A of NEMS Dissolved Oxygen v3.0.0 uses two matrices to decide an initial quality code for the data, which if not QC 200 is then the maximum possible quality code that may be assigned to the processed data.

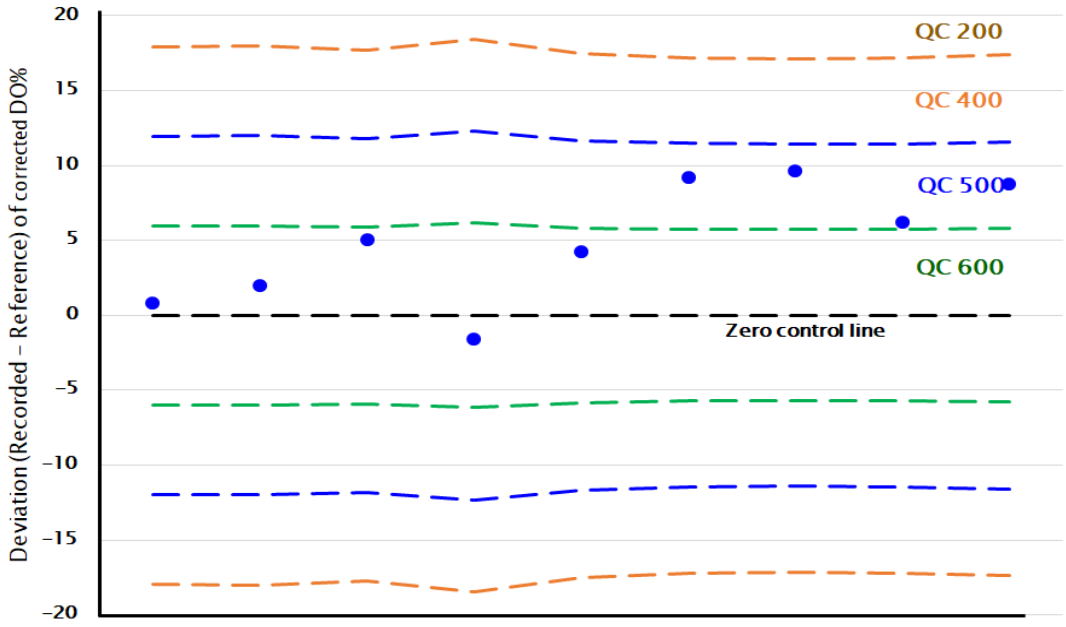


Figure H 1 - An example of a control chart used to track verification deviations and consequent initial quality code for corrected DO% (DO% local) saturation data.

Because of the conversions required (see Section H 1.2), separate charts or plots are needed for uncorrected and corrected DO% saturation, and DO concentration, with the tolerances also converted to align with the units of the data.

Analysis of deviation with range (Figure 12) is also strongly recommended to monitor for loss of linearity, especially in the super-saturated range (DO% > 100%) (see Section H 2.3.1). Note that loss of linearity may affect the in-situ or reference sensor, or both.

Where reliability of reference readings varies, account for their uncertainties (e.g. use error bars on plots).

Tests may be configured to update automatically with new data from the field.

3 Potential Errors and Recommended Editing

This section describes common problems specific to DO data and guides selection of an appropriate method for data repair, including what metadata are then required to be applied and filed.

3.1 Sources of errors

- Environmental conditions, such as:
  - changes in the light regime that affects instream photosynthesis, due to:
    - intermittent cloud cover
    - periodic shading, and/or
    - variations in turbidity
  - atypical inflows (e.g. an unauthorised discharge)
  - stratification
  - tidal influence.
- Instrument deployment and operation, and conditions that adversely affect them (see NEMS Dissolved Oxygen v3.0.0: Sections 1.3.2, 2.3.2 and 3.3.3), including:
  - proximity of the sensor to the water surface
  - response times, including lag between changes in one or more supplementary variables and the reported DO value
  - the relative locations of the sensor and point of collection of reference measurements at various flows (see Section H 2.3).
- Interference and/or damage from:
  - human activities
  - debris
  - biofouling
  - sensor exposure (including desiccation during storage), and
  - flood damage

(see NEMS Dissolved Oxygen v3.0.0: Sections 1.3.2, 2.3.2 and 3.3.3).

- Instrument performance, including:
  - maintenance of calibration that may be compromised by one or more of:
    - baseline drift
    - loss of span or range
    - loss or gain of amplitude
    - loss of linearity
    - poor signal to noise ratio (luminescent sensors at high DO concentrations)
    - delayed replacement of sensor caps or foils
    - mistakes loading cap coefficients
    - inaccurate, or no compensation for temperature, salinity and/or barometric pressure
    - electronic transients
    - over-ranging.

The effects of environmental conditions are measured as part of the target characteristic(s) and may or may not be regarded as errors depending on the purpose of the monitoring. If they are retained in the data, the causative factors and influences must be described in the Site/Initial Comment (see Section H 4.2.1).

3.2 Data offset

If a persistent constant or near-constant bias is evident from successive verifications (as depicted in a control chart or other quality control deviation test presentation) an offset adjustment can be applied to remove the bias.

Investigate the probable cause and confirm the period of data that is affected. It may be apparent from a visible corresponding step in the data, in which case the adjustment is a constant applied that minimises the step, and the bias, without creating a step in the edited data.

A linear (baseline) drift adjustment (see Figure H 2 and Section H 3.4) may be required leading into and/or out of the offset adjustment to avoid creating a step in the edited data.

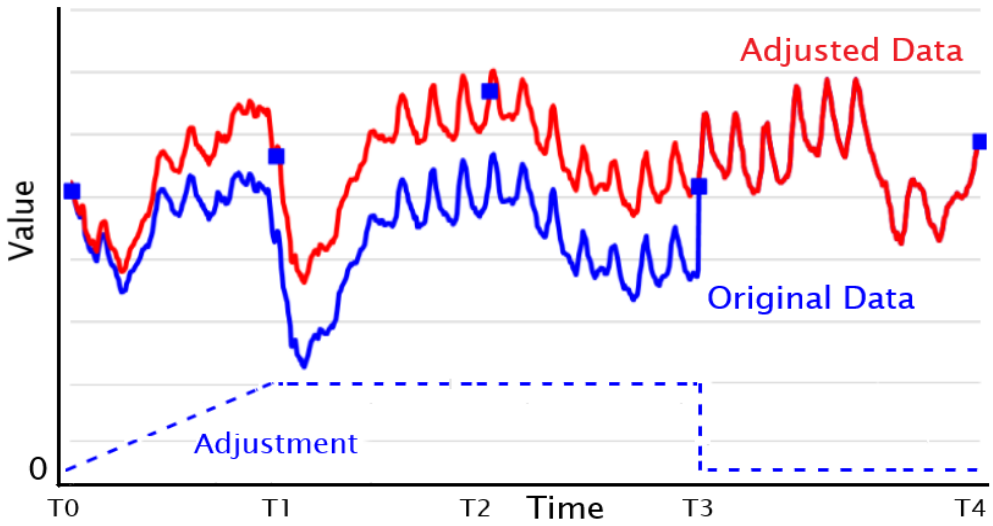


Figure H 2 - An example of dissolved oxygen data offset by a constant amount between T1 and T3 (blue trace), the reference readings (blue squares), adjusted data (red trace), and the adjustment applied (dotted line), which includes a baseline drift adjustment up to T1.

Table H 1 – Guidance for resolving data offset

Guidance for resolving data offset		see Section(s)
Issue(s)	A period of data is biased by a constant or near-constant amount.	H 3.2
Evidence	Pairs of opposing steps in the data. Period between is 'offset' from surrounding data by a constant or near-constant amount; observable in a data plot and/or deviation track, e.g. control chart. Physical cause may be identifiable and a corresponding step in the data may be apparent.	H 3.2 Fig. H 2 H 2.2 Fig. H 1 H 2.4
Solution(s)	Apply an offset shift to the biased period.	4.2
Metadata	The lower of the matrix quality code, or 'minor' (QC 500) or 'significant' (QC 400) modification criteria apply and a Data Processing Comment explaining identified cause and details of the amount and period of adjustment is required.	H 4.1 6.2.3 H 4.2.5 6.2.4.7

3.3 Steps in the data

Steps in the data may result from:

- replacement of the in-situ DO sensor
- change of DO sensor caps or foils and/or their coefficients
- DO sensor recalibration

- a fault with, or recalibration, or replacement of a supplementary measurement sensor
- moving the DO and/or supplementary measurement sensor(s) to a different location (vertical or horizontal)
- interference or disturbance around the DO and/or supplementary measurement sensor(s)
- clearing or cleaning the DO and/or supplementary measurement sensor(s)
- change in the environment, e.g. shading at certain times of the day.

The cause of the step dictates which data should be repaired and how.

Adjustments applied to the recorded data must reflect assumptions made about the nature, timing, duration, and magnitude of the error.

In most cases the appropriate adjustment is a simple special case of linear (baseline) drift correction often referred to as a one-tailed ramp correction, where the adjustment is an offset that increases linearly with time from zero at the start of the affected period to a specified non-zero value at the end of the affected period, or vice versa (see Figure H 2).

3.3.1 Instrument servicing and replacements

If the new instrument is a different type, brand, or model, and/or it cannot be reinstalled in the same location, describe the change in an Operational Comment (see Section H 4.2.3) that references relevant Equipment Comment(s) (see Section H 4.2.2) as needed. If the data subsequently collected are offset from data previously collected because of the change, leave the step-change in the data but identify and explain it in a Stationarity Comment (see Section H 4.2.7).

If the step coincides with a change of DO sensor cap or foil and the sensor calibration coefficients must be manually entered, the problem may be due to a data entry mistake. In some cases, it is possible to recover the correct data (see Section H 3.9), which should eliminate the step. If there is no mistake with the meter coefficients, assume some form of drift exists in the prior data and address it (see Section H 3.4).

If the step is attributable to an issue with necessary supplementary data (water temperature, salinity and/or barometric pressure) it should be addressed in the supplementary data and dependent DO values recalculated (see Section H 1.3). If recalculating DO values is not possible, the recorded DO data may be adjusted directly, assuming an offset (see Section H 3.1) or some form of drift (see Section H 3.4), but the quality code cannot be higher than QC 400 (compromised).

If none of the above situations apply and calibration of the replacement instrument is confirmed pre-deployment, assume some form of drift in the replaced instrument and adjust the data collected from it accordingly (see Section H 3.4).

3.3.2 Interference or disturbance

Physical interference may be due to the actions of people or animals on or about the sensor. Site maintenance, self-cleaning mechanisms, and water sampling activities may also disturb ambient conditions.

If the interference rapidly warms, cools, aerates, or suddenly increases turbidity near the sensor, the DO record may step up or down over one or two recording intervals, then recover when the interference moves or dissipates, or conditions equilibrate. Normal conditions are expected to resume within a few hours.

Data may be offset for the duration of the interference. If bubbles are able to form on the sensor, periods of elevated readings may be prolonged.

The effects of short-duration interference or disturbance may be treated as spikes (see Section H 3.5). Otherwise, adjust for offset as shown in Figure H 2 but with the baseline drift adjustment following the offset shift.

Disturbance may change the position or location of the sensor. Data recorded in these cases may be valid but not fit for purpose and therefore require, as a minimum, an appropriate lesser quality code and a Data Comment (see Section H 4.2.4). If the change is made permanent, treat the step as in Section H 3.3.1.

If the sensor is exposed, or buried (e.g. by accumulation of debris, bed movement, or a relatively sudden event such as bank collapse), the subsequent data may include spurious values and are likely not representative and should be deleted then treated as missing record (see Section H 3.11).

Dissolved oxygen variation due to periodic shading, tidal influence, salinity and water temperature variations, geothermal effects, groundwater interactions, runoff inputs, and passage of floods are part of the target characteristics to be measured and not considered interference or disturbance that requires editing or impacts data quality.

3.3.3 Sensor clearance or cleaning

Clearing or cleaning the sensor may result in a step in the recorded data.

Note: Partial clearing and/or cleaning may occur naturally during floods because of drag induced by higher velocities and increased turbulence, and abrasion by suspended sediment. However, abrasion may damage optode sensors leading to noisy data (Wilcock et al, 2011).

If the sensor was buried by sediment or debris, treat as in Section H 3.3.2.

Biofouling (algal film growing on the sensor, compounded by fine sediment settling in the algae) and chemical fouling (a chemical film, e.g. from tannins or salts in the water) are gradual accumulations that may progressively affect readings.

Fouling behaviour and the corresponding evidence in the data is dependent on cause, and sensor cleaning frequency and method (e.g. wiper or brush, ultrasound, or pumped air or water). Fouling may affect sensor readings non-linearly with time, especially if

the cause is biological accumulation. However, if the magnitude of the error is small, a linear drift adjustment to eliminate any step introduced by cleaning is an acceptable solution (see Section H 3.4).

Fouling may also cause noisy data, which should be smoothed or resampled (see Section H 3.6) before any drift or offset adjustment is applied to eliminate a step.

Table H 2 – Guidance for resolving steps in the data

Guidance for resolving steps in the data		see Section(s)
Issue(s)	Sudden change in DO between successive readings that disrupts continuity of the usual pattern. Prior data are often biased.	H 3.3
Evidence	Physical cause is identified (observed or verified at site, or consequence of an event known to have occurred). Trace of data when plotted steps suddenly up (or down). May be evidence of increasing bias in prior data (e.g. control chart or other deviation test presentation).	Fig. H 1 H 2 3.6
Solution(s)	No adjustment if due to different instrument type or change of location (stationarity is disrupted). Transform if instrument configuration was wrong. Adjust or remove values affected by interference or fouling. Treat any gaps created as missing data. Drift adjustment with maximum adjustment at the step in the trace and no (i.e. zero) adjustment at onset (or resolution) of problem (depending on cause).	H 3.3.1 H 3.9 H 3.3.2 H 3.5 H 3.4 4.4 & 4.5
Metadata	Operational Comment required for change of instrument or location. Equipment Comment also required if instrument type or specification changed. Stationarity Comment required at step. If transforms are fully traceable, quality code is unaffected, but a Transformation Comment is required. Quality code of adjusted data is lesser of matrix, 'minor' or 'significant' modification criteria, or as determined by quality and application of required supplementary data. Data Processing Comment explaining identified cause and details of adjustment(s) applied (amount, type, and period of adjustment) required, OR Refer to missing data guidance as applicable.	H 4.2.3 H 4.2.2 H 4.2.7 H 3.9 & H 4.2.6 H 4.1 6.2.3 H 3.3.1 H 1.3 H 4.2.5 6.2.4 H 3.11

3.4 Drift

Instances of noise (see Section H 3.6), over-ranging (see Section H 3.7), or sensor exposure (see Section H 3.3.2) must be isolated from analysis of drift and treated beforehand.

Elapsed time before drift is detected and confirmed depends on verification frequency and rate of drift. Duration of drift is dependent on frequency of instrument cleaning, servicing, and calibration.

Note: If sensor validation in the field is impractical the in-situ sensor will usually be replaced if cleaning and servicing do not return readings to within verification tolerance. Verification checks may not be available for the lower end of the DO range because DO minima tend to occur at night.

Proper adjustment of the affected data should eliminate any step-change resulting from instrument cleaning, servicing, calibration, or replacement (see Section H 3.3). If affected data cannot be reliably adjusted, delete it from the record and treat the period as missing data (see Section H 3.11).

3.4.1 Baseline drift

Baseline drift may arise from fouling, general degradation of caps and foils, or delamination of optode sensor foils under harsh conditions (high sediment loads or significant depth) often accompanied by increasing noise.

Apply a linear drift adjustment (see Section 4.4) to the affected period unless the diel DO range is large. If the diel range is large treat as for amplitude drift (see Section H 3.4.2).

3.4.2 Amplitude drift

Luminescent sensors are prone to larger errors at higher DO concentrations. If the range of DO values is large, assume widening amplitude of diel DO fluctuations occurs with baseline drift (Wagner et al, 2006). In these cases, a % of value linear adjustment (see Section 4.5) is more appropriate (see Figure H 3).

This adjustment is also applicable to suspected loss of sensor span arising from calibration drift (see Figure H 4).

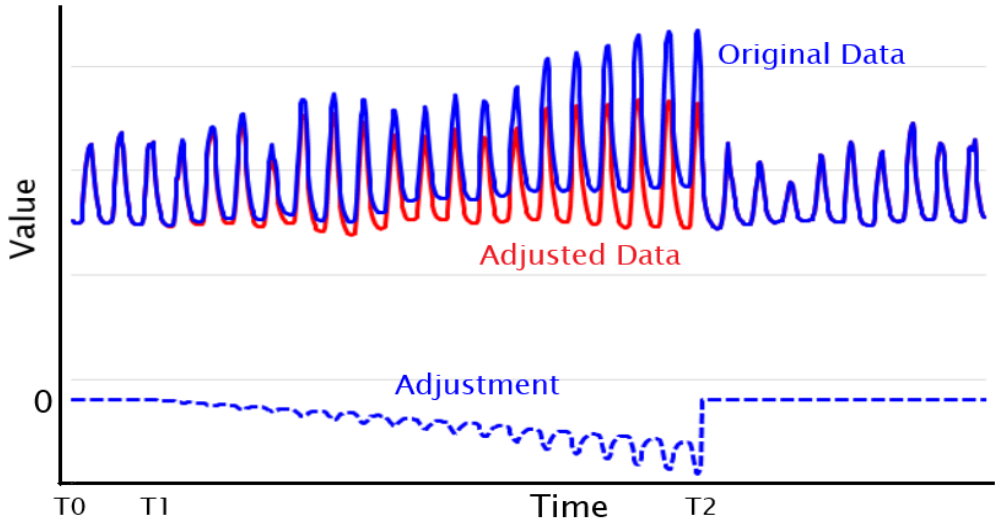


Figure H 3 - An example of a one-tailed % of value linear drift adjustment for amplitude drift between T1 and T2 (blue trace), with the adjusted data (red trace), and the adjustment (dotted trace) shown as the absolute values obtained from 0% of original value at T1, incrementing linearly with time to -20% of original value at T2.

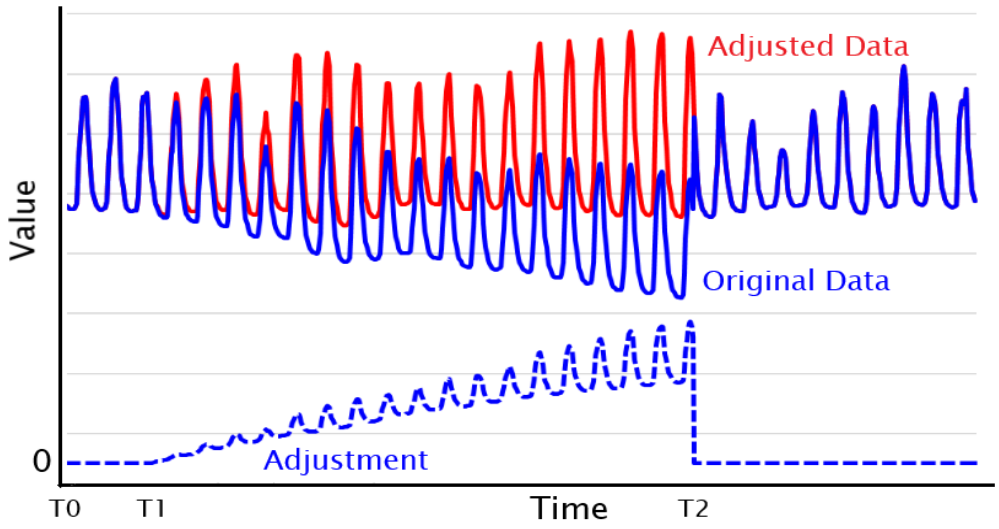


Figure H 4 - An example of a one-tailed % of value linear drift adjustment for loss of sensor span between T1 and T2 (blue trace), with the adjusted data (red trace), and the adjustment (dotted trace) shown as the absolute values obtained from 0% of original value at T1, incrementing linearly with time to +50% of original value at T2.

3.4.3 Loss of linearity

Linearity of optical DO sensors is established by manufacturers. Sensor measurement range may extend to 600% saturation in some cases. User calibration and validation of optical DO sensors is only practicably possible at zero and/or full saturation (see Sections 4 and 5 of NEMS *Dissolved Oxygen* v3.0.0).

Loss of linearity is therefore practically only detectable as trend or cycle in a deviation with range plot (see Section 3.6.4.5 and Figure 13). If the deviation with range plot is sufficiently robust (several verifications over as wide a range of values as possible with

minimal scatter and unaffected by baseline drift) it may be used to derive a non-linear transformation to adjust the data for the calibration error (see Section H 3.9).

Table H 3 – Guidance for resolving drift

Guidance for resolving drift		see Section(s)
Issue(s)	Recorded values are biased by an increasing amount or % of value over time.	H 3.4
Evidence	Deviation of recorded from reference increases with time and/or value. Physical cause may be identifiable, such as biofouling or sensor degradation. Drift may be evident in a data plot as trending baseline and/or widening range.	H 3.4 H 2 3.6
Solution(s)	Apply linear drift adjustment for baseline drift unless diel range is large. Apply % of value linear drift adjustment for amplitude drift, baseline drift when diel range is large, and loss of span. Apply a transformation derived from verification results if loss of linearity is detected.	H 3.4 4.4 Fig. H 3 Fig. H 4 4.5 4.9
Metadata	QC 500 or QC 400 depending on 'minor' or 'significant' change, and Data Processing Comment required explaining identified cause of drift and details of each drift adjustment applied (type, amount, and period of adjustment). QC 400 and Data Comment if loss of linearity is detected but transformation is not possible.	H 4.1 6.2.3 H 4.2.5 6.2.4.7 H 4.2.4 6.2.4.6

3.5 Spikes

Spikes may be due to short-term interference or disturbance (see Section H 3.3.2) or data transmission interruptions, power supply problems, or electronic transients.

Isolated spikes may be deleted or replaced. If deleted, the interpolation engine can be left to interpolate between the remaining adjacent values unless regular interval data are required.

Intermittent spikes may be deleted manually or discarded using a threshold filter. If only one or two successive values are removed at each occurrence the interpolation engine can be left to interpolate between the remaining adjacent values unless regular interval data are required. If more than a few successive values are removed gap processes are then required (see Sections 4.16 to 4.20, and H 3.11).

If spiking is frequent, persistent, and affecting consecutive values, treatment as noise is necessary (see Section H 3.6).

Table H 4 – Guidance for resolving spikes in the data

Guidance for resolving spikes in the data		see Section(s)
Issue(s)	Spurious values recorded.	H 3.5
Evidence	Value significantly different from adjacent values. Observable in a plot of the data. Confirmation by field investigation, and elimination of cause if possible.	H 2 3.6
Solution(s)	Delete or replace spurious values. If more than a few consecutive values are removed, missing data processes are also then required. If spiking is frequent, persistent, and affecting consecutive values, treatment as noise is necessary.	4.11 or H 3.11 or H 3.6
Metadata	QC 500 and Data Processing Comment required explaining identified cause and whether values are deleted or replaced, OR Refer to missing data or noise treatment guidance as applicable. Comments may be aggregated if frequent and repetitive.	H 4.1 6.2.3 H 4.2.5 6.2.4.7 or H 3.11 or H 3.6

3.6 Noisy data

Noise in DO data may be real in response to environmental conditions such as intermittent cloud cover or turbidity, or erroneous due to instrument malfunction or floating algae or small debris obstructing the sensor.

3.6.1 Real noise

Noise that is real retains a pattern consistent with how ambient light regime affects photosynthesis by in-stream algae. Real noise will:

- not be present on a clear day, or at night
- be less in the mornings and evenings
- never exceed the clear day maximum
- have variable periods of high DO in bright sunshine with lag in DO reduction as cloud cover reduces photosynthesis
- be more or less random.

If real noise is excessive with respect to expected precision, reduce the random variation to acceptable variance by:

- manual editing (e.g. 'freehand draw')
- resampling, or

- filtering using a fixed or moving interval mean or median.
- Avoid:
- disrupting expected range, timing, and legitimate features of diel cycles (e.g. avoid inducing lag and/or attenuation, or eliminating rapid change in DO due to bank shading or change in flow), or
- creating a step at the boundary with adjacent unedited data.

3.6.2 Erroneous noise

Erroneous noise can have rapid swings between high and low around the diel light cycle and at night (Wilcock et al, 2011). Faulting electronics may be due to poor connections or imminent failure of the sensor, requiring replacement, and effect on the data may be erratic.

Erroneous data are unusable. Delete the affected period and treat as missing record (see Section H 3.11).

Table H 5 – Guidance for resolving noisy data

Guidance for resolving noisy data		see Section(s)
Issue(s)	Noise obscures representative signal. Fluctuations are high frequency and exceed expected sensor precision. Range of fluctuation compromises use of data in ecosystem models.	H 3.6
Evidence	Trace when data are plotted is 'fuzzy'. Variation between adjacent values is larger than is normal or expected from resolution of the instrument. Real noise varies with ambient light. Erroneous noise is not seen in independent observations.	H 2 3.6
Solution(s)	Method choice is determined by identified cause. Manually edit or resample, or 'smooth' with a statistical filter, if 'real' random noise. Delete affected period and treat as missing if erroneous noise.	H 3.6 H 3.6.1 4.12 H 3.6.2
Metadata	QC 500 or QC 400 depending on 'minor' or 'significant' change, and Data Processing Comment explaining identified cause and method applied, OR Refer to missing data guidance as applicable.	H 4.1 6.2.3 H 4.2.5 6.2.4.7 or H 3.11

3.7 Over-ranging

Over-ranging occurs when measured values are beyond the range of the sensor as stated by the manufacturer. The range may be stated as a measurement range or a calibrated range. Some manufacturers may state both, with the measurement range extending beyond the calibrated range. If a manufacturer states only one range, this NEMS assumes the entire range stated is calibrated (by the manufacturer). Top of

measurement range of commonly deployed optical DO sensors varies between brands and models from 150% to 600% saturation.

Values above 100% saturation are routinely encountered. Values exceeding 200% saturation are rare (unless erroneous). Extreme diel variation in DO is more likely during low flows and warm weather, coinciding with maximum periphyton or macroalgal biomass. Super-saturation generally occurs at very low flows and calm conditions when exchange of DO with the atmosphere is weak. Daily minimum DO% saturation exceeding 100% indicates a sensor needs maintenance and possible replacement (Wilcock et al., 2011).

Any value recorded that:

- exceeds the sensor's measurement range is most likely spurious and the consequence of a fault. Discard the relevant values and treat as missing record (see Section H 3.11), or
- is within the manufacturer's stated measurement range but beyond the stated calibrated range (if less) and is not assessed to be faulty shall be assigned a quality code no higher than QC 400.

Although it is not possible to validate DO measurements above 100% saturation, sensor calibration is assumed to reliably extend into this range. For this reason, the NEMS *Dissolved Oxygen* v3.0.0 (Section 9.4.3.1) does not preclude measurements above 100% saturation from obtaining QC 600 provided all QC 600 calibration and other requirements are met, and data processing does not result in actions that would require a lower final quality code to be assigned.

Note: This is a change from the NEMS Dissolved Oxygen v2.0 and previous versions of the NEMS Data Processing.

Concentrations derived from DO% saturation measurements in the supersaturated range cannot be assigned a quality code higher than their corresponding saturation measurements.

Depending on the sensor and logger configuration, peak clipping may occur, where over-range values are not stored or are set to the nominated maximum value (see Figure H 5). Datasets that include periods of clipped over-ranging may be filed as a censored time series with appropriate metadata (see Sections 1.1.5 and H 4); however, treating affected periods as missing data is preferred (see Section H 3.11). A change of over-range (clipping) threshold and/or over-range treatment may affect stationarity so must be noted in a Stationarity Comment (see Section H 4.2.7).

Clipped values are not recoverable by adjustment. After adjustment the diel maxima will not conform to the original censoring threshold (see Figure H 5) so affected periods must instead be gapped and treated as missing.

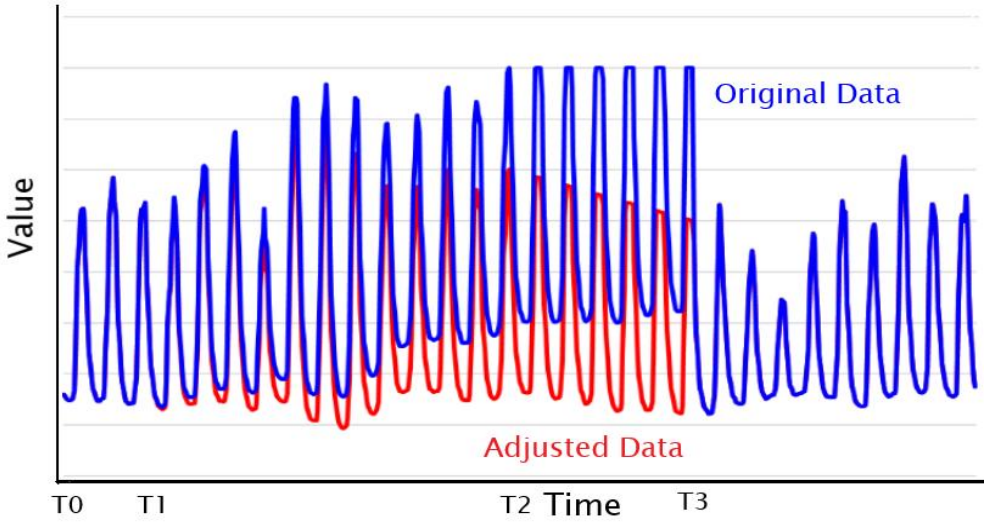


Figure H 5 - An example of clipped over-range DO values between T2 and T3 within a period of amplitude drift from T1 (blue trace), with the adjusted data (red trace), and showing the diel range of the adjusted data from T2 to T3 remains compromised and does not conform to the original over-range threshold.

Table H 6 – Guidance for resolving over-ranging

Guidance for resolving over-ranging		see Section(s)
Issue(s)	Measured values are outside the manufacturer's stated or implied calibrated range of the sensor, or full range of DO is not recorded.	H 3.7
Evidence	Values exceed known calibrated range of the sensor or over-ranged record flatlines or has gaps when DO is at or near a constant high value or known threshold. May be verified by independent measurements.	Fig. H 5 H 2 3.6
Solution(s)	Apply drift adjustments as needed. Remove values that exceed the manufacturer's stated measurement range and treat as missing data. If peaks are clipped, store as censored data, or gap and treat as missing data.	H 3.4 4.4 & 4.5 H 3.7 1.1.5 4.16 H 3.11
Metadata	QC 400 all saturation values that exceed manufacturer's stated or implied calibrated range and corresponding derived concentrations. QC 100 if left missing. Data Comments are required identifying and explaining treatment of periods of clipped over-ranging. A Stationarity Comment is required if threshold and/or treatment is changed.	H 4.1 6.2.3 H 4.2.4 6.2.4.6 H 4.2.7 6.2.4.8

3.8 Sensor exposure

Sensors may become exposed inadvertently because of bed scour, channel migration, channel works, or by deliberate interference, or when removed for cleaning. Measurements while exposed are not representative and may be spurious.

Exposure may lead to sensor cap or foil damage that continues to affect measurements after re-immersion.

If water level is collected as a complementary variable at site and the level of the sensor is known relative to water level datum, a water level threshold can be determined below which the corresponding DO data collected must be regarded as unreliable. Air temperature collected as a complementary variable may also identify periods of sensor exposure by comparison with the water temperature record.

Remove data affected by sensor exposure from the record and treat the period as missing data (see Section H 3.11).

Table H 7 – Guidance for resolving sensor exposure

Guidance for resolving sensor exposure		see Section(s)
Issue(s)	Measurements in air are not representative and may be spurious. Exposure may damage sensor membranes and foils.	H 3.8
Evidence	Physical cause is known or identified (observed or verified at site, and/or from calculation of relative levels of sensor and water, or consequence of an event known to have occurred).	H 3.8 H 2 3.6
Solution(s)	Remove affected data and treat as missing.	4.16 to 4.20 incl. H 3.11
Metadata	QC 300 if replaced with synthetic infill, or QC 100 if left missing. Data Comments are required explaining identified cause and providing details of decisions made and methods applied.	H 4.1 6.2.3 H 4.2.4 6.2.4.6

3.9 Incorrect scaling

Incorrect scaling means that the range of the data is either wrongly reduced or expanded by some factor. The problem usually arises from:

- wrong measurement units, or
- incorrect sensor and/or logger configuration.

3.9.1 Wrong measurement units

Dissolved oxygen data collected in the wrong measurement units are usually recoverable if the necessary supplementary data have been recorded (see Section H 1.3). Explicit conversion by mathematical relation between different units of DO measurement, e.g. % saturation to concentration, is possible (see NEMS *Dissolved Oxygen* v3.0.0 Annex D).

- Metadata must state the units of measurement, and the conversion applied and units in which the data are stored when different (see Sections H 4.2.2 and H 4.2.6).
- Any change to the conversion methods and/or equations applied must be noted in a Stationarity Comment (see Section H 4.2.7).

  Note: Conversion equations are empirically derived, and the equations and methods of application vary.

- Verification data must be in the same measurement units as the continuous data collected to be directly comparable.

3.9.2 Wrong instrument configuration

Replacement DO sensor caps and foils may be supplied with new coefficients requiring upload by the user. If a mistake is made when entering one or more coefficients, DO data are recorded using an incorrect calibration relation between the sensor output and DO value.

If the calibration equations are published by the manufacturer, the necessary supplementary measurements are available, and the incorrect and correct coefficients are known, the instrument output can be calculated and the correct calibration then applied to obtain the correct DO values.

If the transformations are fully traceable to preserved calibration records, quality code is unaffected, but a Transformation Comment is required.

Some manufacturers provide proprietary software that allows coefficients to be edited, then revises the DO measurement values if the raw sensor output stored in temporary memory has not been overwritten. DO data recovered in this way may be regarded as replacement original record.

If transformation or recovery is not possible but the calibration equations are known, assess the recorded data for impact of the incorrect coefficient(s). If the impact is not significant and the data are not misleading they may be retained, quality coded as QC 400 (compromised) and explained with a Data Comment.

If the affected data cannot be assessed, or are assessed as unreliable and not representative, they must be deleted and the period treated as missing record.

Table H 8 – Guidance for resolving incorrect scaling

Guidance for resolving incorrect scaling		see Section(s)
Issue(s)	Scale and/or units of the data is/are wrong.	H 3.9
Evidence	Differences between reference and logged values are variable and often large. Data inconsistent with expected range. A step-change occurs at time of configuration change.	H 3.9 H 2 3.6
Solution(s)	Apply conversion equations, to equivalent precision, if measurements are in the wrong units. For instrument configuration errors, apply transformations reversing the applied instrument configuration parameters to obtain raw signal, then apply the correct configuration parameters to the recovered raw signal, OR Assess impact of configuration error(s) and if not significant or misleading, file data with lower quality code and comment, OR Delete affected data and treat as missing.	H 3.9.1 H 3.9.2 4.7 H 3.11
Metadata	If the correction required is fully traceable, quality code is unaffected, but a Transformation Comment is required. QC 400 and Data Comment detailing assessment if configuration error is assessed as not significant, OR Refer to missing data guidance as applicable.	H 3.9 H 4.2.6 H 4.1 H 4.2.5 6.2.4 H 3.11

3.10 Time faults

A time shift may be needed to obtain data in NZST or to correct for an incorrectly configured or defaulted logger (see Section 4.3).

If the time fault caused existing data to be overwritten or conflicting new data elements to be discarded, some missing record at period start if shifted forward, or period end if shifted back, is also a consequence that must be addressed (see Section H 3.11).

Time drift adjustment is rarely needed with modern electronic loggers (see Section 4.6). If logger date/time does not agree with actual date/time it is more likely the logger has stopped and there is a gap in the record, possibly unmarked, needing to be identified and addressed.

Most time-series management software has the ability to make time adjustments simultaneously with value adjustments. There is risk when using drift adjustment tools that time is unintentionally adjusted and time faults are introduced into the processed data. This is relatively easy to detect in fixed interval data by analysing the timesteps or inspecting the timestamps.

Table H 9 – Guidance for resolving time faults

Guidance for resolving time faults		see Section(s)
Issue(s)	Temporal distribution of recorded data is wrong and/or data are missing.	H 3.10
Evidence	Logger date/time is different from actual at inspection. Investigation finds configuration error or reset, and/or temporal distribution anomalies are apparent when compared with data from a similar nearby site.	Fig. 18 Fig. 26 H 2 3.6
Solution(s)	If wrong time zone, apply time shift then address any missing record created at the start (or end) by the shift. If a clock fault, replace with reliable backup if independently logged and available, OR if clock is slow or fast, apply time drift adjustment, OR if clock stopped, treat period until restart as missing record.	4.3 or 4.6 Fig. 19 Fig. 27 and/or H 3.11
Metadata	If the time shift is fully traceable, quality code is unaffected, but a Data Processing Comment is required explaining identified cause and details of the shift applied. QC 100 if missing, or QC 300 if infilled, and a Data Comment. Some cautions apply. Otherwise, 'minor' or 'significant' modification criteria apply and a Data Processing Comment explaining identified cause and details of the amount and period of adjustment is required.	4.3.3 H 4.2.5 H 4.1 H 4.2.4 6.2.3 H 4.2.5 6.2.4

3.11 Missing data

When considering the treatment and associated metadata requirements for missing continuous DO data the following broad descriptions of duration are helpful:

- a brief period is a few recording intervals up to an hour
- short duration is between adjacent peaks and troughs of the diel cycle, i.e. within the rising or falling side of the sine curve, but not over the peak or trough
- a longer period may be one or more days up to one week
- an extended period may be a week or more.

DO is influenced by local factors such as:

- position of the sensor in the depth profile
- nature of the surrounds above and below water (e.g. shading, wind, and presence of algae and/or macrophytes)
- the degree of mixing brought about by velocity distribution.

When selecting and applying an appropriate method for resolving missing DO record, take account of the:

- likely variation at the sensor location
- possibility of extreme highs or lows having occurred in the period, and
- duration of the missing data (see Appendix H.1).

A maximum duration of fourteen (14) days for any period of synthetic infill is recommended, dependent on:

- the typical and expected variation in DO at the sensor location during the period
- the possibility of one or more significant events having occurred that may have altered the sensor environment (e.g. floods and/or algal blooms), and
- reliability of the relationship(s) used to generate the synthetic record.

For DO, provided it is collected near the primary sensor or in a well-mixed environment, backup data include:

- data obtained from another continuous sensor at site of a different type and/or standard, and
- manual observations using a reference meter that are intended to fill a period of missing data, i.e. measured at a frequency that captures the full range and rate of change of DO in the period.

3.11.1 Methods for infilling gaps

For details on specific methods for infilling gaps in DO series, see Appendix H.1 to this Annex.

Table H 10 – Guidance for resolving missing data

Guidance for resolving missing data		see Section(s)
Issue(s)	Data are missing.	H 3.11
Evidence	Expected timestamps are not present in the original data. A gap marker may or may not be present depending on data collection method. Data plot shows entire, or parts of cycles are missing. Investigation confirms data were not logged and/or not collected, OR data have been intentionally removed.	4.16 Fig. 9 H 2 3.6
Solution(s)	Use at-site backup data, and manual observations including verification readings where available, OR if brief, interpolate across gap, except if a peak or a trough if short period, interpolate across gap, or infill with a curve, but not over a peak or trough	App. H.1 H 3.11 4.16 to 4.20 incl.

	reinstate a clipped peak by substitution for longer and extended periods, apply methods to infill with synthetic data, or mark the gap if more than 14 days are missing, mark the gap, or note a temporary site closure.	5.4 & 5.5
Metadata	No effect on quality code if brief and interpolated. Otherwise, quality code as applicable to the backup record or QC 300 if infrequent manual observations or synthetic infill, or QC 100 if left as missing. Data Comments are required explaining identified cause and providing details of decisions made and methods applied, including expected reliability of any synthesised infill.	H 4.1 6.2.3 H 4.2.4 6.2.4.6

4 Metadata

4.1 Quality coding

Quality code for DO data is set by five different but related sets of criteria:

- the quality coding flowchart
- the Quality Coding Matrix
- blanket provisions
- quality of any required supplementary data, and
- data editing actions and adjustments.

The quality coding flowchart and Quality Coding Matrix may be found in NEMS *Dissolved Oxygen* v3.0.0. The flowchart is also available in NEMS *National Quality Code Schema*.

4.1.1 The Quality Coding Matrix

The Quality Coding Matrix uses information about the site, instruments, records, and results of each verification to differentiate between a maximum possible quality code of QC 400, QC 500, or QC 600 for the data collected between each inspection. This assessment should, for quality assurance preventive action purposes, be completed before departing the site, but if not, becomes the first step of quality control during data processing.

By applying the Quality Coding Matrix at the time of data collection it is possible to assign quality codes higher than QC 200 to unprocessed data, but this may be misleading because data editing actions may result in periods of data acquiring a different code (see Section H 4.1.2).

An initial quality code of QC 200 (quality unknown) is also a possible outcome of the Quality Coding Matrix if data quality is unable to be determined without further investigation during data processing. In many cases, issues leading to the initial quality code of QC 200 can be resolved during data processing and QC 200 then replaced with one of the other quality codes, either because of additional checks and evidence

indicating a code of QC 400 or higher is justified, or by replacing or removing faulty data.

- Quality of any required supplementary measurements is also a factor when deciding a quality code for any dependent DO data (see Sections H 1.3 and H 4.1.3). Calibration, validation and verification requirements for these supplementary variables are included in the Quality Coding Matrix assessment. Compensation for water temperature, salinity, and/or barometric pressure by calculation from logged data is not regarded as data editing and does not have any further effect on DO quality code beyond the interaction with quality of the supplementary data.

4.1.2 Blanket provisions

The following provisions apply to all DO and supplementary data when deciding a final quality code, in addition to the generic application of quality codes as set out in the quality coding flowchart descriptions, the initial quality code determined from the Quality Coding Matrix (see Section H 4.1.1), interaction with quality of supplementary measurements (see Section H 4.1.3) and any revision of initial quality code as a consequence of data editing (see Section H 3):

- supplementary data required to be permanently stored (see Section H 5) that are not verified and processed according to their relevant NEMS, or for which no NEMS Standard exists (see Section H 1.3) shall:
  - retain quality code of QC 0 if the data are original (see Section 3.1.1) and not inspected, edited for gross errors, or quality reviewed (see Section 7.2)
  - be assigned QC 200 if checked for gross errors, and quality reviewed (see Section 7.2) with or without verification data, or if edited from the original.
- continuous DO% Local data that are only partially compensated for local barometric pressure variation (i.e. using altitude or a spot measurement of barometric pressure and not a concurrent continuous record of barometric pressure) cannot be quality coded higher than QC 500.
- continuous DO concentrations in seawater that are compensated for salinity using a correction factor and not a concurrent continuous record of salinity (or conductivity and water temperature) cannot be quality coded higher than QC 500.
- continuous DO concentrations in estuarine and tidal waters (where salinity varies with time) that are compensated for salinity using a correction factor and not a concurrent continuous record of salinity (or conductivity and water temperature) cannot be quality coded higher than QC 200.

- a period of data retained in the verified DO time-series that has not been corrected for known incorrect sensor cap or foil calibration coefficient(s) (see Section H 3.9.2) cannot be quality coded higher than QC 400.

4.1.3 Interaction with quality of supplementary measurements

The maximum possible final quality code of dependent DO records (including forms of DO measurement that are calculated from the logged data) may also be limited by the differences found during verification of the required supplementary data (see Section 7.5 of NEMS *Dissolved Oxygen* v3.0.0) and whether the supplementary data have been quality reviewed (see Section 7.2) or fully processed.

- DO data cannot attain a final quality code higher than that achieved by any supplementary record that is fully processed to NEMS and then used for compensation of, or conversion to or from, dependent DO values during DO data processing.

If there are no other criteria assigned a lower quality code in the completed Quality Coding Matrix (see Section H 4.1 and Annex A of NEMS *Dissolved Oxygen* v3.0.0), nor any subsequent editing of the DO data:

- QC 600 is possible if the required supplementary data passed verification (i.e. difference from reference is within tolerance) and have been quality reviewed with no issues found.
- QC 500 is the maximum possible if the required supplementary data:
  - passed verification but have not been quality reviewed, or
  - failed verification by up to two times their verification tolerance but have been quality reviewed with no other issues found.
- QC 400 is the maximum possible if the required supplementary data:
  - failed verification by up to three times their verification tolerance but have been quality reviewed with no other significant issues found.
- QC 200 continues to apply (as per the initial assessment) if the required supplementary data have not been quality reviewed and failed verification by up to three times their verification tolerance.

If the required supplementary data failed verification by more than three times their verification tolerance, then neither the supplementary nor the dependent DO data are reliable, and careful consideration should be given to removing the offending supplementary and dependent DO data from their respective final processed and/or archived records.

4.1.4 Data editing actions and adjustments

The quality code of any data collected may be affected by subsequent editing actions and adjustments made to the data. Minor modifications reduce quality code to QC 500. Significant modifications reduce quality code further to QC 400. Refer to Section 6.2.3 for definitions of 'minor' and 'significant'.

Compensation for water temperature, salinity, and/or barometric pressure, and conversion between DO units of measurement, have no additional effect on the quality code, i.e. these actions are effectively exempt from the quality coding flowchart data modification test.

Further guidance on how and when quality code must change as a consequence of data processing is provided in Section H 3 of this Annex.

4.2 Example DO comments

The following are templated examples of comments for DO monitoring stations.

Every comment must be assigned a fully specified timestamp and be associated with the relevant data (the time series of DO measurements) via some form of 'Site' and 'Measurement' database key combination. The database keys are usually specified in some form of record header not shown here.

4.2.1 Site/Initial Comments

River station

Type: Site
Measurement: Dissolved Oxygen
Initial comment for *<river name>* River dissolved oxygen *<saturation or concentration>* at *<site name>*
Site number *<network number, ID or code>* on river *<river number>*27
The site is situated *<distance to coast>* km from the mouth at grid reference *<map co-ordinates and type28>*, *<altitude>* masl. Drains *<catchment area to site>* km2 and is monitored for *<site purpose and target characteristics>*.
Additional information: Site is affected by *<persistent adverse conditions at site (e.g. biofouling, discharges, low velocity, bed movement)>*. Sensor is located *<brief description of sensor placement and environment>*. Data are affected by *<influences incorporated in target characteristics>*. Site evaluation is available from *<reference>*. *<Saturation values are fully (or partially) corrected for local barometric pressure (or referenced to 1 atmosphere)>*. *<Some (or All) quality control (and/or data editing) is automated; refer to the relevant Data Processing Comments.> <Data are stored as a censored series.>*
The following is also measured at this site: *<list variables, including any backup DO recorder and separately logged supplementary data>*; *<This record is used to derive <list variables e.g. DO concentration from DO% saturation (reference)>>*.
The local recording authority is: *<name of recording/archiving agency>*

[27] from *Catchments of New Zealand* (SCRCC, 1956).
[28] state the co-ordinate system: NZTopo50 or NZGD 2000 preferred (latitude/longitude to 6 decimal places)

Lake station

Type: Site
Measurement: Dissolved Oxygen
Initial comment for *<name of water body>* dissolved oxygen *<saturation or concentration>* at *<site name>*
Site number *<network number, ID or code>* on river *<river number>*29
The site is situated *<distance to outlet>* km from the outlet at grid reference *<map co-ordinates and type30>*, *<altitude>* masl. Drains *<catchment area>*km2 of *<river name>* River catchment and is monitored for *<site purpose and target characteristics>*. Lake area is *<surface area>*km2 and level is controlled by *<describe features e.g. natural outlet, dam, weir etc.>*
Additional information: Site is affected by *<persistent adverse conditions at site (e.g. biofouling, some form of regular disturbance, etc.)>*. Sensor is located *<brief description of sensor placement and environment>*. Data are affected by *<influences incorporated in target characteristics>*. Site evaluation is available from *<reference>*. *<Saturation values are fully (or partially) corrected for local barometric pressure (or referenced to 1 atmosphere)>*. *<Some (or All) quality control (and/or data editing) is automated; refer to the relevant Data Processing Comments.> <Data are stored as a censored series.>*
The following is also measured at this site: *<list variables, including any backup DO recorder and separately logged supplementary data>*; *<This record is used to derive <list variables e.g. DO concentration from DO% saturation (reference)>>*.
The local recording authority is: *<name of recording/archiving agency>*

Coastal station

Type: Site
Measurement: Dissolved Oxygen
Initial comment for *<name of water body>* dissolved oxygen *<saturation or concentration>* at *<site name>*
Site number *<network number, ID or code>* at grid reference *<map co-ordinates and type31>* Situated *<brief location description>* and is monitored for *<site purpose and target characteristics>*.
Additional information: Site is affected by *<persistent adverse conditions at site (e.g. biofouling, some form of regular disturbance, etc.)>*. Sensor is located *<brief description of sensor placement and environment>*. Data are affected by *<influences incorporated in target characteristics>*. Site evaluation is available from *<reference>*. *<Saturation values are fully (or partially) corrected for local barometric pressure (or referenced to 1 atmosphere)>*. *<Some (or All) quality control (and/or data editing) is automated; refer to the relevant Data Processing Comments.> <Data are stored as a censored series.>*
The following is also measured at this site: *<list variables, including any backup DO recorder and separately logged supplementary data>*; *<This record is used to derive <list variables e.g. DO concentration from DO% saturation (reference)>>*.
The local recording authority is: *<name of recording/archiving agency>*

[29] from *Catchments of New Zealand* (SCRCC, 1956).
[30] state the co-ordinate system: NZTopo50 or NZGD 2000 preferred (latitude/longitude to 6 decimal places)
[31] state the co-ordinate system: NZTopo50 or NZGD 2000 preferred (latitude/longitude to 6 decimal places)

4.2.2 Equipment Comment examples

Type: Equipment
Measurement: Dissolved Oxygen
Recorder installed on *<dd-mm-yyyy hhmmss>* is a *<describe main logger features e.g. how powered, compact (or otherwise e.g. PLC), on-board, multi- or single input, programmable etc.>* data logger, recording *<describe logging and sampling regime e.g. instantaneous readings at fixed intervals of x-minutes>*. The DO sensor is a *<type and platform e.g. electrochemical probe or optode sonde>* measuring *<list relevant on-board measurements, including supplementary variables, e.g. uncorrected DO% saturation, water temperature, salinity (or conductivity), etc.>* installed in (or on) *<brief description e.g. weighted cable x-m down well, or below moored buoy, plastic conduit attached to timber pier, steel box section secured on piles etc.>* positioned at *<reduced level and datum, or equivalent stage, or depth from water surface, or other (briefly describe)>*. Sensor range is *<range and units>* with resolution of *<resolution>* and nominal accuracy of *<accuracy specification>* calibrated on *<calibration date>*. Sensor output is converted to logged values of concentration or *<<(uncorrected or (partially) corrected)>* % saturation by *<briefly describe the barometric compensation method e.g. "adjusting for site altitude (or local pressure at time of on-site calibration) (or real-time local barometric pressure), and/or calibration equation(s) e.g. "by a modified Stern-Volmer equation with <x>* calibration coefficients">. Sensor calibration is valid for *<calibration period>*. Site is visited *<verification frequency>*. Data are collected by *<method e.g. telemetry and occasional manual download>*.

Create a similar but separate comment for any:

- backup sensor or secondary source of DO data at the site, to avoid the comments becoming too long and complex
- replacement sensor if any of the previously described details change as a consequence. Include confirmation that all other details have not changed, for example:

Type: Equipment
Measurement: Dissolved Oxygen
Replacement DO sensor is a *<type and platform e.g. optode sonde>* installed on *<dd-mm-yyyy hhmmss>* in the existing installation. New sensor range is *<range and units>* with resolution of *<resolution>* and nominal accuracy of *<accuracy specification>* calibrated on *<calibration date>*. Sensor output, calibration frequency, site visit frequency, and data collection method are unchanged.

Type: Equipment
Measurement: Dissolved Oxygen
Verification data are obtained *<state frequency>* by *<describe method and instrument(s) used e.g. manual readings from a calibrated reference sensor, positioned as close to the sensor as possible, etc.> <Add other relevant information such as form of reference measurements and units, serial number, range, and calibration frequency of the reference sensor>*.

4.2.3 Operational Comment examples

Type: Operational
Measurement: Dissolved Oxygen
Sensor moved on *<dd-mm-yyyy hhmmss>* to *<where in relation to previous>* because *<provide reason for relocation e.g. exposed, fouled, buried, inaccessible, poor velocity etc.>*. New location is *<describe new environment>*. New sensor position is *<reduced level and datum, or equivalent stage, or depth below surface, or briefly describe>*.

Type: Operational
Measurement: Dissolved Oxygen
Sensor cleaned on *<dd-mm-yyyy from hhmmss to hhmmss>*. Data between these times is not representative of in-stream DO and has been *<describe action e.g. deleted from the record or replaced with manual readings from the reference meter>*.

Type: Operational
Measurement: Dissolved Oxygen
Verification reference reading on *<dd-mm-yyyy hhmmss>* was collected *<distance vertical and/or horizontal>* from the sensor due to *<provide reason e.g. high flood preventing access>*. Some deviation from recorded value is expected.

Type: Operational
Measurement: Dissolved Oxygen
Verification reference reading on *<dd-mm-yyyy hhmmss>* is unreliable because *<give reason>*. *<Recorded data are not adjusted to this check.>*

Type: Operational
Measurement: Dissolved Oxygen
Sensor replaced on *<dd-mm-yyyy hhmmss>* because *<provide reason>*. *<Replacement sensor is a different type (or model) (or range). Refer to the associated Equipment Comment for its specifications.>*

4.2.4 Data Comment examples

Type: Data
Measurement: Dissolved Oxygen
Backup record used from *<dd-mm-yyyy hhmmss>* to *<dd-mm-yyyy hhmmss>* due to *<identified cause of primary recording failure>*.

Type: Data
Measurement: Dissolved Oxygen
Missing record from *<dd-mm-yyyy hhmmss>* to *<dd-mm-yyyy hhmmss>* due to *<identified cause of recording failure>* (or values removed because of *<describe recording fault>*). *<Add any other relevant information such as why the gap has not been filled>*.

Type: Data
Measurement: Dissolved Oxygen
Data may be compromised from *<dd-mm-yyyy hhmmss>* to *<dd-mm-yyyy hhmmss>* due to *<describe cause e.g. low velocity, suspected interference or disturbance, intermittent flow, fouling, low power, pumping, suspected calibration error or loss of linearity, etc.>*. *<Add any other relevant information such as corroborating evidence, limitations on usefulness, or possible reasons for data being reliable.>*

Type: Data
Measurement: Dissolved Oxygen
Synthetic record from *<dd-mm-yyyy hhmmss>* to *<dd-mm-yyyy hhmmss>* due to *<identified cause of recording failure>* (or replaces data affected by *<describe recording fault>*). Record generated from *<provide or describe the relation e.g. state the regression equation>* obtained by *<method e.g. least squares or multiple regression, etc.>* with input data *<list sites, variables, and periods used>*. *<Add indication of reliability e.g. regression coefficient or standard error and analysis sample size, or some other assessment of uncertainty etc.>*, *<Add limitations on usefulness e.g. not recommended as supplementary data or for model calibration etc.>*

Type: Data
Measurement: Dissolved Oxygen
Change of datalogging interval on *<dd-mm-yyyy hhmmss>* from *<previous interval>* to *<new interval>*.

Type: Data
Measurement: Dissolved Oxygen
Barometric pressure is recorded *<state interval>* by (and/or obtained *<state frequency>* from) a barometer at site (or at *<site name>*, site number *<network number, ID or code>*, grid reference *<map co-ordinates and type32>*, *<altitude>* masl, operated by *<recording agency>*). *<Add other relevant information such as barometer type, range, units, precision, and accuracy>*. The data are supplementary; *<reviewed and edited for gross errors but not verified prior to use (or applied as received from the recording agency)>*.

Type: Data
Measurement: Dissolved Oxygen
DO exceeds maximum recording range *<indicate frequency e.g. continuously, occasionally, or each day>* between *<dd-mm-yyyy hhmmss>* and *<dd-mm-yyyy hhmmss>*. Affected periods are deleted and marked as gaps (or censored at *<maximum stored value and units>*).

[32] state the co-ordinate system: NZTopo50 or NZGD 2000 preferred (latitude/longitude to 6 decimal places)

4.2.5 Data Processing Comment examples

Type: Data Processing
Measurement: Dissolved Oxygen
Values deleted and record interpolates from *<dd-mm-yyyy hhmmss>* to *<dd-mm-yyyy hhmmss>* to remove spikes caused by *<identified cause>*. Edited by *<name>* on *<date of processing>*.

Type: Data Processing
Measurement: Dissolved Oxygen
Time shift of -1 hour is applied to convert period logged in NZDT from *<dd-mm-yyyy hhmmss>* to *<dd-mm-yyyy hhmmss>* to NZST. Error due to *<give reason e.g. incorrect clock reset at logger restart>*. Edited by *<name>* on *<date of processing>*.

Type: Data Processing
Measurement: Dissolved Oxygen
Values replaced from *<dd-mm-yyyy hhmmss>* to *<dd-mm-yyyy hhmmss>* to remove spikes caused by *<identified cause>*. Edited by *<name>* on *<date of processing>*.

Type: Data Processing
Measurement: Dissolved Oxygen
Data smoothed using a *<time interval or number of values>* centred moving mean from *<dd-mm-yyyy hhmmss>* to *<dd-mm-yyyy hhmmss>* to minimise random noise caused by *<identified cause>*. Edited by *<name>* on *<date of processing>*.

Type: Data Processing
Measurement: Dissolved Oxygen
From *<dd-mm-yyyy hhmmss>* (to *<dd-mm-yyyy hhmmss>*) automated quality control (and/or editing) is applied to this data. Actions include: *<briefly describe each action in specific terms e.g. Range Test: values < x %Sat or > x' %Sat not accepted (or, removed (and gapped)); Flat Line Test: error flagged if n consecutive values are same; etc.>* (or Actions are documented in *<provide reference to processing system documentation that contains specific detail of the tests applied to this data e.g. the site file, quality management system etc.>*), applied *<describe where in the process, with respect to what is original data, e.g. on the data logger (or telemetry system, etc.) prior to archiving as original data, or, after original data have been preserved but before near real-time web publication etc.>*, using *<provide name(s) of software and version and briefly describe how the actions are specified and/or configured in the system, and/or provide reference to where the code is permanently preserved, configuration files or screenshots are retained or similar>*.

Type: Data Processing
Measurement: Dissolved Oxygen
Data adjusted from *<dd-mm-yyyy hhmmss>* to *<dd-mm-yyyy hhmmss>* by *<method and parameters e.g. offset shift of x %saturation (or mg/L), linear drift adjustment of x0 %saturation (or mg/L) to x1 %saturation (or mg/L) etc.>* to compensate for *<identified cause>*. Edited by *<name>* on *<date of processing>*.

Similar 'automation' comments must be provided each time any relevant detail changes, from change to an action threshold through to a change of organisational procedure and/or software. Cross-reference relevant Equipment and Operational Comments as required to avoid unnecessary duplication. File a corresponding Stationarity Comment if change of methods potentially disrupts stationarity of the data.

The level of detail required in 'automation' comments depends on the extent to which the comments are necessary to ensure traceability of changes made to the raw measurements (see Sections 3.1.1 and 8.2).

4.2.6 Transformation Comment examples

Transformations applied prior to archiving a DO record are included here. Transformations of archived records to other forms of the variable, or to other variables of interest, for analysis or modelling are outside scope (see Section 6.2.4.8).

Type: Transformation
Measurement: Dissolved Oxygen
Archived DO% saturation values are corrected to local barometric pressure recorded at site (or at *<site name>*, *<x>* km from site, with altitude correction) by applying the barometric correction function from Annex D NEMS Dissolved Oxygen v3.0.0 to logged values of DO% saturation (referenced to standard atmospheric pressure). Barometer details are available from the relevant Equipment Comment.

Type: Transformation
Measurement: Dissolved Oxygen
DO concentration values archived in mg/L are transformed from logged values of DO% saturation (referenced to standard atmospheric pressure) and water temperature in degrees C, using the relation C = Cs x (DO%/100) rounded to nearest 0.1 mg/L, where Cs is solubility of oxygen in water at equilibrium under 1 atm of pressure obtained from the APHA 23rd edition equation provided in Annex D of NEMS Dissolved Oxygen v3.0.0.

The above two examples need only be filed once at the start of the relevant archive record, not repeated for each period of data processed.

Type: Transformation
Measurement: Dissolved Oxygen
Data from *<dd-mm-yyyy hhmmss>* to *<dd-mm-yyyy hhmmss>* is transformed by a correlation rating to adjust for suspected loss of calibration linearity. Rating points are (original, adjusted) *<list the rating point pairs>*. Sensor was replaced on *<dd-mm-yyyy hhmmss>*. Edited by *<name>* on *<date of processing>*.

Type: Transformation
Measurement: Dissolved Oxygen
A calibration coefficient was incorrect from *<dd-mm-yyyy hhmmss>* to *<dd-mm-yyyy hhmmss>*. The error was in coefficient *<name, e.g. C0>*; value applied was *<value>*, correct value is *<value>*. Affected data have been corrected by applying transformations to recover raw DO sensor signal, then applying the correct calibration equations and parameters, as provided in the manufacturer's calibration certificate *<calibration certificate reference and/or date>*, to the recovered raw signal. Edited by *<name>* on *<date of processing>*.

4.2.7 Stationarity Comment examples

Type: Stationarity
Measurement: Dissolved Oxygen
Sensor moved on *<dd-mm-yyyy hhmmss>* to *<where in relation to previous>* because *<provide reason for relocation e.g. exposed, fouled, buried, inaccessible, poor mixing etc.>*. Measurement of the target characteristics may be affected. Location and position details are available from the relevant Operational Comment.

Type: Stationarity
Measurement: Dissolved Oxygen
Step-change in data from *<dd-mm-yyyy hhmmss>* is coincident with change of sensor type and installation. The data have not been adjusted because all verification checks are within tolerance and a slight shift in stationarity is suspected. Sensor details are available from the relevant Equipment Comments. Location and position details are available from the relevant Operational Comments.

Type: Stationarity
Measurement: Dissolved Oxygen
New effluent discharge consent *<provide consent number and consenting agency>* operative from *<dd-mm-yyyy hhmmss>* at *<location relative to sensor e.g. x m (or km) upstream>* on *<name of stream, or unnamed tributary>* may affect DO values recorded at this site after this date.

Type: Stationarity
Measurement: Dissolved Oxygen
Method to convert from measured uncorrected DO% saturation to archived DO concentration (mg/L) is changed from *<dd-mm-yyyy hhmmss>*. Refer to the relevant Transformation Comments for method details.

Type: Stationarity
Measurement: Dissolved Oxygen
Data are a censored series. Maximum accepted value and therefore censoring threshold was changed on *<dd-mm-yyyy hhmmss>* from *<x %Sat>* to *<x' %Sat>*. Refer to the corresponding Equipment Comment for logger reprogramming details.

Stationarity Comments can also be used to capture and collate information about historical methods and data.

5 Preservation of Record

Requirements in this section are additional to Section 8 of this Standard for DO sites.

End users must have access to verified DO record in the following forms, either directly or by subsequent calculation:

- DO% saturation:
  - referenced to standard atmospheric pressure (uncorrected, DO% reference), and
  - corrected to local at-site barometric pressures (DO% local), and
- DO concentration (mg/L).

Recording agencies must therefore permanently archive and back up regularly:

- the original DO data as defined by the agency (see Section 3.1.1), which may include on-board (the instrument) corrections for water temperature, salinity, barometric pressure and/or altitude
- the verified and edited series of DO, which may be a different form from the original, and
- at least as supplementary data, any of water temperature, salinity, barometric pressure, or altitude that:
  - have been used to obtain the original DO data
  - have not been compensated for in the original DO data, and/or
  - are needed in combination with the verified and edited DO record to derive the other forms of DO data.

For example: The processed and permanently archived record of DO at a freshwater site may be of uncorrected DO% saturation provided continuous records of water temperature and local barometric pressure are also permanently archived to enable corrected DO% saturation (DO% local) and DO concentration to be derived from the archived series at any time in the future.

6 References

Soil Conservation and Rivers Control Council (SCRCC). 1956. *Catchments of New Zealand.* SCRCC, Wellington.

Wagner RJ, Boulger RW, Oblinger CJ, Smith BA. 2006. *Guidelines and standard procedures for continuous water-quality monitors—Station operation, record computation, and data reporting.* U.S. Geological Survey Techniques and Methods 1–D3. Retrieved from https://pubs.usgs.gov/tm/2006/tm1D3 (31 May 2021)

Wilcock B, Gibbs M, McBride G, Young R. 2011. *Continuous measurement and interpretation of dissolved oxygen data in rivers.* NIWA Client Report HAM2011-010, prepared for Horizons Regional Council. NIWA, Wellington.

YSI. 2009. *The dissolved oxygen handbook: A practical guide to dissolved oxygen measurements* (76 pp.). Yellow Springs, OH: Yellow Springs Instruments Inc. (www.ysi.com).

Appendix H.1 Methods for Infilling Gaps

1 Information Requirements

The method chosen to infill a gap (i.e. a period of missing record) will depend on:

- the type of water body (e.g. river, lake, estuarine or open coast)
- location of the sensor in the depth profile
- the nature of the surrounds above and below water (e.g. shading, wind, presence of algae and/or macrophytes)
- the duration requiring infilling
- the degree of mixing at-site during the period missing
- availability of other relevant at-site time series, such as:
  - backup dissolved oxygen data (see Section H 3.11)
  - water temperature data
  - flow or water level data
- likelihood during the period missing of:
  - extreme DO highs or lows having occurred
  - an event causing disturbance or alteration of the sensing environment (e.g. floods and/or algal blooms), or
  - local inputs that may affect DO, e.g. a nearby upstream discharge
- availability of supporting observations and other evidence such as:
  - verification readings
  - manual observations using the reference meter, intended as infill, and
  - other readings, e.g. observations during other sampling at-site or nearby in the period, including those measured using an instrument other than the usual reference meter.

2 Recommended Methods

The following methods are candidates for infilling gaps in dissolved oxygen (DO) records:

- inserting one or more of:
  - at-site backup DO data (see Section H 3.11)
  - at-site verification readings
  - other at-site readings obtained using the reference meter
  - at-site manual readings from other instruments
  - readings obtained nearby in the same water body
- synthesising a record.

Synthetic infill can be created using one or more of the following methods:

- manual entry of intuitive estimates for brief and short periods (see Appendix H.1 Section 2.3 and Section H 3.11)
- mathematical calculation of the sine curve or copying from a reference trace recorded at the same site for short periods (see Appendix H.1 Section 2.4 and Section H 3.11)
- superimposing a recorded peak from the same site to reinstate a clipped peak (see Appendix H.1 Section 2.5 and Section H 3.7)
- generating a record from results of a linear or curvilinear regression with one or more suitable donor sites (see Appendix H.1 Section 2.6).

Manual readings can be incorporated into all the above methods to improve confidence in the synthesised data.

Periods of fourteen (14) days or more should not be filled with synthetic data.

2.1 Infilling with backup dissolved oxygen data

Backup DO data (see Section H 3.11) must be compensated, verified, edited, and quality coded as for the primary record for the period it is needed, including assessing for recording problems that would preclude its use.

If the backup data are manual readings from an instrument other than the primary in-situ sensor, note their source and uncertainty in the Data Comment and select a quality code for the period by following the schema.

Local effects and differences in instrument design and calibration make it unlikely the backup and primary records will directly overlap if not from the same instrument. Small drift adjustments (see Section H 3.4) may be needed to eliminate steps at the junction of the primary and infill backup series.

2.2 Infilling with observations

Verification readings and other manual observations at-site or nearby may be used to assist with infilling a gap.

If a logger and/or sensor is disconnected for a period during a site visit and there is no backup in-situ sensor, manual observations from the primary in-situ sensor and/or reference meter should be collected so they can be inserted into the record as backup data to avoid a gap (see Appendix H.1 Section 2.1).

If the manual readings are not of sufficient frequency or reliability to be backup data, the period infilled by them is an estimate from limited measurements and therefore must be quality coded QC 300.

2.3 Infilling by manual entry

Unless a more sophisticated method is readily to hand, often the most efficient way to fill a short gap (see Section H 3.11) is to intuitively 'draw it by hand', i.e. manually insert values to complete a straightforward rise or fall within a diel cycle. If a straight line is a good approximation, deleting the gap marker may be all that is required to close the gap.

2.4 Infilling the curve between adjacent peaks and troughs

It may be sufficient to copy values from a similar period of record at the same site.

Note: Seasonal variation in diel cycles may need to be taken into account.

An unbroken curve can be estimated by connecting the adjacent periods of good DO record with a straight line or smooth curve on a semi-logarithmic plot.

Otherwise, the curve may be calculated from the sine curve formula $y = a\sin(bx + c)$ where a is the amplitude, b is the period, and c is the phase shift of the sine curve.

2.5 Reinstating a clipped peak

A recorded peak may be superimposed onto a diel cycle to reinstate a clipped peak. The superimposed peak can be offset to merge with the clipped diel cycle but must not be 'stretched' or 'contracted' over its range or with time in order to fit.

This option should be used with caution for lengthy periods of DO% saturation clipped at 120% or less, because while high DO values are less certain and of less ecological concern if occasional, prolonged exposure to DO above 120% may adversely affect fish and other stream life (Wilcock et al, 2011).

2.6 Infilling by regression analysis

The method is described in Appendix 2 to the main document.

Do not use equations forced to zero for regression of DO data. If low DO is predicted, its significance and likelihood at the recipient site must be assessed. If periods of low DO are not plausible the analysis should be discarded.

For river sites, regression analysis should only be used when flow is in recession at the donor and recipient sites and at least five days has elapsed since the most recent fresh at either site(s).

Apply the regression equation intended to generate the synthetic record to another period of record of similar duration, season, and flow conditions, where recipient site data exist and compare actual and predicted maximum and minimum DO values. If the difference between actual and predicted for either extreme exceeds ± 10% of the actual value, the analysis should be discarded.

Ensure the summary statistics from the regression are documented in the associated comment, including period used for analysis, interval and type of the regressed data, sample size, equation(s) used to generate the infill, and the regression coefficient (R^2).

2.6.1 Selecting suitable donor sites

One or more donor sites should be selected from other DO recording sites with similar physical characteristics in the same water body. For rivers, donor and recipient sites may be some distance apart provided they are physically similar.

If more than one suitable donor site is available, multiple regression can be used. The regression analysis determines the relative contributions of each donor site. Multiple donor sites are also useful to test for and minimise bias from and/or dependence on a single donor source (Joenssen and Bankhofer, 2012).

Compare an extended period of record from all candidate sites. Assess whether lag is needed on any input.

Note: Lag may be observed if thermal lag and/or shading is a factor at any of the sites. Lag due to relative timing of flow variations should not be a significant feature of DO data between sites under the flow conditions recommended for regression analysis.

2.6.2 Time resolution of the synthetic record

Time resolution of the synthetic record should match the primary recording interval.

Note: Although a longer interval average may improve the correlation, incorporating average in preceding or succeeding interval data into an instantaneous series with diel cycles distorts the timing of those cycles unless the time-series manager permits mixing of average in interval and instantaneous data in the same series.

The filed comment(s) must make clear how the synthetic infill was derived and then incorporated into the record.

2.6.3 Seasonality of relationships

Seasonal variation in DO is typical for most water bodies except deep groundwater. The effect of seasonality on the relationship used to derive a synthetic record should be explored, especially if potentially influenced by factors such as high temperatures, algal blooms, high macrophyte biomass and stratification. If significant, relationships may be required for each season.

3 References

Joenssen D, Bankhofer U. 2012. *Hot deck methods for imputing missing data*. In: international workshop on machine learning and data mining in pattern recognition. Springer Berlin Heidelberg. Retrieved from http://link.springer.com/chapter/10.1007/978-3-642-31537-4_6 (14 July 2020).

Annex I Discrete Water Quality Data Processing

1 General Overview

This Annex contains further processing guidance specific to discrete water quality data measured with hand-held field meters and devices, and by laboratory analysis of water, and possibly sediment, samples.

The data may include measurements of water temperature, turbidity, and dissolved oxygen, for which there are other annexes. While general data curation principles applicable to a continuous time series of a water quality variable also apply to discrete measurements, methods for data and quality management differ sufficiently that this annex should be used for discrete measurements of those variables when they are part of a long-term programme of periodic water quality monitoring.

Discrete water quality data may be stored in a time-series manager as data type discrete (see Section 1.1.2), but because of its diversity relative to its frequency it is more commonly stored and managed in a conventional relational database or a hybrid. More about data storage architecture is provided in Section I 1.5.2.

1.1 Normative references

This Annex shall be read in conjunction with the following references:

- NEMS Water Quality
- Part 1 of 4: Sampling, Measuring, Processing and Archiving of Discrete Groundwater Quality Data
- Part 2 of 4: Sampling, Measuring, Processing and Archiving of Discrete River Water Quality Data
- Part 3 of 4: Sampling, Measuring, Processing and Archiving of Discrete Lake Water Quality Data
- Part 4 of 4: Sampling, Measuring, Processing and Archiving of Discrete Coastal Water Quality Data

Where reference is made from this Annex to sections of the above documents, the title is abbreviated, and the relevant part(s) and version(s) are stated, e.g. 'NEMS *Water Quality Parts 1 & 3* v1.0.0', or *'Parts 2 to 4* v1.0.0*'*. Where requirements and/or procedure in this Annex duplicate and possibly conflict, this Annex shall prevail.

1.2 Scope of this annex

The normative reference is in four parts (see Section I 1.1); one for each of the four water body domains of groundwater (including springs), rivers, lakes, and coastal waters (including the tidal reaches of rivers). While its partitioning was necessary to cater for important differences in sample collection and measurement requirements (e.g. methods, calibrated range, and detection limits), data processing requirements are

sufficiently similar that procedures in this Annex can be applied to data from all four water body domains.

Note: Interpretation of "tidal reach" may differ between water quality and water quantity specialists. Tidal backwater can affect water levels many kilometres further inland than the salt wedge extends.

1.3 Variable names and nomenclature

To facilitate inter-agency data exchange and future internal data migration, and improve consistency of inter-agency, inter-regional, and national reporting:

- use the variable names and nomenclature tabled in the Scope of each NEMS *Water Quality Parts 1 to 4* v1.0.0 when exchanging, reporting, and preferably also when storing discrete water quality data
- except for turbidity, where the measurement units must be added to the variable name (e.g. Turb – field FNU) (see Section I 1.4).

1.4 Units of measurement

Units of measurement for water quality variables may be determined by one or more of the measurement method, range of expected values, compensation(s) for interference(s), and reference to a standard, e.g. a standard temperature or pressure.

Units of measurement for each water quality variable covered by NEMS *Water Quality Parts 1 to 4* are stated in 'The Standard' of each Part. Agencies may collect and store data in other measurement units, but the data cannot then be quality coded QC 600.

In all cases the measured values of any discrete water quality variable must be clearly and unequivocally associated with their applicable units.

Explicit conversion between measurement units is not possible for relative measures such as turbidity and oxygen-reduction potential (ORP), or indirect measures such as chlorophyll a by fluorescence. Conversion of these variables can be achieved via a relationship calibrated with paired measurements in both the original and desired units, but accuracy and reliability of the converted values are compromised by uncertainty in the relation.

Additional more complex considerations apply for turbidity and dissolved oxygen (DO). Refer to the following sections for more information and any related requirements:

- this document, Sections E 3.9 (turbidity) and H 1.2 (DO)
- NEMS *Water Quality Part 1* v1.0.0 (groundwater) Section 3.1.2 (DO)
- NEMS *Water Quality Parts 2 & 3* v1.0.0 (rivers and lakes) Sections 3.1.2 (DO) and 3.1.5 (turbidity)
- NEMS *Water Quality Part 4* v1.0.0 (coastal water) Sections 3.1.2 (DO) and 3.1.6 (turbidity).

1.5 Effect of data type

1.5.1 Discrete data (non-interpolating)

Depending on the sensor, measurement values may be instantaneous or a short-interval average of up to 1-minute. The exception is light penetration (PAR), which may be logged over a longer period to average out surface distortion focusing effects (see NEMS *Water Quality Part 3* v1.0.0 Section 3.3.1.4 or NEMS *Water Quality Part 4* v1.0.0 Section 3.3.1.6). All are treated as instantaneous measurements with no interpolation between adjacent values.

1.5.2 Data storage architecture

Continuous data requires the use of a time-series manager (TSM) to define and implement the appropriate interpolation mechanism between each data element.

Discrete data by definition is not interpolated so there is no fundamental requirement for discrete data to be stored in a TSM. This Standard therefore allows discrete water quality data to be stored, processed, documented, and permanently archived in a conventional relational database or data warehouse facility.

However, for long datasets the ability to manage and select data using true time queries is beneficial as is the ability to integrate water quality data with continuous variables such as flow. For these reasons this Standard does require discrete water quality data to be stored in a system designed to support time dependent functions. There are advantages in also maintaining a corresponding verified and quality coded time series of the variable in an industry recognised TSM (see Section I 4.2).

Regardless of the storage architecture, quality coded water quality data must be accessible via sector-specified application programming interfaces (API's) to facilitate data sharing and exchange, e.g. publication to LAWA (Land, Air, Water Aotearoa).

Note: Hilltop Software's architecture is a hybrid where the measurement results, and measurement and sample metadata, are stored in the TSM using a dedicated pair of data types with discrete interpolation, while the possible measurement and sample metadata items (parameters) are stored in a database table. Measurements with the same date and time are automatically grouped together as the sample, to which the sample metadata then applies, rather than being grouped via the assigned sample ID.

1.6 Supplementary variables

Supplementary water quality variables are those required to be measured concurrently with the target variable for calibration, validation, standardisation to a reference temperature and/or pressure, and/or compensation of a target variable measurement.

They include:

- water temperature for dissolved oxygen (DO), specific conductivity (SpC), and pH, and

- for DO, salinity if greater than 8 ppt (i.e. includes all coastal waters), and local true barometric pressure and/or altitude of the site if not at sea level.

Compensation for these supplementary variables is usually performed on-board the field meter, but if not, the relevant supplementary variable values must be inspected and edited for gross errors, then stored as additional data items with the target measurement(s).

If a supplementary value is edited it may change the dependent target variable value. Both should be reviewed together and change of a supplementary value must be noted against both the supplementary and dependent target measurement, whether the dependent target value is also changed or not.

Stored supplementary variable values must have a quality code that is determined as if they were the target variable. If there is no NEMS for the supplementary variable, assign QC 200 (of unknown quality).

The compensated or standardised target variable cannot acquire a quality code higher than that of its applied supplementary variable(s), except for when QC 200 has been assigned to the supplementary variable(s).

If QC 200 has been assigned to the supplementary variable(s), the lesser of QC 500 or the code determined from the NEMS *Water Quality Parts 1 to 4* v1.0.0 Matrix A score then applies to the compensated or standardised target variable value.

When required for calibration and/or validation, supplementary variable values are recorded on the calibration form. Unless at-site calibration was required, it is only necessary to ensure the calibration and validation records are appropriately preserved (see Section I 7).

If calibration was performed at site, supplementary measurement values will be recorded on both the field record and calibration forms and should be reconciled, and any anomalies addressed, when the field record data are processed.

1.7 Complementary observations and measurements

Complementary observations and measurements are those collected to aid interpretation of the target variable(s). They may include:

- the observations and measurements listed as required or recommended in the relevant Site Metadata and Visit Metadata sections of NEMS Water Quality Parts 1 to 4
- GPS location of boat and helicopter accessed sites
- weather conditions, including air temperature, wind speed and direction, and rainfall on the day

- sky and/or ambient light conditions and/or % cloud cover (for visual clarity and colour measures), and indication of antecedent rain, for surface waters
- solar altitude for light penetration
- water levels, including depth to water or pressure head of groundwater and phase of the hydrograph or tide cycle
- discharge for river sites (including tidal reaches), obtained as:
- concurrent values for 'flow stamping', and/or
- a continuous series for load calculations.
- by:
    - gauging during the site visit, and/or
    - applying a stage-discharge rating for the site (requires stage measurement(s)), or
    - estimating from a nearby site, between-site relationship, or model

    Note: Discharge ratings, relationships and models are often continually reviewed and updated so derived discharge data are seldom static. Unless gauged during the site visit, retrieving the discharge as required is preferable to storing a derived discharge value(s) with the water quality results.

- date/time stamped, and geo-referenced site photos taken at least annually, including lake and coastal sites if near-shore, appropriately indexed and stored for later search and retrieval
- pH when measuring ammoniacal nitrogen and/or metals
- bathymetry of lakes and coastal water bodies
- delineation of the stratification regime of the lake or coastal water body (often as a pilot study to assist with designing the monitoring strategy) (see NEMS *Water Quality Parts 3 & 4* v1.0.0 Section 2.4)
- measurements required to design and monitor the purging of groundwater wells (see NEMS *Water Quality Part 1* v1.0.0 Section 4.1)
- appropriately identified photos of water colour to build a resource to aid development of an image analysis method for colour measurement
- surface sediment quality as an alternative or complementary to water column measurement in coastal waters, including photos of sample cores and their sample properties (see NEMS *Water Quality Part 4* v1.0.0 Annex D).

Store the observations and measurements as values in appropriately configured database fields in preference to within a document (whether paper or electronic) or as free format text (e.g. in a comment) especially if the data are or can be numeric, e.g. wind speed and direction, depth, water level etc.

If using text fields, standardise the vocabulary to minimise data entry errors and search complexity.

Apart from discharge, which may be used for subsequent calculation of loads, agencies may choose whether to quality code complementary observations and measurements. Discharge values will usually have been assigned a quality code when stored, or when accessed if obtained from a rated flow series. If not, assign QC 300 (synthetic) to estimated discharge values derived from between-site relationships or hydrological or hydraulic models and QC 200 (of unknown quality) to all other discharge values.

1.8 Documenting the data management system

1.8.1 Field and Office Manual

A Field and Office Manual or equivalent is required to be developed, maintained, and implemented by the monitoring agency. The manual must include agency procedures for quality assurance, quality control, documentation, preservation, and audit of the data collected (see NEMS *Water Quality Parts 1 to 4* v1.0.0 Section 1.1).

1.8.2 Monitoring objectives and sample design elements

While these aspects are beyond the scope of NEMS to address, they should be formally recorded in one or more documents that are catalogued, filed securely, and retrievable as required, because they influence what is measured where, how, when, by whom, for how long, and for what purpose.

The document(s) should contain maintained lists of which sites are included in which monitoring programmes, which variables are to be measured at each site, and what methods are to be used for each variable.

These documents can be associated with the data collected via a Site History Record (see Section I 1.8.3) and a Site/Initial Comment (see Section I 5.3.1) so the data are traceable to their purpose and sample design, which assists a future data user to assess fitness of the data for their purposes.

1.8.3 Site History Record

The Site History Record is a dedicated facility in which to store and maintain the site metadata (see Section I 2.2.3) for each site. For example, it may be a paper or electronic document, file, or folder per site, or one or more database tables.

Each Site History Record should link to or reference the governing monitoring objectives and sample design (see Section I 1.8.2).

The Site History Record is summarised in the Site/Initial Comment and important changes at the site relevant for an end user of the data are documented over time in a series of Operational Comments (see Section I 5.3).

1.8.4 Forms

Field Record forms

Field Record forms are used for data collection, i.e. to record observations and field measurements. Initial sample metadata including initial treatment of the sample such as filtering is also recorded on this form. Once completed these forms are an original record that must be secured and preserved as described in Section I 7.1.1.

Calibration and validation

The Field Meter Calibration form is used to record hand-held field meter calibrations and validations. Each meter must have a unique identifier. Once completed these forms are a quality assurance record that must be secured and preserved as described in Section I 7.4.1. Completed forms may be stored and follow-up actions tracked in an asset management system.

Laboratory calibrations and validations, and curation of the associated records, form part of the laboratory's internal quality management system, which may be independently IANZ accredited. A monitoring agency's ability to view and query these records if required when using an external contracted laboratory should be incorporated into the laboratory service contract.

Chain of custody

This form travels with the samples to the laboratory providing the laboratory with information about the origin of the samples and what tests to perform. The laboratory assesses timeliness and condition of the samples on arrival and records receipt of them and any issues on the same form, a copy of which is then returned to the monitoring agency, providing assurance that samples were not lost or compromised on the way.

Information on the form about condition of samples on receipt is used when quality coding the sample results and forms part of the sample metadata that must be permanently stored with the sample results. Completed forms must therefore be retained at least until all expected results from the samples are received from the laboratory, fully processed and quality coded, the metadata has been compiled, and all are permanently archived and backed up.

Customisation of forms

Customisation of forms is encouraged to minimise data entry time in the field and allow for some flexibility in the monitoring programme and formation of sampling runs but the process must be managed within a controlled document system. Each form should have a unique identifier, be subject to a formal approval process before being used, and be versioned to prevent old forms from being inadvertently used.

1.8.5 Identifier conventions

Each agency must develop, document, implement, and maintain conventions for:

- unique identification of field meters and measurement apparatus
- site and visit (sampling event) identifiers, and

- sample identification and tracking.

Site and visit identifiers

A sampling event is a single visit to a site to take measurements and collect samples. When combined, the site and visit identifiers associate the site visited and the date and time of the visit with the visit's metadata, field measurements, and sample results.

The site identifier must be unique to the monitoring site (see NEMS *Water Quality Part 1* v1.0.0 Section 4.5 or *Parts 2 to 4* v1.0.0 Section 2.6.1). It may be a name, code, or combination, but for ease of use it should be broadly recognisable if also used as the site name for the data in the database and/or TSM. Depending on the data storage system, data collected at different depths in a profile may require a different site identifier for each depth. In rivers, the sampling location is representative of the reach so if the sampling location is moved within that reach a new site identifier may not be necessary. The site identifier can also be used to associate the site history record with the site's measurement results.

The visit identifier is the adopted common date and time of the visit that is assigned to all field measurements and samples collected during the site visit, i.e. the date and time of the last field measurement at the site, to the nearest 5 minutes (see NEMS *Water Quality Part 1* v1.0.0 Section 4.6 or *Parts 2 to 4* v1.0.0 Section 2.6.2).

Sample identification

Sample identifiers are used to associate field records of samples collected with their laboratory records, including the chain of custody and laboratory results report. They may be used to uniquely label each sample bottle if they are themselves unique, or made unique, e.g. by suffixing with the depth for samples in a profile.

If the sample identifiers are associated with sites and sampling runs when generated the sample identifiers may also be used when results are received electronically from the laboratory to direct the results automatically on import to the correct site and sampling run in the database.

1.8.6 Tracking the status of samples

The monitoring agency must record which samples were sent where, when, by whom and with whom, e.g. by recording courier tickets (tracking numbers) against the sample identifier(s), and have some documented process to monitor:

- timely notification of receipt of a shipment by the laboratory
- timely return of the completed Chain of Custody form
- start of receipt of analysis results
- when all sample results are back
- when all sample results are checked, quality coded, and archived, and
  - formal 'closure' of the sampling run, or
  - cancellation/abandonment of the sampling run with no data to archive.

The monitoring agency must document how orphan results are managed and resolved, i.e. analysis results wrongly identified, attributed, and/or reported, and/or from samples not able to be identified.

1.8.7 Method detection limits

A method detection limit (MDL) is the lowest concentration for a test that a laboratory can be 95% confident is above zero (see NEMS *Water Quality Parts 1 to 4* v1.0.0 Section 5.4.2). Sample analysis results that are less than the test MDL are formally reported as censored values.

MDL's for methods covered by NEMS *Water Quality* v1.0.0 are set out in 'The Standard' for each Part (and *Part 1* Table 3, *Part 2* Table 4, and *Parts 3 & 4* Table 5). However, agencies are provided some discretion to use higher or lower MDL's than appear in 'The Standard' if the range of concentrations sampled from a site are atypical. The detection limit for a variable may also change when the test method is changed. Thus, the MDL applicable for a variable may vary with site, and over time within a site record.

The above means that the applicable MDL cannot be attributed to the variable or the test method and must instead be stored as a measurement result, i.e. value attribute.

1.8.8 Quality control and quality assurance processes

Quality control (QC) and quality assurance(QA) processes must be documented in the Field and Office Manual (see Section I 1.8.1).

Note: QC checks the data whereas QA checks performance of procedures.

Workflow should be designed to minimise manual data entry and data editing, and facilitate transparent, optimised data curation.

Processes should include procedures for review, to ensure timely and appropriate response to issues identified, and prevent future recurrence.

Any automated QC or QA must be fully described (e.g. by reference to a technical and/or user manual) and controlled (i.e. releases must be formally managed), whether implemented in data collection apps, e.g. electronic field sheets, or on the database. Examples are warnings or restrictions applied during data entry or import such as rejection of a pH value outside the range 1 to 14.

Performance of automated functions for QC and QA must be regularly checked and the outcome of those checks documented and retained (see Section I 7.3.2).

1.8.9 Original records

The monitoring agency shall define and formally document which records are considered original, and therefore required to be secured, preserved, and permanently retained (see Section I 7.1).

The following guidance is modified from Section 3.1.1, which was designed for continuously logged data measured using a permanently installed sensor.

Original discrete water quality records generally will comprise the original data, and all metadata essential to verification of that data and full traceability of any archived result. Full traceability means that:

- initial measured values and observations are able to be referred to during data verification and retrieved at any time in the future, or
- all modifications made to the initial measured values during data capture and collection are known, documented, able to be confirmed as valid during data verification, and able to be reversed if found necessary, and
- results supplied by a laboratory are fully traceable within their internal system(s) and via the chain of custody, or
- individual field meter calibration and validation records can be accessed during data verification and retrieved at any time in the future.

Completed Field Record and Field Meter Calibration forms, populated electronic field sheets, and official laboratory reports are all considered to be original records.

Data prior to verification and any associated editing by a suitably skilled and experienced person is regarded as original data, to be assigned quality code QC 0 (non verified).

Original data may be:

- raw, i.e. exactly as measured
- as recorded during data collection if modified from raw by documented automated checks
- the 'first write' to the database system that will be used to process and store the data, provided all changes to the data already made are known and traceable
- as reported by a laboratory to a representative number of significant figures (see Appendix 3), and/or
- censored to a method detection limit (see Section I 1.8.7) or calibrated range (see Section 1.1.5).

NEMS *Water Quality* v1.0.0 recommends laboratories also be requested to supply the raw (i.e. uncensored, unrounded) measurements and their associated uncertainty of measurement (UoM) (see NEMS *Water Quality Parts 1 to 4* v1.0.0 'The Standard' (second table) and Section 5.5.1). If an agency opts to obtain the raw laboratory data, the agency must also document (and implement):

- how it will ensure raw (uncensored, unrounded), and rounded and/or censored, versions of the data are not muddled
- how integrity of both versions will be managed in the database
- how each version will be identified, and
- which version will be supplied for publication or to a data user.

Note: Some data users may prefer the raw measurements with their UoM over the 'official' reported results (which may be rounded or censored), e.g. when the results of analysis of water samples are used to 'field calibrate' an in-situ sensor using a TSM Rating Curves toolbox.

2 Quality Control

Quality control procedures should be undertaken regularly and within the period that samples are retained by the laboratory for retesting if required. NEMS *Water Quality* v1.0.0 recommends laboratory results are reviewed within two weeks of receipt (see NEMS *Water Quality Parts 1 to 4* v1.0.0 Section 5.5).

2.1 Quality coding matrices

Quality coding matrices A and B should be completed while on site at each visit, but if not, they should be completed as the first quality control task of data processing (see also Section I 5.2.1). Completed matrix assessments, whether done in the field or the office, form part of the records of data processing that must be preserved and indefinitely retained (see Section I 7.2.4).

2.2 Additional metadata required

General requirements for metadata are set out in Section 6.1.

NEMS *Water Quality Part 1* v1.0.0 Section 2.3 and *Parts 2 to 4* v1.0.0 Section 2.2 list the site metadata to be collated and collected. *Part 1* v1.0.0 Section 4.4 and *Parts 2 to 4* v1.0.0 Section 2.6 list the visit metadata to be collated and collected. To verify and annotate for archiving the field data collected and the sample results, additional metadata are needed and created. For discrete water quality data there is a hierarchy to the metadata that can provide storage and retrieval efficiencies.

2.2.1 Monitoring programmes

Lists which sites are to be visited, how frequently, which variables are to be measured at each site, and what methods are to be used for each variable. Sites to be visited may be grouped into runs.

2.2.2 Sampling runs

The date, set of sites visited on that day, usually in a predetermined and set order, and the collective group of samples and measurements required and obtained from the sites.

2.2.3 Sites

A site is a location visited for the purpose of making measurements and observations and collecting samples. Site attributes are specific to the location. They may change with time but generally not on each visit. Multiple visits may be made to a site over the course of a long-term monitoring programme.

A site may be part of several monitoring programmes with separate runs associated with each programme. It is possible for a site to be visited and sampled more than once on the same day. Multiple sampling events at the same site on the same day can be differentiated by their visit times.

Note: Most TSM's do not permit two data elements in the same time series to have the same timestamp. If two or more items of data must share the same date and time, they must be stored as multi-item data.

The required site metadata are listed in NEMS *Water Quality Part 1* v1.0.0 Section 2.3 and *Parts 2 to 4* v1.0.0 Section 2.2. Annual review and update of this metadata is also required.

In addition, for river sites, identify the extent of the reach represented by the sampling location, by description, and by distance from a landmark, or GPS the upstream and downstream ends.

2.2.4 Visits

A visit is a single sampling event, i.e. one occasion of collecting measurements and samples from a site. Required visit metadata are listed in NEMS *Water Quality Part 1* v1.0.0 Section 4.4 and *Parts 2 to 4* v1.0.0 Section 2.6 and includes specific observations made about where and when field measurements and water samples were collected. The observations and attributes are usually applicable to all measurements and sampling carried out during the visit, i.e. they are unlikely to vary between samples and measurements on the same occasion, but will vary between visits. Visit metadata are recorded on Field Record forms (see Section I 1.8.4).

2.2.5 Instruments

One or more instruments may be used at-site or over time at any site. Field meter metadata includes all calibration, validation, and maintenance records from the manufacturer and/or supplier, and those generated by the monitoring agency, e.g. Field Meter Calibration forms (see Section I 1.8.4).

Water quality field instruments require a unique identifier, e.g. their serial number, and the instrument metadata must include the make or brand, and model (i.e. they are exceptions from the guidance in Section 6.2.4.4).

2.2.6 Laboratories

One or more laboratories may be used over time and test methods may change as a consequence. A quality assurance sample may be split and sent to two separate laboratories, i.e. results for the same sample may be received from two different laboratories.

The laboratory service contract or agreement, details of accreditation and/or other means of quality management and completed chain of custody forms are required metadata.

The laboratory that performed the test must be recorded against each sample result (see Section I 2.2.9).

2.2.7 Samples

A unique sample identifier (ID) is usually issued at this level, applicable to a volume of water collected. A range of tests may be carried out on a sample.

The sample ID is associated with the site and sampling run and can be used to label the bottles transferred to the laboratory. If sub-sampled into smaller bottles a suffix may be added to uniquely identify each bottle.

If discrete volumes are collected through a depth profile, the sample ID may apply to the profile instance (described by its location, date/time, and range of depths) and suffixes added to uniquely label each bottle filled from each discrete sampling depth. Depth-integrated samples submitted in a single bottle can be identified by the sample ID on its own.

Any sample collection metadata applies to all bottles filled from the sample and all tests performed on the sample.

2.2.8 Bottles

Bottles must be uniquely labelled. The bottle labels are then used to record on the Field Record form what bottles were filled in the field, and to record on the Chain of Custody form which bottles were sent to which laboratory.

A sample may be sub-sampled into multiple bottles.

Sample preservation, preparation (e.g. if filtered), and condition metadata apply at this level and to all tests performed on the water contained in each bottle.

2.2.9 Measurements

While for data processing and reporting, every stored result must be able to be associated with all relevant of the above metadata, i.e. every result must be traceable to the visit, site, run, and programme, and to the sample and laboratory or the field instrument used to obtain it, metadata at this level must be stored with the measurement result.

Each water quality measurement is required to be stored with:

- its associated measurement date, time, and units
- field instrumentation (make, model and number) or laboratory name, location, and test method (whichever is applicable)
- clear reference to its associated form (dissolved, total, reactive, etc.), where applicable (e.g. nutrients and metals)
- all relevant visit-related metadata, including the name(s) of personnel conducting field measurements and sampling (see Section I 2.2.4)

- relevant laboratory comments where applicable (see Section I 2.4.2), and
- its associated quality code (see Section I 5.2).

The test method used must be attributed at this level because choice of test is possible and may change within a site's dataset.

For example: the laboratory changes method because of physical sample matrix issues, or the variable is measured via sampling instead of field measured due to difficulty obtaining a stable field instrument calibration, or clarity instrument and/or disk size is varied to suit visibility conditions at the time.

Measurement units are usually determined by the test method and therefore may also change. TSM's in general expect the same units to apply to the entire time-series record so unit conversion may be required if the data are stored in a TSM. Explicit conversion of measurement units may not be possible for some variables, e.g. turbidity (see Sections I 3.7 and I 4.1).

Change of test method (e.g. change of chemistry or instrument principles of operation), may cause a potential stationarity issue (see Section I 2.4.5).

For example: recent studies have concluded that changing brand and/or model of turbidity instrument disrupts stationarity (see NEMS Turbidity v2.0).

Variations in the same method must also be differentiated. These include visual clarity disk/instrument selection on each occasion, and whether the sample was diluted before analysis (which increases the UoM). Details of the dilutions applied, and subsequent calculations are not required to be stored with the measurement result if they are traceable for verification via the laboratory records.

MDL's must be attributed at this level because they can vary with water domain, laboratory, or instrumentation, and may be adjusted at any time at the discretion of the agency upward to reduce testing costs or downward if the frequency of censored values being returned is excessive (see Section I 2.4.2 Censored Results).

2.3 Plots and comparisons

2.3.1 Scatter plots

Scatter plots (see Section 3.6.4.1) are a useful way of visually inspecting discrete water quality data. Scatter plots of closely related variables, e.g. visual clarity with turbidity, can assist with identifying inconsistencies in either measurement and prompting further checks or investigation.

Note: The range of some variables can extend to several orders of magnitude, which may make a scatter plot less useful. A log scale or normalising the variable(s) may assist.

2.3.2 Mapping services

Use mapping services to confirm the recorded location of new sites and to periodically check all geographic references in the database. The annual review of site metadata is a good time to do this.

2.3.3 Comparisons

Use comparisons to:

- cross-check data for anomalies, and
- confirm editing and adjustments have been properly applied.
- compare the recorded data with:
  - previous data recorded at the site
  - other associated variables recorded at the site, e.g. relevant supplementary variables, and water level or flow
  - an in-situ instrument at the same site, e.g. a multi-parameter sonde that may be recording over a different range, accuracy and/or resolution, provided it is not also affected by the same data quality issue(s)
  - verification measurements, and validation results, if any.

With respect to, and over time:

- Sanity check sampling dates and times, e.g. if within daylight or business hours on a weekday.
- Check consistency over time of sampling time of day (within one or two hours).
- Compare new data with expected values for the site and variable (see Section I 2.5.2).
- The above checks may be pre-populated, automated, and implemented on the field form to warn and provide opportunity to re-check data entry and instruments and/or re-measure while still on site.

With respect to, and through the depth range (profiles):

- Compare new data with the expected range for the variable at the site and for the applicable stratification zone, trophic state, and season.
- Plot the depth profiles and inspect for anomalies (see Figures 2 and 3 of NEMS *Water Quality Part 3* v1.0.0 for examples).

2.3.4 Between-variable comparisons

Compare measurements with corresponding at-site measurements of:

- their relevant supplementary variables
- closely related variables, e.g. visual clarity and turbidity
- water level or flow

- periodic verifications using another method, e.g. beam transmissometry and visual clarity.
- Examples of useful relationships are:
- turbidity is inversely proportional to visual clarity
- E. coli and total phosphorus are typically positively correlated with turbidity and TSS
- high dissolved Mg or Na concentrations are typically consistent with low DO concentrations.
- Sanity check depth of measurement or sample against depth to water and borehole depth of wells and water level and bottom depth of rivers and lakes.

2.3.5 Between-site comparisons

Unless affected by substantially different inputs, for some water quality variables, e.g. water temperature, there can be good agreement between quite distant sites within the same water body or river system, and between nearby sites in adjacent rivers of similar physical character, sufficient to use a comparison between the sites to alert for inconsistencies that should be further checked and/or investigated, e.g. a systematic shift in the relationship between the two.

2.4 Reliability of measurements

2.4.1 Calibration and validation of field meters

To verify and quality code field meter measurement results the following must be accessible and consulted as required:

- the meter's formal calibration records
- results of periodic validations of the meter where applicable (annual, quarterly, or monthly depending on the variable measured), and
- results of pre-deployment checks.

Some variables, e.g. Chlorophyll *a* and turbidity, are also verified periodically with a laboratory analysed sample. Others, e.g. PAR, are validated periodically by comparison with readings from a second field instrument that is assumed reliable.

For the highest quality code (QC 600) to be assigned:

- calibrations must be current as specified by the manufacturer and NEMS requirements for the meter and variable measured
- successful calibration for pH and SpC must be in terms of a standard (reference) temperature of 25°C
- instruments must be recalibrated and/or validated after sensor maintenance, e.g. change of sensor cups, electrolyte, filters etc.

Refer to NEMS *Water Quality Parts 1 to 4* v1.0.0 Table 1 for a summary of recommended calibration and validation procedure for selected variables.

Sampling day deployment tests and checks

To verify and quality code field meter measurement results, the outcome of pre-departure, at-site, and end of day calibrations, validations, and/or condition checks must be available and considered.

Which instrument checks are needed and when depends on the variable to be measured and the instrument.

For example: at-site validation of SpC is required if there is no temperature correction function on the instrument or the correction function is found faulty during the pre-departure validation.

Some pre-departure validation failures must be followed by recalibration (e.g. DO). Refer to NEMS *Water Quality Parts 1 to 4* v1.0.0 Table 1 (as applicable to each domain) for requirements.

NEMS *Water Quality Parts 1 to 4* v1.0.0 Matrix B scores performance and outcome of these checks as a factor in determining a quality code for the data.

If a meter fails end of day (EOD) validation, results for the day can be archived but with a lower quality code as determined by Matrix B. An Operational Comment is also required to identify that the lower quality code is due to an EOD validation fail and not some other factor (see Section I 5.3.3).

Matrix B does not specifically include the situation of validation at-site but by extension, if performed but the associated records are incomplete 1 point is accrued and the data might still achieve QC 600 depending on the points accrued for other criteria, but if not done then the data must be assigned QC 400.

2.4.2 Laboratory results

Accreditation

The degree of formal quality management applied by the laboratory helps determine quality code for a sample result and is assessed in NEMS *Water Quality Parts 1 to 4* v1.0.0 Matrix C. Only results obtained from a laboratory that has current IANZ accreditation for the measurement method can achieve the highest quality code (QC 600).

Sample preparation

Samples may be filtered or preserved in the field or laboratory. Dilutions are performed in the laboratory. Any of these actions should be noted, with the date of the action, on the Field Record Form, Chain of Custody Form, and the laboratory records and official laboratory results report, as is appropriate to where the action was taken.

The sample result should also be tagged in the database to indicate whether the sample was filtered and/or diluted so sample preparation can be reconciled with the stated test method's requirements and calibrated range, and dilution calculations re-checked if necessary, e.g. during a data audit (see Section I 6.4).

Note: Dilution calculations are required to be checked during validation of the laboratory results report prior to it being released to the monitoring agency.

Sample timeliness and condition

Sample (bottle) timeliness and condition is assessed by the laboratory on arrival (see NEMS *Water Quality Parts 1 to 4* v1.0.0 Section 5.2.2).

The laboratory notes any issues on the Chain of Custody form (see NEMS *Water Quality Parts 1 to 4* v1.0.0 Section 1.11) and reports them with the analysis results (see NEMS *Water Quality Parts 1 to 4* v1.0.0 Section 5.2). Assess impact on quality code using NEMS *Water Quality Parts 1 to 4* v1.0.0 Matrix C.

If microbial samples show evidence of icing they may still be analysed, and a result reported, but Matrix C requires the result to be assigned QC 100, i.e. 'no result'. This means there may be values present in a measurement dataset that are quality coded as missing. A Data Comment must be filed providing explanation (see Section I 5.3.4).

Chain of custody

The Chain of Custody form (CoC) provides an audit trail of sample transfer from collection to laboratory, informs the laboratory what tests are to be performed on the samples, and records the checks of sample integrity on arrival.

Office procedure should include a bring-up system to follow up CoC's submitted but not returned promptly (i.e. same day; see NEMS *Water Quality Parts 1 to 4* v1.0.0 Section 5.2).

Preferably prior to CoC submission, but at least on the CoC's return:

- reconcile it with the corresponding Field Record form
- resolve any anomalous information, e.g. date and time, sample ID's, filtering requirements and status
- notify the laboratory to correct their information if necessary.
- If there is no separate form or record, the CoC could be resubmitted with any requests for retests, also noting the date of the request and who made it, and any comments in reply from the laboratory.

Significant figures

All laboratory measurements shall be reported to one, two or three significant figures as dictated by the uncertainty of measurement for the test method (NEMS *Water Quality Parts 1 to 4* v1.0.0 'The Standard').

The database storing the reported results must also be set up to comply with the above requirement.

Refer to Appendix 3 for an explanation of the use of significant figures.

Censored results

Censored water quality results are reported as less than or greater than a threshold value. The threshold value may be the test's method detection limit (MDL) or maximum

calibrated range. Either may vary between sites for the same variable, and/or over time within a dataset from the same site (see NEMS *Water Quality Parts 1 to 4* v1.0.0 Sections 5.4.2 and 5.5.1).

The MDL used must be equal to or lower than that specified in NEMS *Water Quality* v1.0.0 'The Standard' (all parts, and *Part 1* Table 3, *Part 2* Table 4, and *Parts 3 & 4* Table 5) for results consequently censored to qualify for the highest quality code (QC 600).

If an MDL higher than that specified in NEMS *Water Quality* v1.0.0 'The Standard' is used there must be no more than one censored value in every ten for the data to qualify for QC 600. If exceeded, the censored data cannot be quality coded higher than QC 400. See Section I 5.2.2 for how this is assessed.

Calculated results

Laboratory results may be calculated from other results, e.g. some forms of nitrogen (see NEMS *Water Quality Parts 1 to 4* v1.0.0 'The Standard' and *Part 1* v1.0.0 Table 3, *Part 2* v1.0.0 Table 4, or *Parts 3 & 4* v1.0.0 Table 5), or averaged from duplicates to report a single value.

If a constituent sample is retested its measurement value may change and the calculated value must also then be revised, therefore any calculated result must be traceable to its constituent results including any retests.

Agency software may also calculate archived results from other results using supplier or user-developed code, which may run automatically as new constituent results are added, or 'on the fly' every time the calculated variable is accessed. Every new release of such code must be tested to ensure it is still performing the calculation correctly, with record of the tests maintained, and suitable precautions initiated to prevent use of incorrect results until any problem found is rectified. The procedure(s) used must be documented as part of the data management system documentation (see Section I 1.8).

If calculated results are formally validated either by the laboratory (see NEMS *Water Quality Parts 1 to 4* v1.0.0 Section 5.6), or by the documented agency procedure for software described above, and do not rely on empirical relationships, they need not be regarded as synthetic data and may be assigned a quality code higher than QC 300, determined as if they were a measured result.

Raw results

If an agency chooses to receive raw laboratory results, they must be supplied and stored with their UoM.

As raw data they are universally assigned quality code QC 0.

Raw data must be kept separate, and clearly identified, from the official rounded and possibly censored results. The agency must document how this is to be achieved (see Section I 1.8.9).

Unidentifiable samples

Samples that cannot be identified may still be analysed and a result reported.

Depending on the sample's available records and the agency's data management system (see Section I 1.8), results received for unidentifiable samples may be lodged against the sampling run (which may be ascertainable) and/or as orphaned records.

Orphaned records must be regularly reviewed and resolved whenever possible, following the agency's documented procedure (see Section I 1.8.6).

Unidentifiable sample results must be quality coded QC 100 (see the NEMS *Water Quality Parts 1 to 4* v1.0.0 Quality Codes flowchart). If subsequently identified, the quality code assigned can be reassessed using the matrices.

Note: At time of writing this Annex, the Quality Codes flowchart in NEMS Water Quality v1.0.0 conflicts with Matrix C which assigns 12 points and therefore QC 400 if the sample cannot be identified.

Other anomalies

A laboratory may include other comments about measurement reliability in the laboratory report. If the issue raised is not assessed by one of the criteria in the quality coding matrices A or C consider downgrading the quality code of affected results to QC 400 (compromised).

In any case, on each occasion, the laboratory comment must be preserved in the original record, summarised and stored with affected results, i.e. as measurement metadata, and explained in a Data Comment (see Section I 5.3.4).

2.4.3 Standardisation and compensation

To assign the highest quality code of QC 600:

- specific conductivity and pH must be corrected to a reference water temperature of 25°C
- dissolved oxygen (DO) must be compensated for water temperature and salinity and reported as local DO% Saturation, i.e. adjusted for local barometric pressure at the time of measurement.

These QC 600 requirements partly define the units of measurement, which should be consistent within a dataset unless the relevant measurement units are bound to each result.

If the above requirements are not or cannot be met, Matrix B (for field measurements) or Matrix C (for laboratory results) assigns a lower quality code.

Note: At time of writing this Annex, Matrix B assigns 12 points if data are uncorrected, so the maximum possible quality code is QC 400, but Matrix C assigns up to 6 points (via test method and units criteria) so that a quality code of QC 500 is possible.

Because a lower quality code may be assigned for other reasons, agencies must give some consideration to, and formally document, the data management practices that will ensure corrected and uncorrected data are never confused.

Barometric pressure

Refer to Annex H Sections H 1.2 and H 1.3 for explanation of and requirements for barometric compensation of DO.

2.4.4 Uncertainty of measurement

Every measurement has an associated uncertainty.

Field measurements are not required to be reported or stored with their uncertainty, but quality code assessment (NEMS *Water Quality Parts 1 to 4* v1.0.0 Matrix B) takes into account accuracy of the meter used and therefore provides some relative indication of the measurement uncertainty.

Laboratory results are either rounded to a number of significant figures consistent with their uncertainty of measurement (UoM) at the 95% level of confidence or provided raw with the UoM stated. The official laboratory report must include the UoM for each result reported (see NEMS *Water Quality Parts 1 to 4* v1.0.0 Section 5.5.) . Matrix C requires UoM for nutrients be available when assessing quality code for soluble and total nutrient ratios.

2.4.5 Non-standard methods and method change

Measurement methods other than those specified in NEMS *Water Quality Parts 1 to 4* v1.0.0 may be used but the maximum quality code then achievable is QC 500.

Ad-hoc change of method must be clearly identified, with reason noted, on the field sheet or laboratory report, and in the measurement metadata that is stored with the result.

Replacing a method may disrupt stationarity of the record, i.e. cause a step-change in the variable's trend or descriptive statistics. A Stationarity Comment (see Section I 5.3.7) must be filed when the new method is introduced.

A period of duplicate record is recommended when a method is to be replaced (see NEMS *Water Quality Part 1* v1.0.0 Section 1.11, or *Parts 2 to 4* v1.0.0 Section 1.12).

- Store data from the proposed new method separately until assessed by a suitably skilled person who decides whether the new method's results are sufficiently similar to continue to add to the old dataset, and if so, when method changeover is effective from, and duplicate data collection can cease.
- Sample size, and therefore suitable duration of duplicate data collection, depends on data collection frequency, desired level of confidence, and the range and temporal variation of likely values. A year of monthly samples is the recommended minimum.
- A suitably skilled person has understanding of the statistics, and the chemistry or microbiology of the methods.
- If too dissimilar, data obtained using the new method should begin a new dataset.

- Provide details of any relationship derived between the new and old data intended to 'align' them (i.e. compensate for any introduced bias):
- in a Stationarity Comment if old and new data are combined
- in Data Comments for both old and new data if not combined
- in a Transformation Comment if the relationship is applied to the old data to 'align' it with the new.

2.4.6 Review of results

Reconciliation of data imports

Data may be imported from electronic field sheets, recording sondes, and/or data files transferred from the laboratory (e.g. CSV, XML, or JSON), usually separately from the laboratory report, which is typically supplied as an electronic document (e.g. a pdf).

- Check each import for gross errors (e.g. unexpected termination, skipped or missing fields, or data corruption).
- Periodically check the integrity of the import against the original data (i.e. the field sheet and/or the laboratory report).
- After a software update and/or template change, always thoroughly check the first one or two imports to ensure they have operated as expected.

Reconciliation with original records

- Check the intended sample information was received and acted on by the laboratory.
- Check the recorded date and time of measurements and results to ensure they are:
- correct
- in, or converted to NZST (or CHAST)
- between noted arrival and departure times
- grouped as a single visit time, to the nearest 5-minutes unless part of a profile (see NEMS *Water Quality Part 1* v1.0.0 Section 4.6 or *Parts 2 to 4* v1.0.0 Section 2.6.2), and
- appropriately associated with their related data when stored.

  Note: Hilltop Sampler uses the file time of the measurements and results to group them into a sample, not the sample ID.

- If environmental conditions were changing at site and there was delay between field measurements and sample collection, choice of file time may need further consideration and action appropriate to the database used to store the data (e.g. storing measurements at different times, adding a comment, etc.).
- Check that required supplementary values are consistent between the Field Record form and Field Meter Calibration form if calibration has been performed at site (see Section I 1.6).

- Ensure relevant field observations are correctly incorporated into the stored site and visit metadata.
- Ensure sample condition information on the CoC corresponds with the laboratory report and is correctly included in the stored measurement result metadata.

Verification measurements

For some variables additional independent measurements are recommended to verify measurements obtain by the standard method. Review data against these verification measurements as they become available. Examples of verification measurements are:

- use of beam transmissometry to check visual clarity measurements
- measurement and/or sampling from a boat to check or locally calibrate helicopter work
- a monthly laboratory sample from one site to verify field meter measurements of turbidity and chlorophyll *a*.

Dilutions

- Check if dilutions were required and/or have been performed and are documented as required or recommended, e.g. for E. coli.
- Check field dilution calculations.

Note: Dilutions should be included in the laboratory report with calculations validated by the laboratory prior to issuing the report.

Balances

Use balances to identify anomalous analytical and/or calculated results. Tolerances are defined and outcomes assessed for quality coding using NEMS *Water Quality Parts 1 to 4* v1.0.0 Matrix C. Balances must be recalculated and reassessed if any subspecies is retested. Examples of balances are:

- soluble and total nutrient ratios
- dissolved and total metals concentrations
- anion-cation balance.

Specialist advice

Refer questionable results unable to be resolved to a suitably skilled and experienced domain specialist or monitoring programme scientist.

Record any cautions advised by the scientist about reliability and/or use of the result in the result's measurement metadata and in a Data Comment (see Section I 5.3.4).

2.4.7 Stationarity

Significant change of monitoring location or method may disrupt stationarity of the record sufficiently to affect use of the data.

Monitoring location

- Consistency of monitoring location is assessed for quality coding using NEMS *Water Quality Parts 1 to 4* v1.0.0 Matrix A. Consistency is in terms of:
- XYZ location for surface water measurement (which may vary due to access issues including weather and/or water and/or flow conditions, and stratification)
- GPS location and descriptors, and consistent choice of, and acceptable condition of the outlet (e.g. tap or fitting), and location relative to tanks and pressure cylinders for groundwater measurements.

  Note: GPS'd location and descriptors are both needed for groundwater to ensure the correct bore was sampled. There may be several bores on the same property and/or other bore(s) very close by.

Measurement and/or analytical methods

Consistency of measurement and/or analytical method is assessed for quality coding using NEMS *Water Quality Parts 1 to 4* v1.0.0 Matrix B for field measurements or Matrix C for laboratory measurements.

For groundwater, record in the visit and/or measurement metadata when a flow cell has been used.

Note: Use of a flow cell is recommended for all groundwater field measurements (see NEMS Water Quality Part 1 v1.0.0 Section 4.1.6.1) but is only required when low-flow purging, or when measuring DO with an electrochemical sensor. Quality coding Matrix B assesses for use of a flow cell only for DO and in combination with other factors.

Refer to Sections I 2.4.5 and I 2.2.9 for more information, including other requirements when a method is, or has, changed.

2.5 Deviation tests

2.5.1 Deviation over time

Monitor over time the items listed in the sub-sections that follow, for the reasons given in each sub-section. A true time axis is not essential so a simple control chart, tabulation or similar is adequate.

If a field meter requires maintenance as a consequence of performance issues identified by these tests:

- review all data measured with the field meter for the variable of interest during the problem period, and
- downgrade the quality code of the data within the problem period to the lesser of the outcome of validations and/or quality code assessment using NEMS *Water Quality Parts 1 to 4* v1.0.0 Matrix B, or

- QC 500 if still a 'fair' representation of the variable, or
- QC 400 if compromised and needing to be treated with caution
- If undecided, apply the lower code, i.e. QC 400.

pH

- Monitor the deviation from zero of handheld pH meter output in mV ± the manufacturer specified tolerance, when in a standard pH 7 solution.
- Obtain the deviation data from the start and end of day validations.
- Use as an indicator of sensor condition. Maintenance is required if tolerance is exceeded and/or drift is detected (see NEMS *Water Quality Parts 1 to 4* v1.0.0 Table 1).

Turbidity

- Monitor outcomes of monthly handheld field meter validations and verifications (see NEMS *Water Quality Parts 2 to 4* v1.0.0 Table 1), i.e.:
- zero-point in distilled water, and
- a simultaneous sample measured by the laboratory.
- Use to identify degradation of the optics, and declining performance of the sensor in general. Maintenance is required if drift, bias, or erratic response is detected.

Chlorophyll a

- Monitor outcomes of monthly handheld field meter verifications (see NEMS *Water Quality Parts 2 to 4* v1.0.0 Table 1), i.e.:
- a simultaneous sample measured by the laboratory.
- Use to identify degradation of the optics and filters, and declining performance of the sensor in general. Maintenance is required if drift, bias, or erratic response is detected.
- Calculate annual median chlorophyll *a*.
- If > 0.005 mg/L, a different analytical method is recommended (see NEMS *Water Quality Part 2* v1.0.0 Section 5.4.3.8, or *Part 3* v1.0.0 Section 5.4.3.7, or *Part 4* v1.0.0 Section 5.4.3.6).
- See Section I 2.4.7 for more information on changing a method.

Frequency of censored values

- Monitor the frequency of censored values. See Censored Results in Section I 2.4.2 for requirements.

  Note: Laboratory results are censored whenever the measurement value is less than the method detection limit (MDL) or exceeds calibrated range.

2.5.2 Departure from expected values

The following tests require historical data to be available and accessible for calculation of expected values, or a corresponding estimate to be pre-determined. The tests are

intended to alert to possible problems. Degree of departure on its own does not directly influence the quality code assigned to the measurement.

Departure from measure of central tendency

- Compare each new value with the long-term mean, median or mode as is best suited to the variable or sub-variable (e.g. each depth in a profile) being measured.
- Values tested may need to be further partitioned, e.g. into seasons, stratification zones, or flow 'bins' (e.g. high, moderate or low flow).
- Significant departure from the long-term value indicates the new value is an anomaly that requires further investigation and confirmation.
- Significance may be tested statistically.

Value range test

- Decide a suitable range envelope for the variable, for example:
- the valid range of the variable, e.g. pH, or
- a parametric or non-parametric statistical threshold, for example:
- two standard deviations from the long-term mean
- the 5th and 95th percentile values of the last five years of data, or the last 60 results
- the lower quartile value minus 1.5 times the inter-quartile range and the upper quartile value plus 1.5 times the inter-quartile range.
- If the new value falls outside the envelope it is an outlier and further investigation is needed, followed by action to correct, confirm, caution, or discard the value.

The above tests can be incorporated into a simple control chart (see Figure I 1).

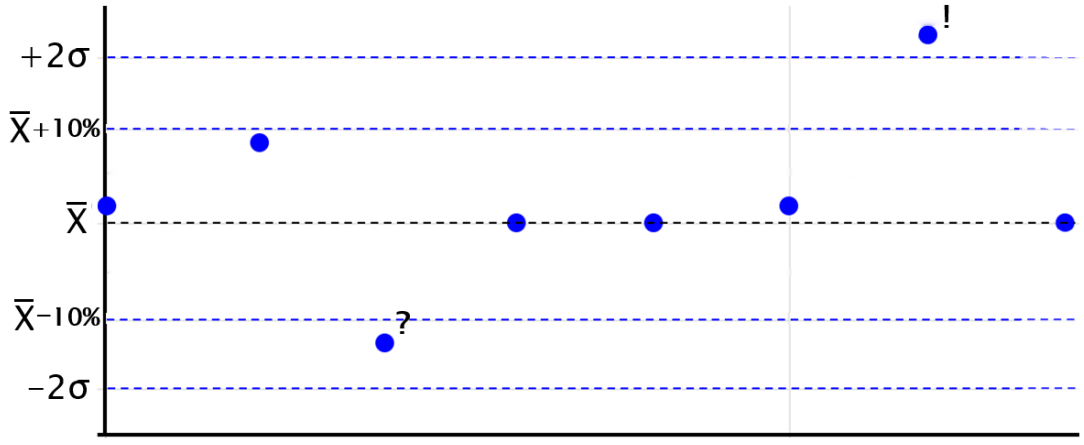


Figure I 1 – An example of a control chart showing values tested against thresholds of ±10% of the long-term mean ($\bar{X}$) and two standard deviations of the mean (±2σ).

2.5.3 Automation

Deviation tests may be automated to run on data entry or import, and/or configured to update automatically with the new data. If implemented in a field application, they provide quality control of data entry at site (see also Section I 2.3.3).

See Sections I 1.8.8 and 3.6.1 for requirements relating to the machine algorithms and their implementation.

3 Potential Errors and Recommended Editing

This section describes common problems with discrete water quality data, and guides data repair if appropriate, and what metadata are required to be applied and filed.

Undertaking data processing in batches is recommended for efficiency and consistency. An original version of the data must be preserved (see Section I 1.8.9). Editing and new metadata created should be peer reviewed prior to committing to archive (see Section I 6.1).

3.1 Sources of errors

3.1.1 Systematic error

Systematic errors (biases) are a consequence of measurement method limitations or errors, poor sample collection and/or mishandling, or use of instrumentation in compromised condition. Careful field practice is the primary means of reducing systematic error in discrete water quality measurements. If bias is suspected a repeat measurement can be made in some circumstances, e.g. retesting a sample.

3.1.2 Field measurement errors

Potential error sources are:

- measurement instability, e.g.:
- insufficient time for instrument to equilibrate
- incomplete purging of a groundwater well
- instrument calibration drift.
- environmental conditions and interferences, e.g.:
- strong shadows (for variables involving light)
- sediment plumes
- localised groundwater upwelling
- helicopter rotor wash or boat wake.
- data entry mistake in or on the Field Record Form.

3.1.3 Sampling error

Known issues affecting sample collection, handling, and condition should be noted on the Field Record form and/or the Chain of Custody form by the sampling and/or laboratory personnel.

Potential sampling error sources are listed below under their respective sub-categories.

Sampling technique

- bottle contamination, insufficient sample volume, over or under filling
- poor or no pre-treatment (e.g. filtering)
- catching the surface layer or bottom sediments
- sediment plumes, incomplete purging of a groundwater well.

Sampling location (horizontal position and depth)

- environmental conditions, e.g. shallow depths, bed disturbance
- location not representative of the water body, e.g. poorly mixed or purged, or from a backwater or near a significant inflow.

Sample identification

- lost or obscured labels
- sample not uniquely labelled
- switching pre-labelled bottles (causing spurious error that would not be obvious during sample quality control checks).

Sample condition

- chilly bin temperature too hot, or too cold (samples icing or frozen)
- sample preservation requirements not adhered to
- delay to analyse samples
- bottles not sealed
- samples lost in transit.
- For more information see Section I 2.4.2.

3.1.4 Manual data entry

Potential error sources are:

- keying mistakes
- transcription errors.
- The laboratory is expected to validate all manual data entry contributing to their official laboratory report prior to releasing the report and results.

3.1.5 Data import

Potential error sources are:

- gross errors (e.g. unexpected termination, skipped or missing fields, or data corruption) (see Reconciliation of Data Imports in Section I 2.4.6)
- orphaned results (see Unidentifiable Samples in Section I 2.4.2)
- repeat laboratory results, including:
- results sent again, either by mistake, or because the laboratory has added or changed previous information, or
- the laboratory has retested one or more samples.

3.2 Data offset

A data offset is a persistent constant or near-constant bias in the data. For discrete water quality, the bias may persist:

- in successive measurements over time of the same variable at the same location
- for one or more sampling runs and affect several sites, and/or
- through one or more instances of a set of measurements, e.g. of a profile.

In most cases, if the bias is due to instrument calibration and/or performance it will be identified and quantified by validations (see Section I 2.4.1) and/or verification measurements (see Section I 2.4.6). These are tracked in the deviation over time tests (see Section I 2.5.1).

Persistent bias might also be evident from a control chart (see Figure I 1) or by plotting the data with time or as a sequence of overplots. An offset apparent as a sudden 'step change' in overall trend of the data is often associated with a change of measurement location or method (see Section I 3.3).

The bias may be compensated by applying an offset shift, i.e. adding a constant amount (+ve or -ve) to all affected measurement values. Investigate probable cause, confirm what data are affected, and decide if adjustment is appropriate.

Table I 1 – Guidance for resolving data offset

Guidance for resolving data offset		see Section(s)
Issue(s)	A sequence of measurements is biased by a constant or near-constant amount.	I 3.2
Evidence	Persistent bias is apparent from the deviation tests or time-dependent plot(s) of the data. A 'step change' is evident in the data's overall trend.	I 2.5 Fig. I 1 I 3.3
Solution(s)	File a cautionary Data Comment and downgrade the quality code of the affected data, OR Apply an offset shift to the biased data, and quality code and comment the adjustment as described below.	I 5.3.4 I 2.5.1 4.2

Metadata	The lowest of the relevant combined matrix quality code, or as assigned from deviation over time assessment, or from blanket provisions, with a Data Comment describing the issue(s) and response, OR If data are adjusted, the lowest of the relevant combined matrix quality code, or as assigned from deviation over time assessment, or from blanket provisions, or 'minor' (QC 500) or 'significant' (QC 400) modification criteria as applicable, with a Data Processing Comment explaining identified cause and details of amount of adjustment to which data.	I 5.2 I 2.5.1 I 5.2.2 I 5.3.4 6.2.4.6 6.2.3 I 5.3.5 6.2.4.7

3.3 Steps in the data

Steps in the data are a sudden systematic shift or 'break' in the overall trend (in contrast to a gradual drift) and are usually due to some deliberate action, e.g. change of instrument, location, method etc., i.e. stationarity of the data is disrupted by the change.

In periodic discrete data a step may be difficult to identify solely from a plot, control chart or similar until there is a reasonable amount of data available before and after the suspected initiating change.

In most cases the most effective approach is to be aware of the potential for an action to introduce a step and compare the data before and after for any significant difference by using one or more of between-variable and/or between-site comparisons (see Sections I 2.3.4 and I 2.3.5.), or statistical homogeneity tests.

If the step is determined to be a constant through the range of values, i.e. affects the 'baseline', it may be treated as a data offset (see Section I 3.2). Otherwise, any adjustment of data requires a more complex relationship to be derived between data before and after the step.

3.3.1 Instrument servicing and replacements

Unless a laboratory advises otherwise it can be assumed that instrument servicing or replacement is not an issue for data obtained by laboratory measurement.

For each field measurement the individual field meter used must be identified in the metadata and able to be related to its validation, calibration, servicing, and replacement records. Situations where field instrument servicing or replacement may cause a step-change include:

- change of type, brand or model of instrument, if measuring via a surrogate principle, e.g. optical DO, chlorophyll *a* by fluorescence, turbidity via light attenuation or scattering, temperature by resistance
- For turbidity, change of instrument type constitutes a change of method (see Section I 3.3.2) and possibly a change of units of measurement (see Section I 1.4).

- data entry mistake if entering calibration coefficients manually, e.g. after DO sensor cap or membrane replacement
- If proper calibration records are maintained this error is traceable and reversible with no effect on quality code.
- A brief comment giving reasons should be made in the measurement metadata for any value changed.
- recalibration of an instrument, where the previous calibration was wrong, or the instrument had since drifted
- If the wrong calibration is traceable and reversible, data can be corrected with no effect on quality code, with brief comment giving reasons added to the measurement metadata for any value changed.
- For drift, see Section I 3.4.

3.3.2 Method change

Change of method, in the context of disruption of stationarity and any consequent step in the data, includes:

- a significant shift in measurement and/or sampling location, or
- a change in the principle(s) (physical and/or chemical) of the measurement method, e.g. DO optical vs. galvanic, nutrients, turbidity ISO 7027 vs. EPA 180.1

A Stationarity Comment, and an Operational Comment or Equipment Comment as applicable (see Sections 6.2.4.5 and 6.2.4.4) must be filed for each change, and site location details updated in the Site/Initial Comment.

If method change means a change of measurement units, e.g. for turbidity, then a new time series may also be necessary, in which case add existence of multiple time series to the 'Additional Information' in the Site/Initial Comment for each series.

Also see Sections I 1.4, and I 2.2.9 (measurements and units) and I 2.4.5, and I 2.4.7 (method changes and stationarity) for further guidance and requirements.

Table I 2 – Guidance for resolving steps in the data

Guidance for resolving steps in the data		see Section(s)
Issue(s)	Sudden change between successive values that disrupts continuity of overall trend.	I 3.3
Evidence	An action is known to have occurred (instrument service or change or change of location). A 'step change' in the data's overall trend is evident from comparison(s) and/or statistical homogeneity test.	I 3.3 I 2.3.4 I 2.3.5
Solution(s)	No adjustment if due to change of instrument or location (stationarity is disrupted).	I 3.3.2

	Correct values for wrong calibration if error is traceable and reversible. Otherwise, resolve confirmed constant bias as a data offset.	I 3.3.1 I 3.2
Metadata	Operational Comment required for change of location. Equipment Comment required if instrument type or specification changed. Stationarity Comment required at step. Quality code unaffected if fully traceable calibration correction but a note in the measurement metadata is required for each value changed. Refer to data offset guidance as applicable.	I 5.3.3 I 5.3.2 I 5.3.7 6.2.4.5 6.2.4.4 6.2.4.9 I 3.2

3.4 Drift

Drift may affect:

- baseline, e.g. instrument zero is drifting from true zero and all measurements are consequently offset
- instrument range, and therefore affects amplitude of diel fluctuations
- linearity of sensor response, i.e. drift in only part(s) of the sensor range.

Laboratory quality assurance procedures are expected to eliminate the possibility of drift affecting laboratory test results. NEMS *Water Quality Parts 1 to 4* v1.0.0 Matrix C assesses for the case of a laboratory not having these procedures for the relevant measurement method.

For field measurements, handheld instrument routine calibrations, validations and verifications are designed to minimise the possibility of drift affecting measurements (see Sections I 2.4.1, I 2.4.6 and I 2.5.1). For sondes, evaluation of potential drift must be included in the agency's standard operating procedure for the instrument and a calibration schedule set to then maintain drift within tolerances (see NEMS *Water Quality Part 1* v1.0.0 Annex G, or *Parts 2 & 3* v1.0.0 Annex E, or *Part 4* v1.0.0 Annex F). Failed or omitted calibrations and validations are accounted for in NEMS *Water Quality Parts 1 to 4* v1.0.0 Matrix B.

However, a lower quality code on its own does not inform of cause. Additional action is required as follows:

- do not adjust the measured values
- ensure relevant instrument validation and calibration records are identifiable and accessible (preferably linked from the instrument identifier stored with each measurement value)
- explicitly identify any result potentially affected by drift as indicated by a failed validation or calibration (as opposed to having not been

carried out), e.g. by placing an additional advisory comment or tag in its measurement metadata

- file an Operational Comment whenever the testing laboratory's IANZ accreditation status changes for the measurement method
- include a caution in the Site/Initial Comment if the dataset contains results from a laboratory not IANZ accredited for the measurement method.

Table I 3 – Guidance for resolving drift

Guidance for resolving drift		see Section(s)
Issue(s)	Measured values may be biased by an increasing amount or proportion.	I 3.4
Evidence	Instrument calibration, validation, and verification records, and analysis of their deviation over time	I 3.4 I 2.4.1 I 2.4.6 I 2.5.1
Solution(s)	Do not adjust measured values. File appropriate metadata.	I 3.4
Metadata	The lowest of the relevant combined matrix quality code, or as assigned from deviation over time assessment, or from blanket provisions. Additional advisory comment or tag in the measurement metadata of any value suspected of being affected by drift. Operational Comment when testing laboratory's IANZ accreditation status changes for the measurement method, and caution in the Site/Initial Comment if dataset contains results from non-accredited laboratory.	I 5.2 I 2.5.1 I 5.2.2 I 2.2.9 I 5.3.3 6.2.4.5 I 5.3.1 6.2.4.3

3.5 Spikes

Spikes in the data are implausible results usually due to spurious errors that are often caused by mistakes, e.g. muddling sample bottles or entering a value into the wrong field on a form, but can be caused by electronic transients.

Spikes may be trapped by automated checks configured to warn and/or act when a value is outside software or user defined bounds (see Section I 2.5.2). Automated checks may be configured to run during data entry, data import, and/or during data processing. The machine algorithms used in these checks and their implementation must be documented and controlled (see Section I 2.5.3).

Treatment of spikes may include one or more of the following:

- a prompt to repeat the measurement with the spurious value replaced
- a warning to the operator, but the spurious value is recorded, and subsequent further quality control decision and action is required
- the result is quarantined, with or without warning, and subsequent review, then quality control decision and action is required
- the result is discarded, with or without warning, and a 'no result' recorded instead.
- If warnings are not provided, maintaining a log of each initial action is strongly recommended for quality assurance purposes, e.g. to identify persistent or increasing problems that could be fixed to prevent future spikes.

Overall method of identifying spikes and treatment of the spurious values may differ for each variable or group of variables, or across domains, and possibly from site to site.

The various ways data spikes may be treated, coupled with options for automation and for defining what is original data, mean that the spikes may be present in some versions of the data and not others.

For example: spikes may be in raw data but not the original data, or in the raw and original data but not the archived data, or in the 'official' results form or report (with a possible warning) and the data transfer file but not in the imported data.

Data should not be routinely discarded, but nor should results known to be false be published or included in a verified and processed dataset delivered to an end-user. For this reason, an implausible or impossible value must be quality coded as if a 'no result', i.e. QC 100 (missing record), regardless of whether it is removed from the dataset or not.

Because of the breadth of options available, agencies must formally document the detail of their treatment of spurious values (data spikes) in their Field and Office Manual (see Section I 1.8.1), taking the above into account.

Table I 4 – Guidance for resolving spikes in the data

Guidance for resolving spikes in the data		see Section(s)
Issue(s)	The measured value is spurious or implausible.	I 3.5
Evidence	Value is an outlier and/or impossible. Detected by value range tests.	I 2.5.2
Solution(s)	Confirm, replace, correct, caution, or discard as per the agency's documented policy for the variable, domain, and/or site.	I 3.5 I 1.8.1
Metadata	If measured value is confirmed or replaced, compose metadata including quality code as normal.	I 5 I 5.2

	If measured value is corrected, quality code as normal and note justification of correction in the measurement's metadata QC 100 (no measurement) and Data Processing Comment giving reason if value(s) are deleted, OR QC 100 ('no result') and Data Comment giving reason if measured value(s) should be considered 'no result'.	I 2.2.9 I 5.3.5 6.2.4.7 I 5.3.4 6.2.4.6

3.6 Over-ranging and non-detects

Over-ranging occurs when a measured value exceeds the instrument's calibrated range. Non-detects are measured values that are less than the method detection limit (MDL) and cannot with confidence be distinguished from zero.

In either case, laboratory measurements will be censored according to the laboratory's reporting procedures (see Section I 2.4.2).

3.6.1 High-end calibration

Any attempt to measure beyond an instrument's operating range will usually return an error or no result. However, many instruments will continue to provide a result beyond their calibrated range. For many water quality variables, linearity of the instrument's scale is only guaranteed within its calibrated range so values that exceed that range are inherently unreliable.

Turbidity is an extreme example where sensor saturation may cause reported values to decrease when the actual turbidity is increasing (see Annex E Section E 3.7).

Any field measurement exceeding the instrument's calibrated range for the variable measured must be quality coded QC 400. For dissolved oxygen (DO), this includes all DO% Saturation values > 120%. DO% Saturation values above 100% and up to and including 120% may be quality coded QC 500 on the basis that validated calibration at 100% can be reasonably assumed to remain valid within acceptable margins of error for up to 20% beyond that range based on instrument manufacturer assurances of calibration linearity and stability.

Note: NEMS Water Quality Parts 1 to 4 v1.0.0 Quality Coding flowchart Note 2 assigns QC 500 to DO% Saturation values > 100% but QC 400 is assigned here to values exceeding 120% to align with continuous DO measurement and with other forms of 'no valid calibration'.

Summarise the normal calibrated range, and calibration and validation frequency for the site and variable in an Equipment Comment at the start of the record and whenever instrument range and/or procedure changes. The calibration and validation records for each instrument can be stored in an instrument database or similar but must be preserved and accessible if needed (see Section I 7).

Laboratories may dilute a sample to bring it within calibrated range. The laboratory should have checked the dilution calculations and noted the dilution in the laboratory report. Other than noting or tagging in the measurement's metadata that a dilution was

performed, laboratory dilutions can be treated as normal measurements (see Sections I 2.2.9, I 2.4.2 and I 2.4.6).

Revalidation

A field instrument may be revalidated retrospectively to extend its effective range so a previously over-range result can fall within it. Quality code the result as normal but add a note to the measurement's metadata that revalidation was performed and to what range.

3.6.2 Method detection limit

See Sections I 1.8.7 and I 2.2.9 for guidance and requirements relating to method detection limits (MDL) and Sections 1.1.5, I 2.4.2 and I 5.2.2 for censored results.

Table I 5 – Guidance for resolving over-ranging and non-detects

Guidance for resolving over-ranging and non-detects		see Section(s)
Issue(s)	The measured value is unreliable and/or only partially known.	I 3.6
Evidence	Measured value is outside calibrated range or below the method detection limit.	I 3.6 I 1.8.7 I 2.2.9
Solution(s)	Reduce quality code of affected results that are not censored or addressed at source by dilution or revalidation, and of frequently censored results if the MDL used is higher than that specified in NEMS *Water Quality* v1.0.0 'The Standard'.	I 3.6 I 2.4.2 1.1.5 I 2.4.2
Metadata	QC 400 all over-range field measurements, except QC 500 for DO% ≤ 120%. Equipment Comment required when calibration and/or validation range or procedure changed. Data Comment required when quality code is reduced due to excessive frequency of censored values. Comment or tag a measurement if a dilution was performed.	I 3.6 I 5.3.2 6.2.4.4 I 5.2.2 I 2.2.9

3.7 Incorrect scaling

Incorrect scaling means that the range of the data is either wrongly reduced or expanded by some factor. The problem usually arises from:

- wrong measurement units, or
- incorrect meter configuration.

3.7.1 Wrong measurement units

'The Standard' in NEMS *Water Quality Parts 1 to 4* v1.0.0 specifies which method and measurement units are to be used in each water domain for each variable but does not exclude use of other methods and units. Data stored in other units must be assigned a quality code lower than QC 600, as assessed by NEMS *Water Quality Parts 1 to 4* v1.0.0 Matrix B or C.

While conventional relational databases can store data in a mix of measurement units provided every value stored is tightly bound to its own appropriate units, a time series in the context of NEMS is expected to comprise a series of values all in the same units. If data are stored in a time series, or a time series of the variable is desired, conversion of units may be essential, either during data entry or import, or during data export.

Dissolved oxygen

Dissolved oxygen (DO) data collected in the wrong measurement units is usually recoverable if the necessary supplementary data have been recorded. Explicit conversion by mathematical relation between different units of DO measurement is possible (see Annex H Section H 1.2).

Turbidity

For turbidity, measurement units depend on the measurement protocol and there is no physical relationship between them. Data collected in the wrong measurement units is not recoverable. Explicit conversion by mathematical relation between different units of turbidity measurement is not possible.

pH and specific conductivity

Measurements of pH and specific conductivity (SpC) must be referenced to a water temperature of 25°C to achieve QC 600, otherwise QC 400 applies as determined by NEMS *Water Quality Parts 1 to 4* v1.0.0 Matrix B.

chlorophyll a by fluorescence

This method is indirect and measures in relative fluorescence units (RFU). A relationship between RFU and mg/L concentration, calibrated using results of laboratory analysed water samples, must be derived to enable conversion to mg/L. The process is similar to field calibrating a soil water sensor (see Annex G Section G 4).

3.7.2 Wrong instrument configuration

If an instrument requires the operator to manually enter and/or upload calibration coefficients or signal multipliers and/or offsets there is potential for data entry error.

If the error can be mathematically reversed out of the data and the correct configuration applied such that recovery of the correct value is fully traceable, quality code as normal but comment in the measurement metadata that it is a correction for wrong configuration. Preserve the configuration and correction details with the instrument records.

Uncorrected data that is known to be misleading due to configuration error should be treated as 'no result', i.e. either discarded, or if retained, it must be quality coded QC 100 and a Data Comment filed explaining the decision and action.

Table I 6 – Guidance for resolving incorrect scaling

Guidance for resolving incorrect scaling		see Section(s)
Issue(s)	Scale of the data is wrong. Measurement units are not as specified in 'The Standard'.	I 3.7
Evidence	Field meter ID. Instrument configuration records. Verification differences. Departure from expected value tests. Step-change at time of configuration change.	I 1.8.4 I 2.4.6 I 2.5.2 I 3.3
Solution(s)	Convert between units as required if possible (requires supplementary data). Reverse configuration errors if possible. If not possible, consider discarding misleading result(s). Create and maintain 'post-processing' calibrated relationships as needed.	I 3.7.1 I 3.7.2
Metadata	Reduce quality code of all measurements with units not as specified in 'The Standard'. QC 100 (no measurement) and Data Processing Comment if affected value(s) are deleted, OR QC 100 ('no result') and Data Comment misleading values affected by configuration error that is uncorrected.	I 5,2,1 I 3.7.2 I 5.3.5 6.2.4.7 I 5.3.4 6.2.4.6

3.8 Time faults

3.8.1 File time of measurements

A single site visit time is assigned as the timestamp for all results from that visit:

- to the nearest whole 5-minutes (on the hour), and
- representative of the time of field measurements for surface waters (see NEMS *Water Quality Parts 2 to 4* v1.0.0 Section 2.6.2), or
- the time of the final field measurement for groundwater (see NEMS *Water Quality Part 1* v1.0.0 Section 4.6).

Profiles and other multi-dimensional or multi-item measurements

Time-series management (TSM) software does not permit duplicate timestamps in a series, so storing results of multiple measurements or samples for the same variable with a single visit time requires an atypical solution. Depending on the brand of TSM

this may be by using a multi-item variable (e.g. one item per depth) or a 2-D or 3-D data type designed for the purpose.

Note: The following requirement in 'The Standard – Timing of Measurements' in NEMS Water Quality Parts 3 & 4 v1.0.0 "Note: Individual sets of measurements or water samples collected at different depths shall be treated as different visits" creates additional complexity if wishing to export and/or store the data in a TSM because a TSM selects and associates data only by time unless multi-item or multi-dimensional storage formats are used, which would require the data to be re-collated and stored with the same timestamp, i.e. as one visit. If the components of a 2-D measurement, e.g. a depth profile, are stored as a sequence of values in a single-item (i.e. 1-D) time series, the TSM will not automatically recognise them as being associated so retrieval of the data as 2-D entities will be difficult, as will selecting all values over time for a given dimension, e.g. a specified depth.

3.8.2 Correction of sample time

Time drift should not be an issue for periodic measurements, especially if a constantly synchronising device, e.g. a smartphone is used to provide the required dates and times.

If dates and times are manually entered there is potential for spurious error, which should be checked for when results are reviewed (see Section I 2.4.6), then edited to correct if an error is identified and the correct date and/or time can be established.

Note: Care is needed if changing dates and/or times in Hilltop Sampler because it uses the file time of the measurements and results to group them into a sample, not the sample ID.

During daylight saving periods times in NZDT (or CHADT) must be converted to NZST (or CHAST as applicable).

Sample date and/or time may need to be changed to resolve orphaned results.

For example: Hilltop Sampler uses date and time to group sample results together rather than the sample ID so if a laboratory result returns with a different date and/or time than the other results it will not be associated with them and will instead be stored as an orphan result. Changing the orphaned result's timestamp to match the rest will reassociate it with the sample and the other results.

Table I 7 – Guidance for resolving time faults

Guidance for resolving time faults		see Section(s)
Issue(s)	Times not in NZST (or CHAST). Spurious date/time errors possible if manually entered. Orphaned results.	I 3.8
Evidence	Routine checks identify date and/or time anomalies. Orphaned records exist.	I 2.4.6 I 1.8.6 I 3.1.5 I 3.8.2
Solution(s)	Convert any wrong time zone to NZST (or CHAST).	4.3

	Edit to correct spurious errors (with caution). Regularly review orphaned records and resolve if possible.	I 3.8.2 I 1.8.6
Metadata	Note in the visit metadata if dates and/or times are changed from the original records.	I 2.2.4

3.9 Missing data

Missing data is a redundant concept in a time series of discrete data because there is no interpolation applied between the stored values, however, for discrete water quality a visit or sample may exist but with no result for a particular measurement, or a sample may be dumped from a run or visit before it is analysed.

Some systems may store a flag, symbol, or code in place of the absent result(s). In some systems, if data are stored as multi-item or multi-dimensional a 'missing data' flag or code must be stored to ensure all database fields are populated.

In some cases, a value may be stored but be regarded as a 'no result'. In other cases, a result may be deleted during data processing (e.g. because it was implausible) then treated as 'no measurement' (see Sections I 3.9.1 and I 3.5).

In all cases:

- 'no measurement' or 'no result' must be quality coded QC 100
- agencies must describe in their data management documentation (see Section I 1.8) their use of flags, symbols, or codes for missing results and have systems in place to appropriately convey this information to any data user
- a Data Processing Comment explaining the deletion must be filed for any value deleted, or
- a Data Comment that provides explanation for the quality code must be filed for any value stored but quality coded QC 100 (i.e. effectively a 'no result'),

Attempt recovery of any result inadvertently lost, in the first instance from original records, or by requesting a retained sample be retested.

3.9.1 Deleting data

Deleting data should be the last resort and only if there is conclusive evidence of measurement error or sampling problems. However, this must be balanced against archiving a known false or misleading result.

If there is doubt about a result, repeat analysis should be attempted first, and if not possible, referral for specialist advice (see Section I 2.4.6).

Data must not be deleted from an original record (see Section I 1.8.9).

An audit trail or log of deleted values must be maintained at least until the associated sample run(s) are verified, peer reviewed, and archived.

Table I 8 – Guidance for resolving missing data

Guidance for resolving missing data		see Section(s)
Issue(s)	An expected measurement or result does not exist or has been deleted and/or replaced with a flag, symbol, or code, or is deemed to be 'no result'.	I 3.9
Evidence	As above.	
Solution(s)	Recover from original records. Retest if possible.	I 1.8.9 I 2
Metadata	QC 100 all 'no measurement' and 'no result'. Data Processing Comment for all values deleted, giving reason(s) for the deletion(s). Data Comment for values stored but assigned QC 100 giving reason(s) for the 'no result'. Maintain audit trail or log of deleted values at least until the relevant sample run is verified, peer reviewed, and archived.	I 3.9 I 5.3.5 6.2.4.7 I 5.3.4 6.2.4.6 I 3.9.1

4 Post-processing

4.1 Transformations

4.1.1 Surrogates

Graphical or statistically derived relationships may be applied to verified clean data to convert a surrogate measure to the target variable.

Examples are:

- turbidity to suspended sediment concentration (SSC) or visual clarity
- chlorophyll *a* by fluorescence
- beam transmissometry for visual clarity.

Transformation of turbidity to SSC is addressed in NEMS Turbidity.

Graphical methods should follow the general principles for developing and applying a rating curve (see NEMS Rating Curves). Rating curve techniques have advantages when relationships are non-linear and if they may change with or over time (the target data are regenerated automatically) but are designed to operate on a time series in a time-series manager (TSM) and be developed using TSM tools.

Statistical methods should follow the procedure and principles for synthesising a record (see Appendix 2). Statistical methods have advantages in terms of ease of use, general application, and ability to quantify goodness of fit but if the relationship is updated all surrogate data may need to be retransformed.

File a Transformation Comment summarising the derivation and application of the relationships(s) and preserve a record of the analysis with the data processing documentation.

4.1.2 Method change 'alignment'

These transformations are intended to 'align' data if a measurement method is changed, i.e. to assist with maintaining stationarity of long-term record as much as possible. The relationship is developed from the overlapping data measured using the old and new methods (see Sections I 2.4.5 and I 3.3.2) and using similar techniques to the transformation of surrogates (see Section I 4.1.1). Examples are:

- change of turbidity units
- oxygen reduction potential (ORP) conversion between different reference electrode systems.
- Also see Section I 1.4.

4.2 Generating a time series

The longer a dataset, the greater the advantage of having the data available as a time series in an industry recognised time-series manager (TSM). How this is best achieved depends on the design of the database regarded as 'the source of truth' for the data and the TSM that will store the time series.

The agency shall include the process in the documentation of their data management system (see Section I 1.8), including consideration of:

- what metadata should also be written to the TSM. Quality codes must travel with the values
- how frequently the time series will update
- how the time series will be identified
- whether to allow values in the time series to be modified and if so, what controls to put in place, and
- how to manage multi-item and multi-dimensional data (see Section I 3.8).
- All 'time-series' comments (see Section I 5.3) for the site and variable must be attached to and/or accessible from the time series generated.

4.3 Data transfer

Quality coded discrete water quality data must be accessible to LAWA (Land Air Water Aotearoa) and other external data consumers via sector-specified application programming interfaces (API's) (see Section I 1.5.2).

- All ‘time-series’ comments (see Section I 5.3) for the site(s), variable(s), and period(s) of data requested by a data consumer who does not have direct access to the agency’s repository must be collated and supplied to the requestee with the data.

5 Metadata

5.1 Description

Because of the variety in discrete water quality data, significantly more metadata must be filed in proportion to the number of values stored than for a continuously deployed sensor measuring only a few variables.

Section 6 remains generally applicable but the distinction between site and time-series metadata differs. For discrete water quality data:

- the site metadata includes all information about the location and sampling programme (see NEMS *Water Quality Part 1* v1.0.0 Section 2.3 or *Parts 2 to 4* v1.0.0 Section 2.2, and Sections I 2.2.1 to I 2.2.3)
- the ‘time-series metadata’ includes all:
- data acquisition records, including sample run sheets, field record forms, chain of custody, and laboratory reports
- visit and sample metadata, which may be associated with multiple measurements (see NEMS *Water Quality Part 1* v1.0.0 Section 4.4 or *Parts 2 to 4* v1.0.0 Section 2.6, and Sections I 2.2.4, I 2.2.7 and I 2.2.8)
- metadata associated with how each measurement is made, including instrument pre-deployment calibrations, validations, and checks (see Sections I 2.2.5 and I 2.2.6)
- measurement metadata (see Section I 2.2.9), including quality codes (see Section I 5.2) and comments (see Section I 5.3)
- data processing records, including quality control (see Section I 2), editing (see Section I 3), and quality assurance (see Section I 6)
- records documenting post-processing (see Section I 4), and
- agreements and/or notices relating to sharing and/or supply of the data.
- Discrete water quality data may not be stored as a time series (see Section I 1.5.2). Agencies have some discretion over where the ‘time-series metadata’ is stored and how it is configured.
- As a minimum, requirements of Sections I 2.2.9 and I 4.2 must be met.
- Agencies must include details of the storage and configuration of their ‘time-series metadata’ in their data management system documentation (see Section I 1.8.5).

5.2 Quality coding

- All discrete water quality data shall be quality coded. The quality code shall be assigned to individual measurements for each water quality variable. The quality code is set by four different but related sets of criteria:
- the quality coding flowchart
- the quality coding matrices A, and B or C
- blanket provisions, and
- data editing actions and adjustments (i.e. data modifications).

The quality coding flowchart and quality coding matrices may be found in NEMS *Water Quality Parts 1 to 4* v1.0.0 Section 6. The flowchart is also available from the NEMS *National Quality Code Schema*.

Any quality code assigned other than QC 600 requires a note or comment in the measurement metadata giving the reason for the lower code. Consider whether a 'time-series' Data Comment (see Section I 5.3) is also needed to inform any data end-user.

5.2.1 Quality coding matrices

The quality coding matrices use assessment of the following records to differentiate between a maximum possible quality code of QC 400, QC 500, or QC 600 for all data collected:

- site and visit metadata (see Section I 2.2)
- Field and Office Manual (see Section I 1.8.1)
- instrument specifications and field meter metadata including calibrations forms (see Sections I 1.8.4, I 1.8.7, I 2.2.5 and I 2.4.1)
- Field Record form (see Section I 1.8.4)
- completed Chain of Custody form (see Sections I 1.8.4 and I 2.4.2), and
- Laboratory Report (see Sections I 1.8.9 and I 2.4.2).

The initial quality code for field measurements should be assigned by the field personnel who made the measurements.

Quality coding of laboratory measurements is a two-step process:

The laboratory undertakes checks and provides comments to the monitoring agency (see Section I 2.4.2),

A suitably skilled person within the monitoring agency collates all the information about the sample, including that provided by the laboratory, to verify the results and decide a final quality code for each measurement value.

Compensation for water temperature, salinity, and/or barometric pressure are not regarded as data editing and are included in the Quality Coding Matrix B assessment.

5.2.2 Blanket provisions

The following provisions apply to discrete water quality data in addition to the generic application of quality codes as set out in the quality coding flowchart, and QC 400, QC 500, or QC 600 as assessed by matrices A, and B or C.

Measurement using a non-Standard method, or a measurement in non-Standard units, cannot achieve QC 600. Examples where quality code of all measurements must be reduced are:

- Total Nitrogen – indirect (TN-K)
- methods other than Colilert for *E. coli*
- visual clarity by Secchi disk when only reappearance is measured.

Note: Standard methods and measurement units are those set out in NEMS Water Quality Parts 1 to 4 v1.0.0 'The Standard – Discrete Water Quality'.

Maximum achievable quality code is QC 500 in the following situations:

- DO% Saturation measurements greater than 100%, and up to and including 120%, and their corresponding concentration values.

Maximum achievable quality code is QC 400 in the following situations:

- turbidity not measured using ISO 7027 compliant instruments
- all results collected since the last good validation or calibration with a 'high quality' sonde that has failed validation
- a result uncorrected but known to be affected by incorrect calibration coefficient(s)
- an over-ranged result, for example:
- a result censored because it exceeded calibrated range
- DO% Saturation measurements greater than 120% and their corresponding concentration values.
- when, after a method detection limit (MDL) is set that is higher than the NEMS specified (see Section I 1.8.7), there is more than one censored value in the first ten measurements.
- All censored results must then be quality coded no more than QC 400 until the MDL is lowered and the next 'first ten' values are similarly assessed, or the new MDL is the NEMS specified (or lower).
- If there is no more than one censored value in the 'first ten', then quality code all results as normal.
- A Data Comment must be filed for each period of downgraded quality codes describing the reason and stating the relevant MDL that was in effect.

Raw results are universally assigned and retain a quality code of QC 0 (see Section I 2.4.2 'Raw results'). Original data as defined by the agency must also be quality coded as QC 0 until verified (see Section I 1.8.9).

After review for gross errors and/or if edited from the original, a quality code of QC 200 (not assigned a final quality code) may be assigned to measurements of, or from, the following:

- variables for which there is inadequate current guidance, including:
- beam transmissometry
- colour (Hue)
- chlorophyll *a* by fluorescence (CHC – Field),
- suspended sediment concentration (SSC).
- supplementary data required to be permanently stored but not verified and processed according to their relevant NEMS, or no NEMS Standard exists for that variable.

A quality code of QC 200 shall be assigned to measurements of, or from, the following:

- 'high quality' sondes not validated before a recalibration (affects only the data collected since the most recent prior calibration)
- samples obtained by auto-sampler.

  Note: Auto-samplers cannot be used for tests requiring sterile bottles, preservation, or no air gap so those would be a 'no result', i.e. QC 100.

For measurements requiring compensation, e.g. DO, maximum possible quality code is the lesser of:

- the quality coding matrices result for the variable, and the final quality code assigned to the supplementary data if also processed to NEMS
- QC 500, and the quality coding matrices result for the variable if the supplementary data are not processed to NEMS but they are reviewed, and edited if necessary for gross error, or
- QC 400, and the quality coding matrices result for the variable if the supplementary data are original as recorded and applied without their review.

5.2.3 Data editing actions and adjustments

The quality code of any data collected may be affected by subsequent editing actions and adjustments made to the data. Minor modifications reduce quality code to QC 500. Significant modifications reduce quality code further to QC 400.

For discrete water quality data, a modification may be considered minor if it:

- applies only to data from a single visit, and
- is made with a high degree of confidence, e.g. swapping values likely to have been misplaced on the field form, or
- is a small change to the value, e.g. changing its resolution.

Further guidance on how and when quality code must change as a consequence of data processing is provided in Section I 3 of this Annex.

The following are exempt from the data modifications test, i.e. quality code is unaffected by the editing:

- changes to data that may be considered administrative, e.g. changing a sample time to resolve an orphaned result, unless the change affects reliability or interpretation of the associated result
- a change that is a fully traceable correction (see Section I 3.3.1)
- a value replaced by a retest result, which would itself be quality coded
- compensation for water temperature, salinity, and/or barometric pressure, which is assessed using Matrix B.

5.3 Example (time-series) comments

- Filed (time-series) comments are intended to inform end users of the data, especially those external to the monitoring agency, i.e. they are intended to be published in some way, or delivered to end users with the data supplied to them (see Section I 4.3). Some of those users may not be familiar with water quality science or the way the data are measured and stored.
- The comments have a specific format and implementation (see Sections 6.2.4 and I 4.2). Their purpose is to:
- summarise the data holdings, their availability, and their limitations
- explain key aspects of the site, monitoring purpose, and methods, and provide references to more detail if required
- guide potential data users as to what data and metadata they should request to meet their needs
- provide a basic level of metadata that can reasonably be directly associated with the data when in time series form
- alert users to potential discontinuities in the data, e.g. location or method change
- identify and explain unusual features of the data not adequately conveyed by quality code, and
- provide information about why a quality code less than QC 600 has been applied so users can determine whether the data are fit for their purposes.

Comments intended for agency internal work programme management and servicing the operational requirements of the data collector may be stored as visit, sample and/or measurement result metadata without needing to conform to the format and style of the examples in the following sections (I 5.3.1 to I 5.3.7 incl.).

Note: The operational requirements of the data collector include the need to quality assure, quality control, and ensure traceability of the data.

Examples include comments and notes:

- about administrative and operational matters
- tracking routine verification and processing of the data, and/or
- imported verbatim from field sheets and laboratory reports.

'Time-series' filed comments summarising the above may be needed to alert an end user to aspects that might affect the data's fitness for their purpose.

All forms of comments may be stored in the same database provided the relevant 'times-series' filed comments can be associated with any time series generated (see Section I 4.2) and/or extracted, reported, and delivered with data supplied to a user external to the monitoring agency (see Section I 4.3).

The following are templated examples of 'time-series' (filed) comments for discrete water quality sites.

Every comment must be assigned a fully specified timestamp and some form of "Site" and "Measurement" database key combination to associate it with the relevant data. The database keys and timestamp are usually specified in some form of record header not shown here.

5.3.1 Site/Initial Comments

The Site/Initial comment states what and where the site is, its name and any other identifiers, and provides a summary of what is monitored there, how and by whom.

Subsequent changes to information provided in this comment, e.g. a change of method or monitoring location, are tracked by one or more of an Equipment, Operational, Data, and/or Stationarity Comment filed at the time of the change.

River site

Type: Site
Measurement: Water Quality ALL
Initial comment for the water quality site *<site name>, <network number, ID, or code>*
On the *<river name>* River, river number *<river number>*[33]
The site is situated *<distance to coast>* km from the mouth at grid reference *<map co-ordinates and type*[34]*>*
Drains *<catchment area to site>* km^2
Measurements are obtained *<give frequency, e.g. monthly, weekly, etc.>* by *<methods, e.g. field meter, grab sample, pumped sample etc.>* from *<describe monitoring location and/or platform>*
Variables, Method (Nomenclature) and Units, unless otherwise stated, are
1) Visual clarity, black disk (VC-BD) in metres
2) Water temperature, field thermometer (Therm) in degrees C
3) Dissolved oxygen, field meter (DO% Sat) as % Saturation (barometric corrected)
4) pH, field meter (pH – field) in pH units @ 25°C

[33] from *Catchments of New Zealand* (SCRCC, 1956).

[34] state the co-ordinate system: NZTopo50 or NZGD 2000 preferred (latitude/longitude to 6 decimal places)

5) pH, APHA 4500-H+B, (pH) in pH units @ 25°C
6) etc.
7) etc.
All measurements are filed at the time of the field measurements to the nearest 5-mins.
<Data for some variables is (or may be) censored.>
Additional information: *<Add purpose of monitoring, including reference to where the objectives and sample design can be found>*. *<Multiple time series exist for <list variable(s) and units, e.g. Turbidity NTU and FNU, DO% Saturation (corrected) and Concentration etc.>>*. *<Add persistent issues that affect measurement quality or reliability, e.g. Laboratory not IANZ accredited (for <list variable(s)>)>*. *<Some (or All) quality control (and/or data editing) is automated; refer to the relevant Data Processing Comments>*.
The following is also measured at this site: *<list variables, e.g. discharge (gauged each visit), continuous flow, continuous turbidity, rainfall intensity etc.>*
The local recording authority is: *<name of monitoring/archiving agency>*

Lake site

Type: Site
Measurement: Water Quality ALL
Initial comment for *<name of water body>* water quality site at *<site name>*, *<network number, ID, or code>* on river *<river number>*[35]
The site is situated *<distance to outlet>* km from the outlet at grid reference *<map co-ordinates and type[36]>*
Drains *<catchment area to site>* km^2 of *<river name>* River catchment
Lake area is *<surface area>* km^2 and level is controlled by *<describe features, e.g. natural outlet, dam, weir etc.>*
Measurements are obtained *<give frequency, e.g. monthly, weekly, etc.>* by *<methods, e.g. field meter, grab sample, pumped sample etc.>* at *<list depth(s)>* from *<describe monitoring platform>*
Variables, Method (Nomenclature) and Units, unless otherwise stated, are
1) Visual clarity, secchi disk (VC-SD) in metres
2) Water temperature, field thermometer (Therm) in degrees C
3) Dissolved oxygen, field meter (DO% Sat) as % Saturation (barometric corrected)
4) pH, field meter (pH – field) in pH units @ 25°C
5) pH, APHA 4500-H+B, (pH) in pH units @ 25°C
6) etc.
7) etc.
All measurements are filed at the time of the field measurements to the nearest 5-mins.
<Data for some variables is (or may be) censored.>
Additional information: *<Add purpose of monitoring, including reference to where the objectives and sample design can be found>*. *<Multiple time series exist for <variable and units, e.g. Turbidity NTU and FNU, DO% Saturation (corrected) and Concentration etc.>> <Add persistent issues that affect measurement and/or sampling, e.g. Laboratory not IANZ accredited (for <list variable(s)>*), periodic drying up, stratification etc.>. *<Some (or All) quality control (and/or data editing) is automated; refer to the relevant Data Processing Comments>*.
The following is also measured at this site: *<list variables, e.g. lake level, continuous turbidity, continuous wind speed and direction, depth profiles, bathymetry etc.>*
The local recording authority is: *<name of monitoring/archiving agency>*

[35] from *Catchments of New Zealand* (SCRCC, 1956).

[36] state the co-ordinate system: NZTopo50 or NZGD 2000 preferred (latitude/longitude to 6 decimal places)

Coastal site

Type: Site
Measurement: Water Quality ALL
Initial comment for *<name of water body>* water quality site at *<site name>*, *<network number, ID, or code>* at grid reference *<map co-ordinates and type[37]> <on river <river number>[38]>*
Situated *<brief location description including type of water body, distance from land>* *<Drains <catchment area to site>* km^2 of *<river name>* River catchment>
<Surface area is <surface area> km^2 and level is controlled by *<describe features, e.g. natural outlet, dam, weir etc.>>*
Measurements are obtained *<give frequency, e.g. monthly, weekly, etc.>* by *<methods, e.g. field meter, grab sample, pumped sample etc.>* at *<list depth(s)>* from *<describe monitoring platform>*
Variables, Method (Nomenclature) and Units, unless otherwise stated, are
1) Visual clarity, secchi disk (VC-SD) in metres
2) Water temperature, field thermometer (Therm) in degrees C
3) Dissolved oxygen, field meter (DO% Sat) as % Saturation (barometric corrected)
4) pH, field meter (pH – field) in pH units @ 25°C
5) pH, APHA 4500-H^+B, (pH) in pH units @ 25°C
6) etc.
7) etc.
All measurements are filed at the time of the field measurements to the nearest 5-mins.
<Data for some variables is (or may be) censored.>
Additional information: *<Add purpose of monitoring, including reference to where the objectives and sample design can be found>*. *<Multiple time series exist for <variable and units, e.g. Turbidity NTU and FNU, DO% Saturation (corrected) and Concentration etc.>>*
<Add persistent issues that affect measurement and/or sampling, e.g. Laboratory not IANZ accredited (for <list variable(s)>), exposure, tidal range etc.>. *<Some (or All) quality control (and/or data editing) is automated; refer to the relevant Data Processing Comments>*.
The following is also measured at this site: *<list variables, e.g. tide level, continuous water temperature, continuous wind speed and direction, depth profiles, bathymetry etc.>*
The local recording authority is: *<name of monitoring/archiving agency>*

Groundwater site – wells

Type: Site
Measurement: Water Quality ALL
Initial comment for groundwater quality at well *<bore name, ID, and/or number>*
Located at *<map co-ordinates and type39>* drilled on *<dd-mm-yyyy>* to depth of *<well depth>*m
Well construction: from *<depth>* to *<depth>*m diameter *<bore dia.>*mm and is *<cased, uncased, or screened>*

[37] state the co-ordinate system: NZTopo50 or NZGD 2000 preferred (latitude/longitude to 6 decimal places)

[38] from *Catchments of New Zealand* (SCRCC, 1956).

[39] state the co-ordinate system: NZTopo50 or NZGD 2000 preferred (latitude/longitude to 6 decimal places)

Well type <*type*>40 for <*purpose*>41 Aquifer type <*type*>42 depth <*depth*>m
Aquifer lithology <*brief description*>
Log available from <*name and contact details*> Consent <*number or permitted use*>
Ground elevation <*level and datum*>m, Static water level <*level and datum*>m
Measurements are obtained <*give frequency, e.g. monthly, weekly, etc.*> by <*methods, e.g. field meter, grab sample, pumped sample etc.*> from <*describe monitoring point (include level of any tap or fitting used)*>
Variables, Method (Nomenclature) and Units, unless otherwise stated, are
1) Visual clarity, black disk (VC-BD) in metres
2) Water temperature, field thermometer (Therm) in degrees C
3) Dissolved oxygen, field meter (DO% Sat) as % Saturation (barometric corrected)
4) pH, field meter (pH – field) in pH units @ 25°C
5) pH, APHA 4500-H+B, (pH) in pH units @ 25°C
6) etc.
7) etc.
The measurements are filed at the time of last field measurement to the nearest 5-mins.
<*Data for some variables is (or may be) censored.*>
Additional information: <*Add purpose of monitoring, including reference to where the objectives and sample design can be found*>. <*Add adjacent bore location information if more than one bore in vicinity, and aquifer properties, water quality grade if applicable*> <*Multiple time series exist for <variable and units, e.g. Turbidity NTU and FNU, DO% Saturation (corrected) and Concentration etc.*>> <*Add persistent issues that affect measurement and/or sampling, e.g. Laboratory not IANZ accredited (for <list variable(s)*>), low-flow purged, frequency and/or seasonality if dries up or pumped etc.>. <*Some (or All) quality control (and/or data editing) is automated; refer to the relevant Data Processing Comments*>.
The following is also measured at this site: <*list variables, e.g. water level (manual or continuous), rainfall intensity, soil water content, barometric pressure etc.*>
The local recording authority is: <*name of monitoring/archiving agency*>

Groundwater site – springs

Type: Site
Measurement: Water Quality ALL
Initial comment for groundwater quality at <*name*> spring, <*network number, ID, or code*>
In the catchment of the <*river name*> River, river number <*river number*>43
Situated at grid reference <*map co-ordinates and type44*> at an altitude of <*elevation*>m
Outlet is <*brief description, e.g. submerged or perched, open pool or contained by headworks etc.*>
<*Water is used for <purpose*>45 Consent <*number or permitted use*>>
Measurements are obtained <*give frequency, e.g. monthly, weekly, etc.*> by <*methods, e.g. field meter, grab sample, pumped sample etc.*> from <*describe monitoring point and/or platform including proximity to source*>

[40] drilled, driven, bored or augured, dug, pit, infiltration gallery, or spring
[41] water supply (domestic, industrial, or public), waste disposal, irrigation, stock, recharge, observation, or disused
[42] confined, unconfined, perched, or fissure
[43] from *Catchments of New Zealand* (SCRCC, 1956).
[44] state the co-ordinate system: NZTopo50 or NZGD 2000 preferred (latitude/longitude to 6 decimal places)
[45] water supply (domestic, industrial, or public), waste disposal, irrigation, stock, recharge, observation, or disused

Variables, Method (Nomenclature) and Units, unless otherwise stated, are
1) Visual clarity, black disk (VC-BD) in metres
2) Water temperature, field thermometer (Therm) in degrees C
3) Dissolved oxygen, field meter (DO% Sat) as % Saturation (barometric corrected)
4) pH, field meter (pH – field) in pH units @ 25°C
5) pH, APHA 4500-H+B, (pH) in pH units @ 25°C
6) etc.
7) etc.
The measurements are filed at the time of last field measurement to the nearest 5-mins.
<Data for some variables is (or may be) censored.>
Additional information: *<Add purpose of monitoring, including reference to where the objectives and sample design can be found>*. *<Add adjacent bore location information if any relevant in vicinity, and water quality grade if applicable> <Multiple time series exist for <variable and units, e.g. Turbidity NTU and FNU, DO% Saturation (corrected) and Concentration etc.>> <Add persistent issues that affect measurement and/or sampling, e.g. Laboratory not IANZ accredited (for <list variable(s)>*), frequency and/or seasonality if dries up>. *<Some (or All) quality control (and/or data editing) is automated; refer to the relevant Data Processing Comments>*.
The following is also measured at this site: *<list variables, e.g. water level and/or discharge (manual or continuous), rainfall intensity, barometric pressure etc.>*
The local recording authority is: *<name of monitoring/archiving agency>*

5.3.2 Equipment Comment examples

Type: Equipment
Measurement: Water Quality FIELD (or *<variable>*)
From *<dd-mm-yyyy hhmmss>* the instrument used for field measurement of *<list variable(s)>* is a *<list type, make and model>*. Unique meter identifier is stored with the measured values. Routine calibration is performed *<briefly describe frequency, method, and calibrated range for each variable, or provide reference to documentation, e.g. NEMS, manual, or SOP including version>*. Routine validation is performed *<briefly describe frequency and method for each variable, or provide reference to documentation, e.g. NEMS, manual, or SOP including version>*. Calibration and validation records are stored in *<provide database or file reference(s) as applicable to each>* and accessible via *<provide means of access, e.g. file request, computer application, intranet etc.>*.

Create a similar but separate comment for any new or replacement meter, noting any changes to previously described details as a consequence. Include confirmation that all other details have not changed.

Type: Equipment
Measurement: Water Quality Visual Clarity
Values from *<dd-mm-yyyy hhmmss>* are the average of two measurements obtained using black disk, sized for visibility range: 200mm > 1.5m, 20mm ≤ 0.5m, otherwise 60mm, and deployed by wading. Viewer is checked against a reference viewer every 12 months.
Type: Equipment
Measurement: Water Quality SAMPLES
From *<dd-mm-yyyy hhmmss>* samples are collected from *<brief description of monitoring point or platform>* using *<brief description of method, e.g. bucket on rope, drone, sampling pole from right bank, flow cell, Nisken sampler etc.>* at depth(s) *<list sample depths, or near-surface and/or near-bottom, or depth-integrated>*. Testing laboratory, test method, and method detection limit are stored with the measured values.

Type: Equipment
Measurement: Water Quality SAMPLES
Testing laboratory changed on *<dd-mm-yyyy hhmmss>*. Test methods and method detection limits are unchanged. (or Test methods and/or method detection limits for *<list variable(s)>* changed.) Testing laboratory, test method, and method detection limit are stored with the measured values.

Type: Equipment
Measurement: Water Quality Specific Conductivity
Measurement method changed on *<dd-mm-yyyy hhmmss>* from laboratory analysed samples to field measurement. See the corresponding field instrument comment for meter details.

Type: Equipment
Measurement: Water Quality Turbidity
Measurement method changed on *<dd-mm-yyyy hhmmss>* from EPA 180.1 compliant *<make and model>* meter measuring in NTU to ISO 7027-1:2016 compliant *<make and model>* meter measuring in FNU. New measurement range is *<provide range & units>*.) See the corresponding field instrument comment for meter details.

5.3.3 Operational Comment examples

Type: Operational
Measurement: Water Quality ALL
Field measurement and sampling location moved *<state where in relation to previous>* on *<dd-mm-yyyy hhmmss>* because *<give reason(s)>*. *<New location is permanent (or temporary>*. *<Photos taken on <dd-mm-yyyy hhmmss>.>*

Type: Operational
Measurement: Water Quality FIELD (or *<variable>*)
Quality code of field measurements of *<list variable(s)>* on *<dd-mm-yyyy>* is reduced because the field meter failed end of day validation.

Type: Operational
Measurement: Water Quality SAMPLES (or *<variable>*)
From *<dd-mm-yyyy>* the testing laboratory *<name (if preferred)>* is (not) IANZ accredited for measurement of *<list variable(s)>*.

Type: Operational
Measurement: Water Quality Turbidity
Laboratory test method for monthly verification samples changed on *<dd-mm-yyyy>* from EPA 180.1 compliant measuring in NTU to ISO 7027-1:2016 compliant measuring in FNU. Maximum calibrated range under the new method is *<max. range>*

Type: Operational
Measurement: Water Quality SAMPLES (or *<variable>*)
All measurements and samples taken on *<dd-mm-yyyy>* were collected using a drone instead of the usual powered boat.

Type: Operational
Measurement: Water Quality ALL
Lake weed cleared by powered boat with mechanical rake on *<dd-mm-yyyy>* (or has been cleared since last visit on *<dd-mm-yyyy>*.)

5.3.4 Data Comment examples

Type: Data
Measurement: Water Quality E. coli
Value at *<dd-mm-yyyy hhmmss>* is unreliable and quality coded 'no result' due to ice present in the sample on arrival at the laboratory.

Type: Data
Measurement: Water Quality *<variable>*
Values from *<dd-mm-yyyy hhmmss>* to *<dd-mm-yyyy hhmmss>* are unreliable and quality coded 'no result' due to an unresolvable instrument configuration error.

Type: Data
Measurement: Water Quality SAMPLES
Samples collected on *<dd-mm-yyyy hhmmss>* were not sufficiently chilled in transit. Results may be compromised and are assigned a lower quality code.

Type: Data
Measurement: Water Quality *<variable>*
From *<dd-mm-yyyy hhmmss>* *<variable>* is (not) measured at this site.

Type: Data
Measurement: Water Quality *<variable>*
Method detection limit for *<variable>* changed from *<old limit and units>* to *<new limit and units>* from *<dd-mm-yyyy hhmmss>*.

Type: Data
Measurement: Water Quality *<variable>*
Measured value of *<variable>* on *<dd-mm-yyyy hhmmss>* is verified but atypical and should be treated with caution. *<It may be affected by <provide reason(s)>>*.

Type: Data
Measurement: Water Quality *<variable>*
Values from *<dd-mm-yyyy hhmmss>* to *<dd-mm-yyyy hhmmss>* are quality coded QC 400 (compromised) because the method detection limit of *<limit and units>* is producing an excessive number of censored values.
Add a comment such as the following example to the end of the 'old' data and the start of the 'new' data when there is a significant change of method that initiates a new dataset, i.e. in the example, attach the comment to the last data before the change (with units of NTU) and the first data after the change (with units of FNU). Corresponding Equipment and Stationarity Comments are also needed (see Sections I 5.3.2 and I 5.3.7).

Type: Data
Measurement: Water Quality Turbidity
Measurement method changed on *<dd-mm-yyyy hhmmss>* from EPA 180.1 compliant *<make and model>* meter measuring in NTU to ISO 7027-1:2016 compliant *<make and model>* meter measuring in FNU. The data from each method are stored separately and should not be considered homogenous. Relationship between the two has been determined from least squares regression of duplicate measurements as FNU = 1.2345 $*$ NTU; n = 14, R^2 = 0.988, and NTU = 0.8001 $*$ FNU; n = 14, R^2 = 0.988. See the relevant Equipment Comments for meter details.

5.3.5 Data Processing Comment examples

Type: Data Processing
Measurement: Water Quality *<variable>*
Measured value(s) of *<variable>* on *<dd-mm-yyyy hhmmss>* (or from *<dd-mm-yyyy hhmmss>* to *<dd-mm-yyyy hhmmss>* is (or are) deleted because *<provide reason(s)>*.
Edited by *<name>* on *<date of processing>*.

Type: Data Processing
Measurement: Water Quality *<variable>*
Measured values of *<variable>* and *<variable>* on *<dd-mm-yyyy hhmmss>* are edited to swap those recorded and suspected to have been transposed on the field sheet. Edited by *<name>* on *<date of processing>*.

5.3.6 Transformation Comment examples

Type: Transformation
Measurement: Water Quality *<variable>*
Archived *<target variable>* from *<dd-mm-yyyy hhmmss>* (to *<dd-mm-yyyy hhmmss>*) is derived from surrogate measurements of *<surrogate variable>* by transformation using the linear (or nonlinear) relation *<provide equation>* derived by *<method>*. The calibration data comprises *<x>* samples (or field measurements) obtained between *<dd-mm-yyyy hhmmss>* and *<dd-mm-yyyy hhmmss>* with range *<range & units of target variable values>* and maximum deviation from the derived relation of *<deviation & units>*. Range of the transformed data is *<range & units>*. *<Add other goodness of fit statistics as applicable, e.g. regression coefficient R^2>*. Applied by *<name>* on *<date of processing>*.

For Transformation Comment examples relating to Dissolved Oxygen see Annex H, Section H 4.2.6.

5.3.7 Stationarity Comment examples

Add a comment such as the following example at the time of a change of method that initiates a new dataset. The comment must be associated with the start of the 'new' data and may also be associated with the end of the 'old' data.

Type: Stationarity
Measurement: Water Quality Turbidity
Measurement method changed on *<dd-mm-yyyy hhmmss>* from EPA 180.1 compliant *<make and model>* meter measuring in NTU to ISO 7027-1:2016 compliant *<make and model>* meter measuring in FNU. The data from each method are stored separately and should not be considered homogenous. See the corresponding Data Comment for more information.

Add a comment similar to one of the following examples, as is applicable, at the time of a change of method that does not initiate a new dataset.

Type: Stationarity
Measurement: Water Quality Turbidity
Measurement method changed on *<dd-mm-yyyy hhmmss>* from ISO 7027-1:2016 compliant *<make and model>* meter to ISO 7027-1:2016 compliant *<make and model>* meter both measuring in FNU. Calibrated range and operational procedures are unchanged. Relationship between the two has been determined from least squares regression of duplicate measurements as 'new' = 1.015 ∗ 'old'; n = 14, R^2 = 0.999, and 'old' = 0.9851 ∗ 'new'; n = 14, R^2 = 0.999. See the relevant Equipment Comments for meter details.

Type: Stationarity
Measurement: Water Quality Dissolved Oxygen
Measurement method changed on *<dd-mm-yyyy hhmmss>* from *<make and model>* galvanic meter to *<make and model>* optode, which may cause a systematic shift in the data. Values are DO% Saturation corrected for local barometric pressure from both instruments, but velocity of flow may affect galvanic measurements. See corresponding Equipment Comments for field meter details.

Type: Stationarity
Measurement: Water Quality Dissolved Oxygen
Measurement method changed on *<dd-mm-yyyy hhmmss>* from *<make and model>* galvanic meter to *<make and model>* optode. Statistical analysis of prior consecutive duplicate measurements each month in the year to *<mon-yyyy>* by *<statistical method>* shows no significant difference at the *<x>*% level of confidence. The new and old methods are considered to produce equivalent results. See the relevant Equipment Comment(s) for meter details.

Type: Stationarity
Measurement: Water Quality Specific Conductivity
Measurement method changed on *<dd-mm-yyyy hhmmss>* from IANZ accredited laboratory analysed samples to field measurement. Statistical analysis of *<x>* duplicate measurements over a period of *<y>* months up to *<mon-yyyy>* by *<statistical method>* shows no significant difference in results at the *<x>*% level of confidence. The new and old methods are considered to produce equivalent results. See the relevant Equipment Comment(s) for meter details.

6 Quality Assurance

Further to the requirements of Section 7 of this Standard, a range of practices are either required or recommended in NEMS *Water Quality Parts 1 to 4* v1.0.0 to quality assure the field work essential to the collection of reliable discrete water quality data (see NEMS *Water Quality Parts 1 to 4* v1.0.0 Section 1).

Quality assurance of laboratory practice is managed by the laboratory, the adequacy of which is accounted for in NEMS *Water Quality Parts 1 to 4* v1.0.0 Matrix C. This requires the monitoring agency to monitor the laboratory's IANZ accreditation status and/or periodically review their quality assurance and quality control procedures, e.g. at contract renewal time (see Section I 6.4).

The quality assurance procedures adopted by the monitoring agency must be documented in their Field and Office Manual (see Section I 1.8.1). Records of the implementation of those procedures and their results must be permanently retained, which may involve storing the measurement values and metadata for samples analysed solely for quality assurance. Agencies must therefore also document and implement data management procedures that ensure quality assurance results do not corrupt actual site data.

The following sections summarise the quality assurance checks and describe associated requirements and the records that must be collated and retained.

6.1 Peer review of data processing

The requirements of Section 7.2 of this Standard apply, except where they are specific to continuously recorded data, e.g. gap handling and infilling.

6.2 Other reviews

6.2.1 Site metadata

Site metadata should be reviewed and updated at least annually (see Section I 2.2.3). Each review should be recorded in the Site History, signed off and dated by the reviewer whether or not changes were made to the metadata.

6.2.2 Visual clarity equipment

Visual clarity viewer integrity should be checked against a reference viewer at least every 12 months (see NEMS *Water Quality Parts 1 to 4* v1.0.0 'The Standard').

Also, periodically:

- measuring tapes should be checked for accuracy and condition, and
- Quality Coding Matrix B results reviewed for instances of data quality code downgraded due to viewer and/or disk or tube condition.

Ensure there are traceable and accessible records collated and maintained of these checks and dates of equipment refurbishment and/or replacement. Assigning and attaching unique serial numbers to this equipment facilitates record keeping.

6.2.3 Light penetration (PAR)

Calibration of PAR sensors is not routinely required but they should be validated against a second sensor or sensor pair at least annually (see NEMS *Water Quality Parts 3 & 4* v1.0.0 Table 1).

Ensure there are traceable and accessible records collated and maintained of these checks and dates of equipment refurbishment and/or replacement. Assigning and attaching unique serial numbers to this equipment facilitates record keeping.

6.2.4 Maintenance of instruments and calibration standards

When a 'high quality' instrument fails validation, NEMS *Water Quality Part 1* v1.0.0 Annex G, *Parts 2 & 3* v1.0.0 Annex E, and *Part 4* v1.0.0 Annex F, recommend that, in addition to cleaning and recalibration of the instrument, a review of its maintenance, and the calibration standard(s) is also undertaken.

The field meter calibration standard solutions for Specific Conductivity (SpC) must also be replaced if the meter fails to recalibrate for SpC after cleaning (see NEMS *Water Quality Parts 1 to 4* v1.0.0 Table 1).

Records of these reviews should be retained in an appropriate form, e.g. as an attachment to the relevant completed Field Meter Calibration form (see Section I 1.8.4 and NEMS *Water Quality Part 1* v1.0.0 Annex F, *Parts 2 & 3* v1.0.0 Annex D, or *Part 4* v1.0.0 Annex E).

6.2.5 Frequency of censored values

For each dataset containing censored values, at least every two years determine the proportion of stored values to date that are censored. If greater than 10% then:

- review the method detection limit for the site and variable, and
- add "Data for <*variable*> contains a high frequency of censored values" to the Site/Initial Comment as a warning to data users (see Section I 5.3.1).
- Add or remove the above comment line as MDL's are adjusted and/or water quality changes and the frequency test' is 'passed' or 'failed'.

6.2.6 Quality coding matrix assessments

Periodically review completed quality coding matrix assessments (see Section I 5.2) to identify persistent or systematic issues that might be resolved with more training, change of method and/or location etc. Records of these reviews should be retained with other quality assurance records (see Section I 7.3).

6.3 Quality assurance (test) samples

Several checks involving submission of 'known' and/or additional samples, both formal and informal, may be initiated by the monitoring agency and/or a third party to provide further assurance of the measurement process from sample collection to laboratory analysis (see NEMS *Water Quality Parts 1 to 4* v1.0.0 Sections 1 and 5.6).

They include:

- replicates, where a sample is split, and one part is submitted for analysis under a false name, so the laboratory does not know which site it came from (also known as blind duplicates)
- duplicates, where simultaneous samples are collected by two different field personnel and despatched to the same laboratory
- external duplicates, where the second set of samples collected are despatched to another laboratory
- field blanks, where distilled water is submitted from the field as if it were a normal sample
- spiked samples, where a known amount of the analyte is added to an otherwise normal duplicate sample and the difference between the spiked and ambient assessed for recovery of the known amount to test for sample matrix (analytical interference) issues.

Methods for storing the results of test samples and their metadata must be carefully designed to ensure their consistent treatment and retrieval as required while preventing unintended corruption, omission, overwrite, conflict and/or loss of actual site data.

Agencies must design the storage methods and associated data management procedures specific to their database software, laboratory service agreements, and quality assurance processes, and document them (see Section I 1.8.1).

The agency must also establish, document, and implement procedures to:

- process and review test sample results, e.g. replicates and duplicates
- receive laboratory advice of test sample results, e.g. field blanks, and
- act on the results and/or advice, including:
- further review of any data affected by issues identified, with possible editing of data already archived and/or reduction of the quality code already assigned
- provision of Data Comments to explain any editing and/or reduction of the quality code, and
- review of sampling and/or analytical methods.

6.4 Inter-agency field practice audit

An inter-agency field practice audit is recommended annually to verify field measurement practice and sample collection and handling (see NEMS *Water Quality Parts 1 to 4* v1.0.0 Section 1.3.1). The audit also generates duplicate samples to be managed according to each agency's documented methods (see Section I 6.3).

Once all results are available, formally report:

- the audit scope and criteria
- who was involved
- date, time and location of the field measurements and sample collection
- measurement methods
- measurement results
- audit outcomes, and
- recommendations.

Store a copy of the signed and dated report with the monitoring programme's quality assurance records (see Sections I 1.8.2 and I 7.3.3).

6.5 Laboratory quality checks

Laboratory quality checks are described in NEMS *Water Quality Parts 1 to 4* v1.0.0 Section 5.6. The laboratory is responsible for the associated records, which can be requested from the laboratory if needed.

Degree of quality assurance implemented by the laboratory is included in assessment of the quality code assigned to a result via NEMS *Water Quality Parts 1 to 4* v1.0.0 Matrix C.

If the monitoring agency discovers an error in any data provided by a laboratory, it must advise the laboratory as soon as possible so the error may be resolved in both the

agency's and the laboratory's records to prevent possible retransfer of incorrect data at a later date.

6.6 Data audit

The requirements of Section 7.3 of this Standard apply, except where they are specific to continuously recorded data, e.g. gap handling and infilling.

Further to the requirements of Section 7.3, include in the audit:

- a summary of the outcomes of inter-agency field practice audits relevant to the data audit period and any recommendations made (see Section I 6.4)
- the status of those recommendations in terms of their implementation at the date of the data audit, and

Note: Inter-agency field practice audits are not required for QC 600 to be assigned to data but do contribute to data quality.

- a summary of the frequency of censored values assessment(s) (see Section I 6.2.5).

If the laboratory used is not IANZ accredited, data audit also may be a convenient time for the monitoring agency to verify the laboratory's quality assurance practices.

7 Preservation of Record

Requirements in this section are additional to, or exceptions from, Section 8 of this Standard.

In the following sections "suitably archived" means securely stored in a system designed for the purpose, whether paper or electronic, such that the records are accurate and complete, preserved in good condition, identifiable, searchable, and readily available and accessible as and when required. If electronic they must be backed up regularly.

7.1 Original data

The recording agency must store and retain indefinitely, and if electronic, back up regularly all original records as defined by the agency (see Section I 1.8.9).

7.1.1 Field Record forms

- If the completed Field Record form is a paper record it may be permanently retained as a uniquely indexed and accessible scanned or verified correctly transcribed electronic copy.
- If an electronic form is used, the information captured may be stored on a field device to be imported or sync'd on return to the office or uploaded directly from the field to the agency's database via the internet and/or cellular networks.

- All information collected using an electronic form must be permanently retained in an accessible form as original records, observations and/or measurements.
- If transmission from the field device of the completed form, or all information captured on the form, is fully automatic, i.e. on connection and 'hands-free', and completes without fault, the file on the field device need not be permanently retained. The integrity of the transfer process should be thoroughly checked when devices and/or software is changed, and then periodically thereafter, to ensure it is working as expected with no data corruption or loss.
- If transfer of information from the field device is not fully automated the field file must be retained until transfer of the original records is confirmed complete and correct.
- If groundwater well purge records are not captured on the Field Record Form, they must be separately captured and preserved as an original record.

7.1.2 Laboratory reports

The Laboratory Report is the official means of conveying analysis results to the monitoring agency. It is usually sent electronically to the monitoring agency, often as a pdf document. Laboratory Reports are original records (see Section I 1.8.9) and must therefore be preserved and permanently retained.

If the monitoring agency operates its own laboratory and information systems are shared:

- Laboratory Reports are superfluous for the purpose of providing analysis results and associated information but should be able to be generated if an external data user requests the official original result(s) for a sample
- there should be a laboratory service agreement in place that describes who is responsible for which aspects of quality control, quality assurance, preservation, and retention of the data.

7.1.3 Laboratory data transfer

Laboratories may also provide analysis results and associated metadata in an electronic format that can be imported directly into the monitoring agency's database, e.g. as CSV, XML, or JSON files.

These files do not replace laboratory reports as the official version of results and therefore do not need to be preserved and retained as original data if laboratory reports are also provided and stored (see Section I 7.1.2). However, the transfer file(s) must be retained at least until the import has been checked (see Section I 2.4.6).

7.1.4 Storing multiple versions of the same result

Multiple versions of the same result may need to be stored as original data in the following circumstances:

- duplicate samples and measurements
- for quality assurance purposes (see Section I 6.3)
- as constituents of an averaged result (see Section I 2.4.2), or
- to provide an overlapping record in advance of a change of method or location (see Section I 2.4.5).
- replicate samples, for quality assurance purposes (see Section I 6.3)
- retests, and recalculation of results dependent on the constituent(s)
- censored and uncensored values (with UoM), or
- rounded and 'raw' unrounded values (with UoM).

The agency's documented data management procedures (see Section I 1.8) must ensure the integrity of each version and allow the source of any data subsequently published and/or processed and archived to be traced.

7.1.5 Supplementary data

If the required compensations for some variables, e.g. DO% Saturation (local), are not built in to the field meter, the necessary supplementary data must be measured in their own right as for any other variable and treated as for any other measured variable, including the requirements for original record preservation (see Section I 1.6).

7.2 Final records

The recording agency must permanently archive and retain indefinitely, and if electronic, back up regularly all final records, which include:

- the verified and quality coded water quality data
- all required metadata
- records of verification and editing of data and metadata
- any supplementary data, checked and quality coded, and
- any complementary data, appropriately curated.

7.2.1 Time series and time-series comments

A time-series record that is generated from another database serving as the recognised discrete water quality data archive (i.e. the 'source of truth') (see Section I 4.2) need not be permanently retained unless it is, or was, used for regulatory purposes.

Time-series comments (see Section I 5.3) must be archived and retained indefinitely in any case, so they are available as and when a time series is generated, and as an easily retrievable, reportable, and standardised metadata summary.

7.2.2 Average of duplicate measurement results

An archived result may be the average of duplicate measurements or results. The average may be:

- manually calculated and entered on the Field Record form or Laboratory Report
- calculated by the field sheet or laboratory application, or
- calculated on transfer to the agency's database.
- How and when the average is calculated should be recorded in the method metadata.
- The measurement metadata must identify the archived result as an average.

The individual constituent results are expected to be recorded on the associated Field Record form or Laboratory Report, which is preserved as original data (see Section I 7.1) to provide the necessary traceability to the initial measurements and enable verification of the calculation(s) as required.

7.2.3 Raw (with UoM) vs. rounded or censored measurement

Both of the following versions of laboratory water quality data shall be archived, retained indefinitely, and maintained:

- official laboratory measurement results with values rounded to the appropriate number of significant figures commensurate with precision of the result, or censored values where appropriate, and
- the raw unadjusted and unrounded measurement data from the laboratory together with the accompanying uncertainty of measurement (UoM).

7.2.4 Data verification and editing

Records of data processing must be kept and retained indefinitely, and if electronic, backed up regularly. They include:

- confirmation of all verification steps
- evidence of quality control, including outcome of checks applied
- log of, and justification for, any editing of data and metadata, and
- explanation of assignment of quality codes, including the completed quality coding matrix assessments (see Section I 5.2).

7.2.5 Results of repeat tests on retained samples

Results from repeat tests replace the initial result(s). Preservation and retention requirements are the same as if they were initial results, but the measurement metadata must include a note that the final archived result is from a retested sample and the date of the retest.

7.2.6 Supplementary data

Supplementary data (see Section I 1.6) must be archived with its required metadata, including quality code, and all retained indefinitely as additional data items associated with the target measurement(s).

7.2.7 Complementary data

All complementary observations and measurements (see Section I 1.7) must be suitably archived and retained indefinitely.

Photos and video

To be useful, photos and video must be curated to maintain control of quality and quantity and identified in their file name by a minimum of the site and date/time taken, to facilitate future selection and retrieval.

7.3 Metadata

All required metadata must be suitably archived according to its purpose and level in the metadata hierarchy (see Section I 2.2) and retained indefinitely.

7.3.1 Quality assurance records

Quality assurance records may take a variety of forms, be in a variety of formats, and not necessarily stored in the same system with the water quality data and/or its immediate metadata.

For example, these records may be stored instead in a formal quality management system whose scope includes the collection, processing and archiving of discrete water quality data, and/or an asset management system that includes instruments.

7.3.2 Records of instruments

All certificates, forms, assessments, and associated information related to instrument calibration, validation, condition checks (visual clarity equipment), servicing, and replacement shall be preserved, indexed, searchable, and permanently retained in an accessible form.

Included is information provided by the manufacturer, servicing agent if different from the manufacturer, laboratory results as applicable, and test and service records created by the monitoring agency.

It is useful to also maintain a readily accessible collated timeline of these events for each instrument, to help with verifying correct assignment of quality codes to data obtained using the instrument.

Note: Although the purpose of the event timeline is for internal operations, time-series Equipment Comments and Operational Comments (see Section I 5.3) can be a convenient way to provide and maintain it.

7.3.3 Checks of automated quality control and quality assurance

All records of regular checks of automated quality control and/or quality assurance algorithms must be suitably archived and retained indefinitely (see Sections I 1.8.8 and 3.6.1).

7.3.4 Records of audits

The following records of inter-agency field practice audits and data audits shall be suitably archived and retained indefinitely:

- a copy of the audit report (see Sections I 6.4 and 7.3), and
- a summary of any recommendations and actions arising from the audit.

Requirements for the preservation of field measurements, sample results, and their associated metadata obtained during an inter-agency field practice audit are the same as for any routine site visit (see Sections I 7.1 and I 7.2).

7.3.5 Measurement results from quality assurance samples

Quality assurance (test) samples and requirements for storage of their measurement results are described in Section I 6.3.

The measurement values and all their associated metadata must be permanently archived as for normal samples. However, they must be separated from, or able to be identified and filtered from, actual site data, while at the same time able to be retrieved when required as individual and/or collated records, by time, by sample ID, by laboratory or by field instrument.

7.4 Documents

The following documents must be stored indefinitely, maintained with editing and version control, and if electronic be backed up regularly, as essential water quality metadata:

- the monitoring objectives and sampling design, (see Section I 1.8.2)
- the Field and Office manual, (see Section I 1.8.1)
- template and/or blank forms, (see Section I 1.8.4)
- laboratory contracts, (see Section I 2.2.6)
- site assessments, (see NEMS *Water Quality Part 1* v1.0.0 Sections 2.3 and 2.4, or *Parts 2 to 4* v1.0.0 Section 2.2 and 2.5)
- site access agreements, (see NEMS *Water Quality Part 1* v1.0.0 Section 2.3, or *Parts 2 to 4* v1.0.0 Section 2.2), and
- data access agreements, waivers, and/or copyright restrictions that constrain dissemination of the data.

7.4.1 Electronic document stores

Electronic document stores are now common. These may be corporate, and part of the same database used to store the water quality data, or corporate but in a separate database from the water quality data, or a document store facility within the dedicated system that is also storing the water quality data, e.g. within a time-series manager.

If an agency uses one or more electronic document stores for water quality metadata a description of what is stored where, and procedures for their use, maintenance, and the indefinite preservation of the documents stored within them, must be included in the formal documentation of the data management system (see Section I 1.8).

7.5 Data migration and integration

Data migration and/or integration into another database requires planning and careful execution to avoid data corruption and/or loss.

Agencies should consider the following aspects:

- previous migration(s) may not have been complete, or the data migrated may have contained errors, or the migration process may have introduced errors
- preservation and security of, and future access to, legacy data that cannot or will not be incorporated into the new system
- any migration or integration must not corrupt data. For water quality data, special attention should be given to measurement definitions including resolution and units, and the various forms of metadata
- fields in the old system may contain data that is not 'true to label', e.g. fields that have been used to store data they were not designed and/or named for
- re-establishing links to essential water quality metadata that is not stored with the data, e.g. site histories, monitoring programme and data management system documentation, and instrument records
- extra care is needed when using spreadsheets as intermediaries. Field overflows, cell formatting controls, and date formats can all introduce problems
- migrating to a temporary or test version of the new system, with planned quality control checks carried out between the old and new, e.g. by randomised comparisons and/or running standard reports on both systems, before release of a production version of the new system when all issues identified on the temporary or test system are resolved
- resourcing of a period of user feedback and fault fixing on the new system as part of the migration and/or integration plan.

8 References

Soil Conservation and Rivers Control Council (SCRCC). 1956. *Catchments of New Zealand.* SCRCC, Wellington.

Annex J Continuous Air Quality Particulate Matter (PM10 and PM2.5) Data Processing

1 General Overview

This Annex contains data processing guidance specifically for airborne particulate matter data measured continuously by automated in-situ instruments.

The monitoring and reporting of PM_{10} is also subject to National Environmental Standards (NES) and associated regulations.

Across New Zealand, air quality particulate matter data are obtained from an assortment of instruments and are stored in a variety of databases and architectures. Accurate reporting of data stored in time-series management systems is sensitive to correct assignment of data type for the sampling and data logging methods used by the instrument. More about storage architecture and data type is provided in Section J 1.5.

1.1 Normative references

This Annex shall be read in conjunction with the following references:

- NEMS Air Quality: Continuous Particulate Monitoring – Measurement of PM_{10} and $PM_{2.5}$ for Environmental Monitoring Purposes
- PM equivalency testing and co-location guide (Mote Ltd., in preparation)
- AS/NZS 3580.9.17 Methods for sampling and analysis of ambient air. Method 9.17: Demonstration of equivalence for ambient particulate matter monitoring methods
- AS 3580.19:2020 Methods for sampling and analysis of ambient air. Method 19: Ambient air quality data validation and reporting.

Note: Validation in AS 3580.19:2020 is verification in the context of NEMS.

Where reference is made from this Annex to specific sections of the NEMS document, the title is abbreviated and version stated, e.g. 'NEMS *Air Quality: Particulates* v1.0.0'. Where requirements and/or procedure in this Annex duplicate and possibly conflict with NEMS *Air Quality: Continuous Particulate Monitoring – Measurement of PM_{10} and $PM_{2.5}$ for Environmental Monitoring Purposes*, this Annex shall prevail.

Where reference is made from this Annex to specific sections of the Australian Standard, the title is abbreviated to its document number and version i.e. AS 3580.19: 2020. Where requirements and/or procedure in this Annex duplicate and possibly conflict with AS 3580.19 the most recent version of either document shall prevail.

1.2 Scope of this annex

This Annex contains processing guidance for airborne particulate matter measured by in-situ continuous instruments. It includes:

- PM_{10} and $PM_{2.5}$ (particulate data, collectively termed PM_x in this Annex)
- the supplementary variables required for accurate measurement of particulate concentrations

Note: Which supplementary variables are required is instrument and method dependent and tend to be of an operational nature e.g. inlet and/or enclosure temperatures.

- complementary measurements and observations that assist with interpretation of the PM_x data, including meteorological variables.

While focus of this Annex is on continuously monitored data from automatic stations that log to a device, manual measurements are performed when equivalency testing. This Annex therefore does include some data management guidance related to the manual sampling of particulates and laboratory analysis of those samples.

1.2.1 Exclusions

This Annex does not address other air contaminants e.g. gases, or processes and management of data associated with the manual collection of samples intended for chemical analysis e.g. for speciation or source attribution.

1.3 Variable names and nomenclature

In this annex, PM_x is used when guidance applies to both PM_{10} and $PM_{2.5}$ but PM_x must not be used as a variable name i.e. the particle size fraction shall be specified in the variable name associated with the data and metadata.

1.3.1 PM_x STP data

PM_x STP data are verified and edited PM_x values that have been adjusted to standard (air) temperature and pressure (STP), which for New Zealand are 0°C (273.15 K) and 1 atmosphere (1013.25 hPa) (see Appendix J.1).

Adjustment to STP may be performed:

- prior to data verification and editing, by:
- the PM_x instrument
- a datalogger separate from the PM_x instrument
- the data collection system (e.g. telemetry or 'smart' import), or
- following data verification and editing (see Section J 5.1.1).

The necessary supplementary measurements must be available (see Section J 1.6).

1.3.2 PM_x Equivalent data

PM_x Equivalent data are the values obtained by applying an equivalency relation (see section J 4) to verified and edited PM_x data i.e. 'cleaned' data adjusted to align with corresponding values obtained using the selected reference method.

Agencies that apply an equivalency relation shall identify the equivalency adjusted data as PM_x Equivalent to distinguish it from PM_x STP and as-measured data ('cleaned' or otherwise).

1.4 Units of measurement

All PM_x data must be recorded and stored as weight of material per volume of air, in units of $\mu g/m^3$ (NEMS *Air Quality: Particulates* v1.0.0 'The Standard').

Measured values of PM_x are sensitive to air (barometric) pressure and air temperature and must be adjusted to standard conditions for New Zealand (NEMS *Air Quality: Particulates* v1.0.0 Section 2.5) to be stored as PM_x STP data (see Section J 1.3.1).

Rounding of PM_x values, when needed, shall be according to the following rules:

- right-most digit *< 5, round down*

right-most digit ≥ 5, round up.

For example: 50.05 rounds up to 50.1; 50.04 rounds down to 50.0

Refer also to Sections:

- J 1.3.1 and J 5.1.1 (PM_x STP data)
- J 1.6 (Supplementary measurements)
- Appendix J.1 (Adjusting concentrations to STP).

1.5 Effect of data type

1.5.1 Data storage architecture

High-frequency continuous data must be stored in a system designed to support time-dependent functions, preferably an industry recognised time-series manager (TSM), so that data averaging (see Section J 1.5.2) and gap-handling (see Section J 1.5.3) are appropriately performed. These systems are also strongly recommended for long-term data collected as daily values to ensure efficient and accurate bulk data-handling and analysis, and metadata storage and retrieval.

There are advantages in storing the particulate data in the same system as is used for any supplementary measurements and the complementary meteorological variables (see Sections J 1.6 and J 1.7).

Regardless of the storage architecture, quality coded particulate data must be accessible via sector-specified application programming interfaces (API's) to facilitate data sharing and exchange (see Section J 10), e.g. publication to LAWA (Land, Air, Water Aotearoa).

1.5.2 Data averaging

The National Environmental Standards for Air Quality (NES-AQ) regulations require continuous monitoring from which to calculate 24-hour averages.

Instruments may output instantaneous values and/or the average over the recording interval depending on method. NEMS Air Quality: Particulates v1.0.0 Section 2.6 requires values that are averages to be timestamped at the end of each relevant interval. Such data must be stored as 'value in preceding interval' (histogram) data (see Section 1.1.3).

Averages timestamped at the start of each relevant interval (succeeding interval data (see Section 1.1.4)) are also possible from some instruments but are not NEMS compliant.

Ultimately hourly (on hour), daily (midnight to midnight, where midnight is end of day i.e. 24:00), and annual averages are required from the data. Values of these aggregated statistics are affected by the data type assigned to the higher frequency data (see Section J 5.1.3 and Appendix J.2). The correct data type for the recording method must be assigned to the stored data to ensure correct calculation of aggregated statistics.

Note: From version 2303.0, Hilltop Software includes a specific 'Air Quality Data' data type that enforces 'histogram' (average in preceding interval) representation on data stored with that data type and implements gap-handling consistent with the NES-AQ definition of "meaningful data". Relevant existing air quality data sources should be changed to this new data type.

A Data Comment (see Section J 7.3.4) shall be filed with each dataset that describes the measurement frequency, subsequent algorithms used to arrive at the recorded values, and includes explanation and justification of the data type assigned to the stored data.

1.5.3 Running or moving statistics

Some instruments may output hourly or higher frequency values that are running or moving averages updated at sub-intervals within the recording interval as sampling progresses e.g., an instrument returning values that are 15-minute moving averages updated every minute (after the first 15 minutes).

Note: Other terms used for this type of data include rolling, short-term, real time, or user-defined averaging.

- Some manufacturers state that this type of data should only be used for trend analysis and not for calculation of hourly averages, which the instrument may also report (Met One Instruments Inc, 2012).
- Most, if not all, time-series management (TSM) systems in use in NZ can store values that are moving averages, but only as either instantaneous data or fixed interval averages.
- Running or moving average data should therefore be collected and stored as separate time series and not be used for calculating the hourly averages required by the NES-AQ regulations.

Under the NES-AQ regulations, the data capture rate to ensure "meaningful data" (see Section J 1.5.4), and the number of permissible exceedances of air quality thresholds, are determined using a rolling consecutive 12-month period.

In practice however, calendar years are accepted for the determination of exceedances because they capture the entire winter season and are easier to understand (Ministry for the Environment, 2011).

Note: All TSM's in use in NZ are capable of reporting by calendar year or a rolling 12-month period either directly via existing tools or by creating simple user-defined scripts.

1.5.4 Gap handling

The NES-AQ amendments (2011) define "meaningful data" for the purposes of calculating and reporting averages in terms of acceptable rates of data capture and valid data retained, recognising that some gaps and invalid data are possible in any continuous record.

The data management system used for PM_x data must be capable of marking gaps, preventing interpolation across a marked gap, and accounting for gaps when reporting. For further information and guidance refer to Section J 3.8.

1.6 Supplementary data

Supplementary data are those required to be available with PM_x measurements for standardisation (see Section J 1.3.1), quality control (see Section J 2), and/or quality assurance (see Section J 8).

Requirements for quality control and quality assurance are method and/or instrument dependant and include instrument diagnostic data, where available, and/or one or more of:

- inlet and/or enclosure (housing) temperature (NEMS Air Quality: Particulates v1.0.0 Section 3.1)
- flow rate
- relative humidity

Measurement of PM_x STP (see Section J 1.3.1) requires concurrent at-site measurement of:

- ambient air temperature, and
- local true barometric pressure (not adjusted to sea level)

but the relevant supplementary variable may be approximated by:

- seasonal average ambient temperature for the sampling site
- average barometric pressure for the sampling site
- adjustment for altitude, if not at sea level and at-site barometric pressure is unknown.

Conversion to PM_x Equivalent (see Section J 1.3.2) involves gravimetric sampling to obtain reference measurements. The method requires balance room temperature and relative humidity to be controlled and recorded (see Annex D of NEMS Air Quality: Particulates v1.0.0).

Organisations may choose to permanently store continuous supplementary data as a supplementary rather than primary time series and therefore not apply all procedures in this Standard to that data. However, as a minimum, continuous supplementary data must be:

- identified in the PM_x Site/Initial Comment (see Sections 6.2.4.3 and J 6.3.1)
- described in the archived PM_x time-series Data Comments (see Sections 6.2.4.6 and J 6.3.4)
- inspected and edited for gross errors
- quality coded QC 200 if edited from the original and/or if quality reviewed (see Sections 3.1 and 7.2), otherwise retain QC 0, and
- accompanied by Data Processing Comment(s) if editing was applied (see Section 6.2.4.7).

PM_x STP data cannot attain a quality code higher than that achieved by any fully processed and quality coded supplementary record used for the adjustment to STP.

Note: The above requirement may reduce the quality code obtained from the quality coding matrix (see NEMS Air Quality: Particulates v1.0.0 Section 6.2 for the PM_x data

Note: If there is no NEMS Standard for a required supplementary variable there is no mechanism to assign a quality code higher than QC 200 to that supplementary data.

If the supplementary data used for separate adjustment to STP (i.e. not on-board the instrument) retains QC 0 as described above, QC 200 (quality unknown) applies to the processed PM_x STP record regardless of the quality code assigned by the quality coding matrix (see NEMS Air Quality: Particulates v1.0.0 Section 6.2) to the PM_x data.

Note: When adjustment to STP is done on-board the PM_x instrument it is assumed that instrument validation and calibration checks act to verify the supplementary as well as the primary PM_x data.

If supplementary values used for separate adjustment to STP are an approximation, as listed above, QC 300 (estimated from limited measured data) applies to the processed PM_x STP record regardless of the quality code assigned by the quality coding matrix (see NEMS Air Quality: Particulates v1.0.0 Section 6.2) to the PM_x data.

Note: The above requirements apply to the parent quality code. A 'higher' child code may still be used to indicate particulate source(s) once the parent code has been established.

If supplementary data are edited it may change dependent PM_x STP values, therefore:

- processing inter-dependent time series together is strongly recommended

- the impact on PM_x STP of editing one or more supplementary data series must be assessed, which will normally require the supplementary data be reviewed and/or processed first
- inconsistent adjustments between supplementary data and dependent PM_x STP record must be avoided
- editing of necessary supplementary data must be described and explained in a Data Processing Comment attached to the PM_x STP time series.

1.7 Complementary data

PM_x measurements are influenced by source activity (timing and particle combination) and weather. Complementary observations and measurements are those collected to aid interpretation of the PM_x data.

They may include:

- emission inventories and exposure assessments
- territorial authority records of number and location of domestic fires
- consent details including any emission offsets
- consent compliance self-reporting (ambient and incident)
- implementation (or lifting) of any bans e.g. outdoor fire bans, use of domestic open fires and/or wood burners
- meteorological observations, with their location if not co-located
- wind speed and direction, including occurrence of calm nights
- ambient air temperature, especially overnight minima
- relative humidity
- solar radiation
- rainfall
- air temperature profile (at two or more heights)
- presence of inversion layers
- pollen reports
- traffic volumes if a traffic site
- records of relevant anomalous events
- pollution complaints
- media reports
- webcam or CCTV footage
- earthworks, roadworks, and demolition
- open burning, large building fires, wildfire, or eruption
- celebrations involving fire or fireworks
- temporary obstructions to airflow at site
- power supply shortages and interruptions (directly impacting the site's operation and/or exacerbating use of domestic fires).

Store complementary meteorological variables collected as high-frequency continuous data in a system designed to support time-dependent functions, preferably an industry recognised time-series manager (TSM) and the same system as the high-frequency continuous air quality and supplementary data.

Store the observations and measurements as values in appropriately configured database fields in preference to within a document (whether paper or electronic) or as free format text (e.g. in a comment), especially if the data are or can be numeric.

Store synoptic observations and ad hoc information as timestamped Data Comments (see Section J 7.3.4) if there is no dedicated database facility for them. If using text fields, standardise the vocabulary to minimise data entry errors and search complexity.

Agencies may choose whether to quality code complementary observations and measurements.

1.8 Documenting the data management system

The local recording authority (monitoring/archiving agency) shall prepare procedures that expand on those in this Annex as needed to maintain adequate quality control and that relate to specific data management and storage systems they use.

1.8.1 Monitoring objectives and design

While these aspects are beyond the scope of NEMS to address, they should be formally recorded in one or more documents that are catalogued, filed securely, and retrievable as required, because they influence what is measured where, how, when, by whom, for how long, and for what purpose.

The document(s) should state the reasons for location and instrument selection(s), the variables to be measured at each site, which methods are to be used for each variable including any relevant Standards, and what additional analyses may be performed e.g. chemical speciation and source apportionment.

These documents can be associated with the data collected via a Site History Record (see Section J 1.8.2) and a Site/Initial Comment (see Section J 6.3.1) so the data are traceable to their purpose and monitoring design, which assists a future data user to assess fitness of the data for their purposes.

Screening surveys

Results from any screening survey (used to decide if more permanent monitoring is needed and where and how that monitoring should take place) should be included in the monitoring objectives and design documentation but the data obtained need not be verified or retained indefinitely.

Data obtained from screening surveys shall be clearly identified and stored separately so that they are not inadvertently used to determine regulatory compliance.

1.8.2 Site History Record

The Site History Record is a dedicated facility in which to store and maintain the site metadata for each site (see Sections 6.1 and J 7.1.1). It may be a paper or electronic document, file, or folder per site, or one or more database tables.

Each Site History Record should link to or reference the governing monitoring objectives and sample design (see Section J 1.8.1).

The Site History Record is summarised in the Site/Initial Comment (see Section J 7.3.1) and important changes at the site that are tracked in the Site History Record but relevant for an end user of the data are summarised over time in a series of Operational Comments (see Section J 7.3.3).

1.8.3 Forms

Field Record forms

Monitoring agencies should design, implement, and control Field Record forms (field sheets) for use when on site to record observations, field measurements, and instrument servicing actions. The form may be paper or electronic.

A Field Record form must include fields for site name, date and time of visit, and person(s) carrying out the inspection(s) and/or servicing and completing the form.

Note: An example field form can be found in Ministry for the Environment (2009) Appendix E (Routine check sheet for a BAM instrument).

Once completed these forms are an original record that must be secured and preserved as described in Section J 9.1.1 and be available and accessible when verifying PM_x data collected from the site.

Calibration and validation

Monitoring agencies should design, implement, and control forms for prompting actions and recording results of calibration or validation of in situ instruments and any equipment used for calibration, validation, or servicing of the in-situ instrument that itself requires calibration or validation. The forms may be paper or electronic.

Once completed these forms are a quality assurance record that must be secured and preserved as described in Section J 9.3 and be available and accessible as needed, when verifying PM_x data collected from the site. Completed forms may be stored and follow-up actions tracked in an asset management system.

These forms may be combined with the Field Record form, in which case they become an original record (see Section J 1.8.3 Field Record forms).

Note: An example calibration form can be found in Ministry for the Environment (2009) Appendix F (Maintenance and calibration record for an FH62 instrument).

Laboratory calibrations and validations, and curation of the associated records, are part of a laboratory's internal quality management system, which may be independently IANZ accredited. A monitoring agency's ability to view and query their records if

required when using an external contracted laboratory should be incorporated into the laboratory service contract.

Customisation of forms

Monitoring agencies should standardise the design and control the modification and distribution of forms to ensure all necessary information is captured, and to prevent use of unauthorised or outdated forms.

Customisation of forms is encouraged within their overall design, to minimise data entry time and errors in the field, and allow for variations in methods and instrumentation, but the process must be managed within a controlled document system. Each form should:

- have a unique identifier
- be subject to a formal approval process before being used, and
- be versioned to prevent old forms from being used inadvertently.

1.8.4 Method detection limits

Monitoring agencies should formally document any applicable method detection limits for methods they implement. These may be stated by the manufacturer, laboratory, relevant AS/NZS Standard or can be assessed using the statistical method suggested in AS 3580.19:2020 Section 3.5.

A limit of reporting (LOR) may be established by the agency, below which results are not reported. The LOR may or may not be statistically determined but shall not be less than the corresponding method detection limit.

1.8.5 Equivalency testing

The monitoring agency shall design, document, and implement suitable systems to collate, manage, store, and preserve all equivalency test records required and generated, as detailed in Section J 4.

Procedural documentation is provided in AS/NZS 3580.9.17 Methods for sampling and analysis of ambient air. Method 9.17: Demonstration of equivalence for ambient particulate matter monitoring methods under which equivalency testing must be undertaken (NEMS Air Quality: Particulates v1.0.0 Section 4.1).

Note: At time of writing this Annex, further guidance, tools, and requirements for the proposed standardised analysis and reporting and sharing of equivalency testing results (NEMS Air Quality: Particulates v1.0.0 Section 4) is pending publication of the PM Equivalency testing and co-location guide (in preparation), which will provide the most up to date tools and guidance for equivalency testing and co-location in NZ.

1.8.6 Original records

The monitoring agency shall define and formally document which records are considered original, and therefore required to be secured, preserved, and permanently retained (see Section J 9.1).

The following guidance modifies parts of Section 3.1.1:

- Supplementary data includes any required recording of inlet/housing environment controls, flow rate, and other instrument diagnostics (NEMS Air Quality: Particulates v1.0.0 Section 2.5). See also Section J 1.6.
- Conditions applicable to telemetered data when implementing automated quality control (QC) or quality assurance (QA) prior to manual data processing are extended to include smart data loggers, smart data import facilities, and the database in which original data as defined is stored.

  Note: Instrument servicing, validation, and calibration results are considered to be verification data for air quality particulate monitoring i.e. the absence of routine periodic independent measurements of samples of ambient air for direct comparison with instrument values is not considered to be "recorded without acquiring verification data" (see Section J 2).

- Performance of automated functions for QC and QA shall be regularly checked and the outcome of those checks documented and retained.

Manual gravimetric measurements

Results supplied by a laboratory are fully traceable within their internal system(s) and via the chain of custody (see Section J 6.1.1).

Laboratories may report to a representative number of significant figures (see Appendix 3) and/or may censor results to a method detection limit (see Section J 1.8.4) as may be required by their quality management system, but raw measurements (i.e. uncensored, unrounded) and their associated uncertainty of measurement are more useful when developing equivalency relations (see Section J 4).

If an agency opts to obtain raw laboratory data, the agency must also document (and implement):

- how it will ensure raw (uncensored, unrounded), and rounded and/or censored, versions of results are not muddled
- how the integrity of both versions will be managed if both are stored in the database
- how each version will be identified, and
- which version is to be used for specific purposes.

2 Quality Control

Quality control of particulate data measured continuously by an instrument is achieved by regular servicing, validation, and calibration of the instrument's component parts.

Independently measured 'reference' PM_x data are collected for equivalency testing (see Section J 4) but not routinely collected to verify a continuous record by direct comparison of PM_x values.

Validation of some instruments includes measurement of filters or foils of known particulate concentration or weight (see NEMS Air Quality: Particulates v1.0.0 Sections 3.2, 3.3 and 3.4).

Note: Validation in AS 3580.19 is verification in the context of NEMS. Validation in the NEMS context is included under calibration in AS 3580.19. Valid data in AS 3580.19 is analogous to reliable, representative measured data in NEMS.

The general process for quality control of continuous PM_x data is shown in Figure J 1, adapted from Figure 8,2 of the Good Practice Guide (Ministry for the Environment, 2009).

Quality control procedures should be undertaken regularly within the shorter of:

- the reporting cycles required by the NES-AQ regulations, or
- the period that samples are retained by the laboratory for retesting if required (see Section J 6.1.1).

2.1 Quality coding matrix

The quality code attached to any PM_x value must reflect its quality at the time the value was acquired. For this reason, the quality coding matrix (see also Section J 7.2.1) should be:

- completed when a site begins recording, then
- reviewed and updated:
- at each subsequent site visit, or
- as the first quality control task of data processing.

Completed matrix assessments, whether done in the field or the office, form part of the records of data processing that must be preserved and indefinitely retained (see Section J 9.2.3).

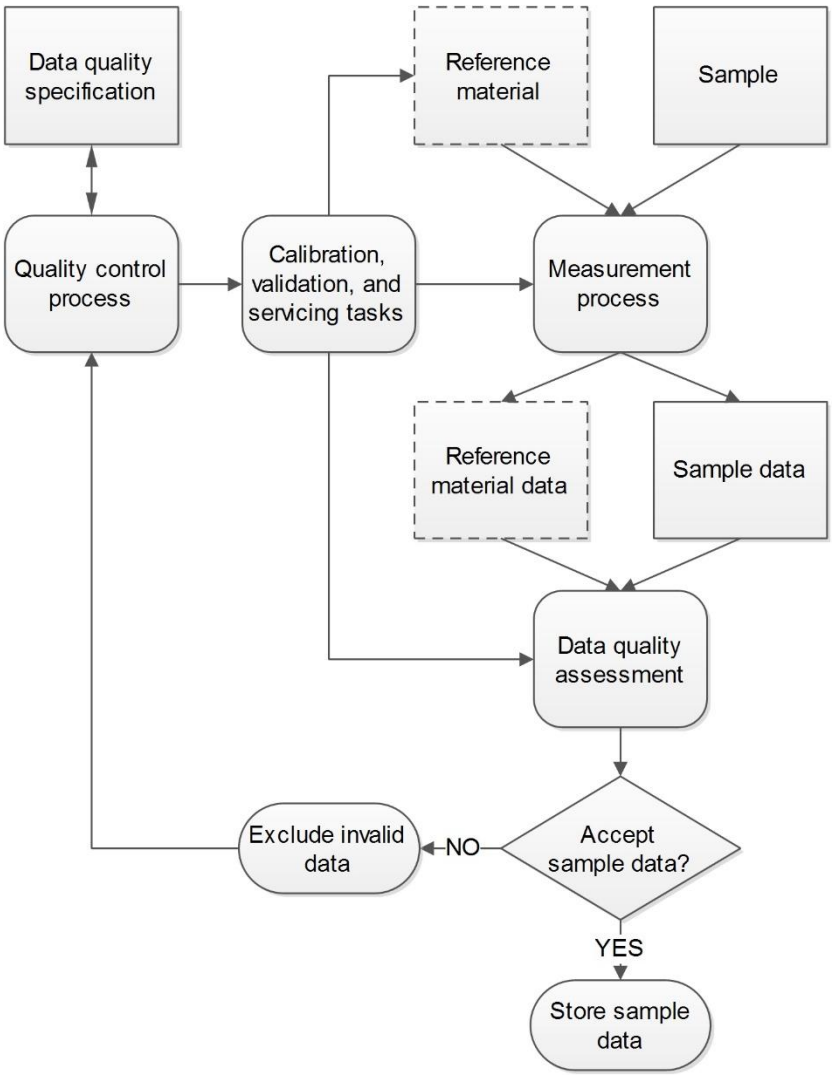


Figure J 1 - The general process for quality control of continuous PM_x data, adapted from Figure 8.2 of the Good Practice Guide (Ministry for the Environment, 2009).

2.2 Additional metadata required

General requirements for metadata are set out in Section 6.1. The following additional metadata, as applicable to the site and deployment, and additional to any required supplementary data (see Section J 1.6), shall be available when verifying air quality particulate data:

- site details (see NEMS Air Quality: Particulates v1.0.0 Section 5.8.1)
- instrument details (see NEMS Air Quality: Particulates v1.0.0 Section 5.8.2)
- deployment details, including, but not limited to:
- characteristics of the monitoring site (see NEMS Air Quality: Particulates v1.0.0 Sections 1.2 and 1.3)
- type of housing and its temperature and humidity controls (see NEMS Air Quality: Particulates v1.0.0 Section 2)
- inlet location(s) (see NEMS Air Quality: Particulates v1.0.0 Section 1.3.9)

- sampling and recording regime, and
- operational requirements and standards (see NEMS Air Quality: Particulates v1.0.0 Section 3)
- instrument performance history, including:
- calibration, validation, and maintenance task records (NEMS Air Quality: Particulates v1.0.0 Section 3.2)
- records of the most recent annual service (NEMS Air Quality: Particulates v1.0.0 Section 3.3)
- results of routine service checks (NEMS Air Quality: Particulates v1.0.0 Section 3.2)
- results of screening checks (see Section J 2.3.1)
- any complementary observations and measurements (see Section J 1.7).

These metadata must be verified, and permanently archived with all other metadata as described in Section 6.

2.3 Plots and comparisons

2.3.1 Screening checks

Routine visual screening of PM_x data is recommended either daily, if telemetered, or immediately after each download and preferably while on-site if manually collected (NEMS Air Quality: Particulates v1.0.0 Section 5.5).

Potential issues that may be identified and therefore addressed promptly include:

- human error
- instrument faults
- power problems
- interference or disturbance
- data spikes
- system failure leading to missing record.

Graphical features that may indicate recording problems are listed in AS 3580.19:2020 Section 2.5.1. Examples of screening criteria for PM_x and meteorological variables can be found in AS 3580.19:2020 Tables 2 and 3.

If screening checks are not done at time of data collection they should be completed as the next step when data processing, after review of the quality coding matrix score (see Section J 2.1).

Records of routine screening shall be maintained and be available for subsequent manual data verification and editing.

2.3.2 Comparisons

Use comparisons to identify anomalies in recorded PM_x data.

Compare the particulate data with any logged instrument diagnostics and/or operational data e.g., housing humidity and temperature, and inlet temperature where these must be controlled within specified limits for the instrument.

Compare PM_{10} with $PM_{2.5}$ if both are recorded at a site. Provided the sampling conditions are the same for both fractions, the $PM_{2.5}$ concentrations should always be less than the concurrent PM_{10} concentrations. Co-location techniques may be used to relate then compare PM_{10} and $PM_{2.5}$ if sampling conditions are not the same (see Section J 4).

If multiple contaminants are being monitored their data may assist with verifying PM_x data.

For example: High levels of NO_2 and possibly CO_2 in association with a high level of PM_{10} at a roadside are probably a genuine event (Ministry for the Environment, 2009).

Air particulate concentrations are highly seasonal and often have daily and weekly temporal patterns consistent with season. Anomalies may therefore also be identified by comparing data year on year and considering time of day and year.

2.3.3 Between-station comparisons

Use comparison with meteorological data from one or more stations to check validity of any unusual timing or range of PM_x values, e.g. elevated concentrations due to an unexpected point source carried by the wind, or a temperature inversion.

If there are multiple air quality stations in the same airshed and/or general location up to a few kilometres apart there may be sufficient similarity between their PM_x data to verify patterns and range of the data. Comparison may reveal calibration drift or confirm apparent outliers as valid data.

2.4 Reliability of measurements

NEMS Air Quality: Particulates v1.0.0 requires use of continuous instruments (i.e. not filter-based and requiring manual removal and weighing). NES-AQ Schedule 2 lists approved instruments for PM_{10} monitoring. Optical instruments are not certified.

Some instruments require housing internal temperature to be maintained within specified limits to accurately measure PM_x concentrations, in which case the housing internal temperature must be logged (NEMS Air Quality: Particulates v1.0.0) and collected as supplementary data (see Section J 1.6). For these instruments:

- If the housing internal temperature is not maintained within the specified limits, all PM_x data collected while temperature is up to 20% outside those limits shall be assigned QC 500 (fair)
- If the housing internal temperature is not maintained within the specified limits, all PM_x data collected while temperature is more than 20% outside those limits shall be assigned QC 400 (compromised).

- If housing internal temperature needs to be controlled but is not monitored and recorded, then the maximum quality code able to be assigned to the PM_x data is QC 200 (unknown quality).

2.4.1 Calibration and validation

Air quality monitoring instruments should be calibrated in-situ, but it is resource intensive so rarely done; operators rely instead on the manufacturer's standard calibration (Coulson et al, 2021).

Most air quality monitoring instruments need validating at regular intervals to minimise baseline (see Section J 3.4.1) and amplitude (span) drift (see Section J 3.4.2), and to check the linearity of the instrument's response (see Section J 3.4.3).

Meteorological instruments and the equipment used to perform validations and calibration of the air quality instrumentation also require regular routine validation, and calibration if validation fails (Ministry for the Environment, 2009).

Servicing and calibration schedules, and acceptable validation tolerances for air particulate monitoring are set out in the relevant AS and AS/NZS standards. These schedules are summarised in NEMS Air Quality: Particulates v1.0.0 Section 3 (Instrument Operation and Maintenance). Frequency of checks varies from monthly to 5-yearly depending on the instrument type and/or item of equipment.

The most common aspects requiring regular, routine validation and/or calibration are:

- air flow rate and flow sensors with calibrated flow meter (NEMS Air Quality: Particulates v1.0.0 Section 3.2.1)
- temperature and pressure sensors
- Particle mass zero and span of BAM using calibrated foils (NEMS Air Quality: Particulates v1.0.0 Section 3.2.2)
- TEOM/FDMS mass transducer (NEMS Air Quality: Particulates v1.0.0 Section 3.2.2)
- barometric pressure
- gravimetric balances (for manual weighing of filter-based samples (NEMS Air Quality: Particulates v1.0.0 Annex D).

Timeliness and outcome of instrument checks and maintenance are assessed via the quality coding matrix (see Section J 7.2.1). The resulting quality code applies from the date and time of the previous assessment unless a specific more recent event is identified as having caused the validation fail and/or need for maintenance and/or re-calibration.

Note: The quality code assigned may change if data are subsequently edited.

A servicing, maintenance, validation, and calibration history shall be maintained, be available and accessible during data processing, and be preserved indefinitely (see Section J 9.3.1).

2.4.2 Reference values

Reference methods for PM_x are gravimetric using USEPA or EU certified reference samplers (filter-based). Instruments utilising other measurement methods have been granted equivalent status by these organisations.

PM_x data from continuous instruments are not routinely verified against gravimetric reference samples.

Gravimetric reference measurements are obtained when equivalency testing (see Section J 4 and NEMS Air Quality: Particulates v1.0.0 Section 4). If equivalency testing is undertaken, factors derived may be used to adjust PM_x instrument measurements to PM_x Equivalent values (see Section J 1.3.2).

Note: Equivalency testing as required to be implemented by NEMS Air Quality: Particulates v1.0.0 assumes the method comparison is independent of location, however "performance of different particle instruments is known to differ by location, depending on source types and meteorology" (Coulson et al, 2021).

A TEOM instrument can be used without FDMS if co-located (see section J 4) with a gravimetric monitor for at least one year then adjusting the TEOM record by the derived adjustment factor(s) (Ministry for the Environment, 2009).

2.4.3 Uncertainty

Calculation of associated uncertainty of measurement (UoM) is required for all measured PM_x data (NEMS Air Quality: Particulates v1.0.0 Section 5.7.3).

Note: Standard methods and calculation templates are under development.

The TSM or other database in which the PM_x data are stored must have the ability to store PM_x values with their UoM.

Note: AS 3580.19:2020 uses uncertainty to assess if PM_x data should be invalidated due to non-conformance with operational criteria e.g. whether error in a temperature sensor that is controlling flow rate is sufficient to cause unacceptable PM_x measurement uncertainty.

2.5 Deviation tests

2.5.1 Deviation over time

Monitoring deviations over time, e.g. by control or run charts or similar is not possible because PM_x reference values are not routinely obtained (see Section J 2.4.2).

Periodically review the servicing and validation history (see Section J 2.4.1) for any trends to assist with diagnosis of faults and indications of developing and as-yet undetected problems.

2.5.2 Departure from expected values

Aspects to consider when assessing departure from expected values include:

- characteristics of the instrument type
- history of the specific instrument's performance
- likelihood of excessive or sudden changes in concentrations with respect to location and/or timing
- weather conditions, and
- knowledge of pollution events.

If measuring PM_{10} and $PM_{2.5}$ at the same site, with the same model of instrument and the same sampling conditions (see NEMS Air Quality: Particulates v1.0.0 Section 2.4), $PM_{2.5}$ values should always be less than the simultaneous PM_{10} values. If they are not, further investigation is needed, followed by action to confirm, caution, adjust, or discard values as appropriate.

Note: $PM_{2.5}$ is mostly from combustion sources. PM_{10} can include other sources such as dust, pollen, and sea salt.

Monitor instrument zero checks to detect baseline drift (see Section J 3.4.1). Assess the combination of zero and span checks to detect amplitude (span) drift (see Section J 3.4.2). BAM and optical instruments are especially prone to amplitude drift.

2.5.3 Automation

Checks on timeliness of servicing and validations may be automated and configured to update automatically with new data from the field.

If validation thresholds are implemented in an electronic field application, they can provide immediate instrument performance information while at site.

3 Potential Errors and Recommended Editing

3.1 Sources of errors

The following potential issues are identified in Bluett et al (2007):

Bias (under-recording) compared to gravimetric results for TEOM(40) and BAM instruments despite being USEPA equivalent designated methods.

TEOM(40) and BAM are influenced by ambient air temperature.

TEOM(40) is influenced by windspeed.

TEOM-FDMS is considered unbiased and is relatively unaffected by wind speed and relative humidity. Volatile loss is accounted for in the measurement method.

Gravimetric methods, and methods that utilise a heated inlet manifold (e.g., BAM and TEOM) can under-record due to volatilisation of a portion of the aerosol sample. Degree of effect varies with site, ambient air temperature, and emission composition. Volatile loss is expected to vary in proportion with the:

- difference between ambient and inlet temperatures, and
- time collected material remains on the filter before being measured.

The relationship between mass and its surrogate measure e.g. beta attenuation, may vary depending on particulate composition.

Moisture/high relative humidity and static effects can make measurements unstable and result in negative values (not applicable to optical sensors).

Inappropriate or over-burdened filters, or improper conditioning of filters used in gravimetric samplers.

Deficiency or fault in flow rate control (flow rate is used directly for determining sample concentration from mass of particulate ÷ volume of air)

Higher proportion of background noise in BAM instrument response over shorter recording periods e.g. 10-minute to 30-minute averages.

The following sources of equipment maintenance issues are identified in Ministry for the Environment (2009) and Ministry for the Environment (2011, updated 2014):

- security
- air-conditioning system
- pneumatics
- electronics
- sample inlets and filters
- vacuum pumps and pump filters
- data logger and instrument timekeeping
- decay of the radioactive source (BAM stations)
- faulty heating of inlet air causing moisture-induced instability
- data logger storage overrun.

Some optical instruments have a poor response to traffic emissions due to the particle size from vehicle emissions being small enough to be effectively invisible to the optics (Coulson et al, 2021).

3.2 Unintended offset or incorrect change of offset

Analogue sensors usually require an offset and multiplier to be programmed into the data logger to convert sensor signal to measurement units. If a mistake is made calculating or entering the offset the data collected are biased by the amount of error in the programmed offset.

Note: An error in the multiplier also affects the value of the offset to be applied.

Instrument zero checks and/or inspection of a plot of the data can identify if the instrument has developed an unintended or incorrect offset. Investigate probable cause and decide if the offset is a sudden change that may be adjusted by shifting the data by a

constant amount as in Figure J 2 or is gradual and due to baseline drift (see Section J 3.4.1).

Note: Some instruments utilize an offset to allow recording of slight negative values, within the noise of the instrument output, when concentration approaches zero (AS 3580.19:2020).

A correctly applied offset adjustment should eliminate any improbable steps in the data.

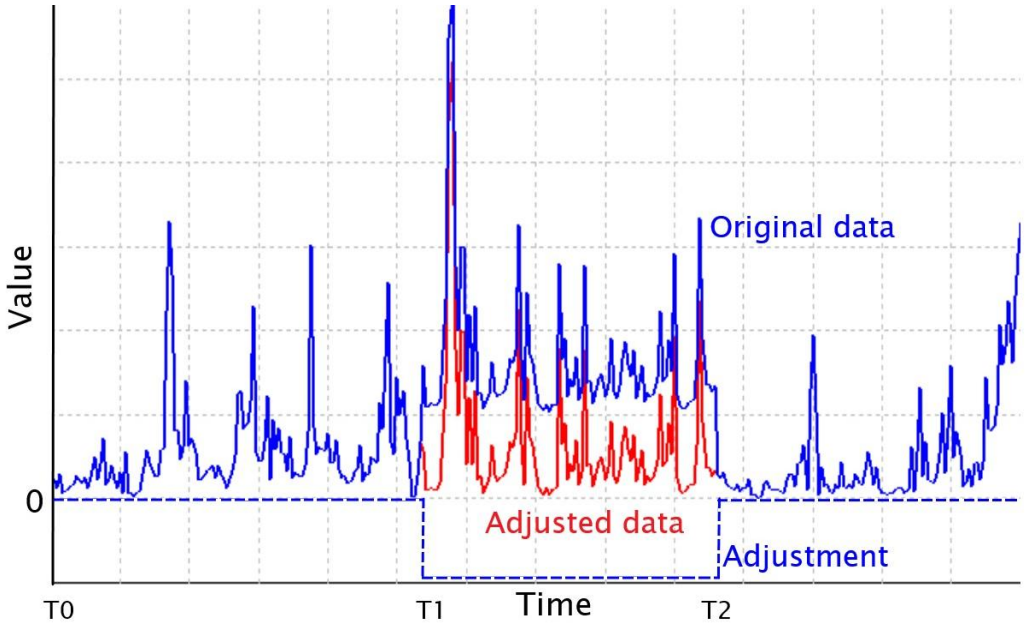


Figure J 2 - An example of a period of PM_{10} data offset by a constant amount between T1 and T2 (blue line) with the adjusted data (red line) and showing the adjustment applied (dotted line).

Table J 1 – Guidance for resolving an unintended offset or incorrect change of offset

Guidance for resolving an unintended offset or incorrect change of offset		see Section(s)
Issue(s)	A period of data is biased by a constant or near-constant amount.	J 3.2
Evidence	Baseline is 'offset' from adjacent data by a constant or near-constant amount, observable in a data plot and/or identifiable at site from zero/span checks.	Fig. J 2 J 3.2 J 2.3 & J 2,5.2 3.6
Solution(s)	Apply an offset shift to the biased period.	4.2
Metadata	If the correction required is fully traceable, quality code is unaffected, but a Transformation Comment is required. Otherwise, 'minor' (QC 500) or 'significant' (QC 400) modification criteria apply and a Data Processing Comment explaining identified cause and details of the amount and period of adjustment is required.	J 7.3.6 6.2.4.8 6.2.3 J 7.3.5 6.2.4.7

3.3 Steps in the data

Steps in the data may result from:

- an unintended offset or incorrect change of offset (see Section J 3.2)
- a change of instrument (see Section J 3.3.1)
- instrument cleaning (see Section J 3.3.2)
- instrument recalibration
- moving, disturbance, or obstruction of the inlet
- moving the instrument to a different location
- a fault with, recalibration, or replacement of a supplementary sensor
- a change in the equivalency relation (see Section J 3.3.3)

Cause of the step dictates how the data should be repaired.

Adjustments applied to the recorded data must reflect assumptions made about the nature, timing, duration, and magnitude of the error.

The appropriate adjustment may be:

- an offset shift (see Section J 3.2)
- a linear (baseline) drift adjustment (see Section J 3.4.1)
- a proportional amplitude drift adjustment (see Section J 3.4.2), or
- a more complex and likely non-linear calibration drift adjustment (see Section J 3.4.3).

3.3.1 Instrument replacement and configuration

If the new instrument is a different type, brand, or model, and/or it cannot be reinstalled in the same location, describe the change in an Operational Comment (see Section J 7.3.3) that references relevant Equipment Comment(s) (see Section J 7.3.2) as needed. If the data subsequently collected are offset from data previously collected as a result of the change, leave the step-change in the data but identify and explain it in a Stationarity Comment (see Section J 7.3.7).

If the step coincides with a change of instrument or recording configuration where settings must be manually entered, the problem may be due to a data entry mistake. It may be possible to recover the correct data (see Section J 3.6), which should eliminate the step. If there is no data entry mistake, assume some form of drift in the prior data and address it (see Section J 3.4).

If the step is attributable to an issue with necessary and/or diagnostic supplementary data (e.g. temperature and/or barometric pressure, or flow) it should be addressed in the supplementary data and dependent PM_x values recalculated (see Section J 1.6). If recalculating PM_x values is not possible, the recorded PM_x data may be adjusted directly,

assuming an offset (see Section J 3.2) or some form of drift (see Section J 3.4), but quality code cannot be higher than QC 400 (compromised).

If none of the above situations apply and calibration and configuration of the replacement instrument is confirmed on installation, assume some form of drift in the replaced instrument and adjust the prior data accordingly (see Section J 3.4).

3.3.2 Interference, obstruction, and disturbance

Physical interference may be due to the actions of people or animals on or about the inlet. Site maintenance, self-cleaning mechanisms, and servicing activities may also disturb ambient conditions.

The PM_x record may step up or down over one or two recording intervals, then recover when the interference moves or dissipates, or conditions equilibrate. Normal conditions are expected to resume within a few hours. Data may be offset for the duration of the interference.

Use instrument diagnostics supplementary data (see Section J 1.6) where available to assist with identifying when disturbance of ambient measurement conditions may be the cause of the step(s).

The effects of short-duration interference or disturbance may be treated as spikes (see Section J 3.5). Otherwise, adjust for offset as shown in Figure J 2 or apply a brief linear drift adjustment that is the reverse of that shown in Figure J 3 i.e. ends with a zero adjustment.

3.3.3 Instrument cleaning

Cleaning a sensor may result in a step in recorded supplementary and/or PM_x data. Unless a specific and more recent event is identifiable, assume the sensor's condition deteriorated gradually over the elapsed time since it was last cleaned and apply an appropriate drift adjustment (see Section J 3.4) to eliminate the step.

If supplementary data are adjusted, recalculate the dependent PM_x values. Quality code of the recalculated PM_x values is determined by the quality code of the supplementary data (see Section J 1.6).

3.3.4 Application of equivalency relations

Despite the objective of equivalency being to adjust all data to a common instrument-independent reference, because equivalency relations are empirical and not required to be site-specific (NEMS Air Quality: Particulates v1.0.0 Section 4) it is possible for a step to be introduced into the PM_x Equivalent time series when an instrument is replaced with a different type unless a co-location relationship is first derived and applied for the site so that only one equivalency relation need apply to all the PM_x record.

There is a trade-off between the additional uncertainty introduced into the PM_x Equivalent record by applying successive empirically derived transformations and a possible disruption of stationarity at the time of the change of instrument as a

consequence of applying the equivalency relation for each instrument (replaced and replacement).

Whichever approach is taken a suitable combination of Transformation (see Section J 7.3.6), and Stationarity (see Section J 7.3.7) comments shall be filed to adequately explain provenance of an PM_x Equivalent time series and alert to any additional uncertainty and/or anomalies introduced.

Table J 2 – Guidance for resolving steps in the data

Guidance for resolving steps in the data		see Section(s)
Issue(s)	Sudden change between successive values that disrupts continuity of the usual pattern. Prior data may be biased.	J 3.3
Evidence	An action is known to have occurred (instrument service or change (including supplementary sensors), obstruction or shift of inlet, or change of location or equivalency relation). Trace of data when plotted steps suddenly up (or down).	Fig. J 2 & J 3 J 3.3 J 4 3.6
Solution(s)	No adjustment if due to change of instrument, equivalency relation, or location (stationarity is disrupted). Transform to reverse wrong configuration then apply correct configuration if error is traceable and reversible. Adjust supplementary data then recalculate dependent PM_x values if issue is with supplementary measurements. Otherwise, resolve short-duration bias as spikes, or constant bias as a data offset, or assume and adjust for drift.	J 3.3 J 3.5 J 3.2 J 3.4
Metadata	Operational Comment required for change of location. Equipment Comment required if instrument type, configuration, or specification changed. Transformation Comment required when equivalency relations are applied. Stationarity Comment required at step. Quality code unaffected if fully traceable configuration error correction but a Data Processing Comment is required. Data Processing Comment required for adjustment of supplementary data. Refer to data offset or drift guidance as applicable.	J 7.3.3 J 7.3.2 J 7.3.6 J 7.3.7 J 7.3.5 6.2.4 J 3.2 J 3.4

3.4 Drift

3.4.1 Baseline drift

Baseline drift is identified by instrument zero checks and/or by inspection of a plot of the data.

Baseline drift may be linear or non-linear with time and is not value dependent, i.e. all values are offset by an amount (positive or negative) that increases in magnitude proportional only with time until cause is resolved and/or true zero is re-established.

If the baseline drift is linear with time, adjust affected data by applying a linear drift adjustment (also known as a 'ramp correction') (see also Section 4.4).

Apply the adjustment from the time of the event likely to have initiated the drift e.g. power cut or instrument malfunction, or if no identifiable event, from the most recent previous check or calibration at which the instrument was deemed to be operating correctly.

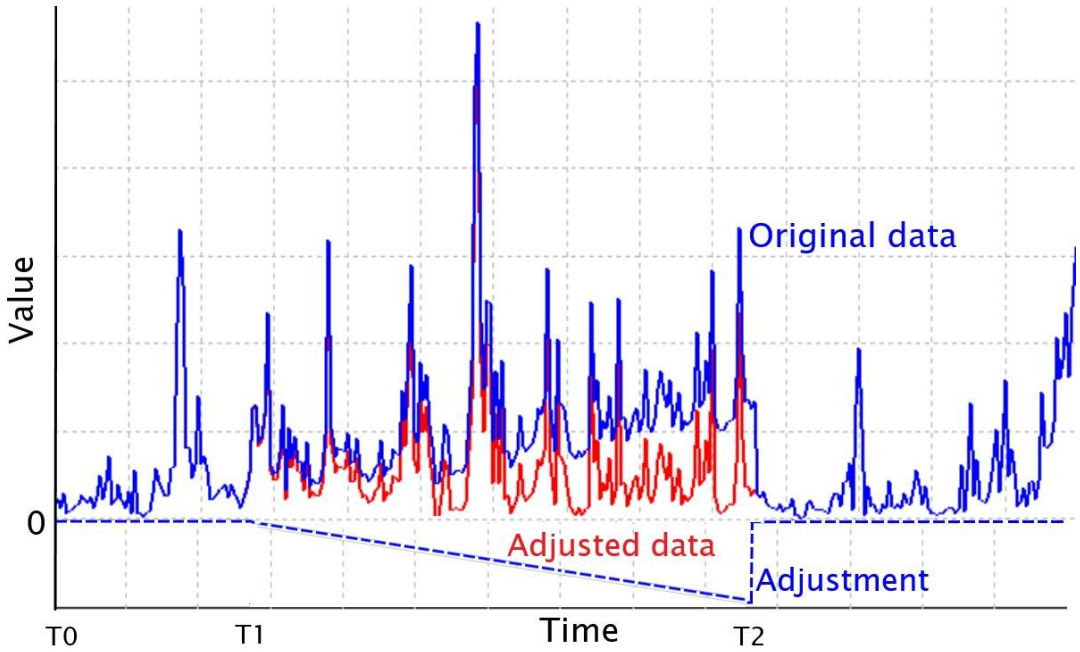


Figure J 3 - An example of a period of PM_{10} data experiencing linear baseline drift between T1 and T2 (blue line) with the adjusted data (red line) and showing the linear drift adjustment ('ramp correction') applied (dotted line).

Non-linear baseline drift with time may be adjusted using suitable non-linear baseline drift adjustment tools or may be approximated by a sequence of small, short-duration linear baseline drift adjustments over time, but these must be applied carefully to avoid distorting the record. The linear approximation is acceptable when daily instrument zero checks are performed, and for data from instruments with high frequency self-zeroing mechanisms.

3.4.2 Amplitude (span) drift

Amplitude drift (also known as span drift) can occur in very dirty air. The instrument's effective range decreases (or possibly increases) with time i.e. the drift progressively alters the scale of the data.

Unless severe, the drift may not be apparent in a plot of the data but can be detected from regular instrument zero and span checks. The instrument's response is usually adjusted while on-site if a zero or span check falls outside expected tolerance for the instrument. Any adjustment of the preceding data for drift should therefore end at the

time of that instrument adjustment and eliminate any step in the data created by the resetting of the instrument.

Note: Two-point checks cannot diagnose loss of calibration linearity. At least three check points within the instrument's range are necessary.

A simple form of amplitude drift affects each value by a factor that progressively increases or decreases linearly with time (see Section 4.5) and can be compensated by applying a linear %value drift adjustment as illustrated in Figure J 4 using the function given in Section 4.5.5.

Apply the adjustment from the time of the event likely to have initiated the drift e.g. power cut or instrument malfunction, or if no identifiable event, from the most recent previous check or calibration at which the instrument was deemed to be operating correctly.

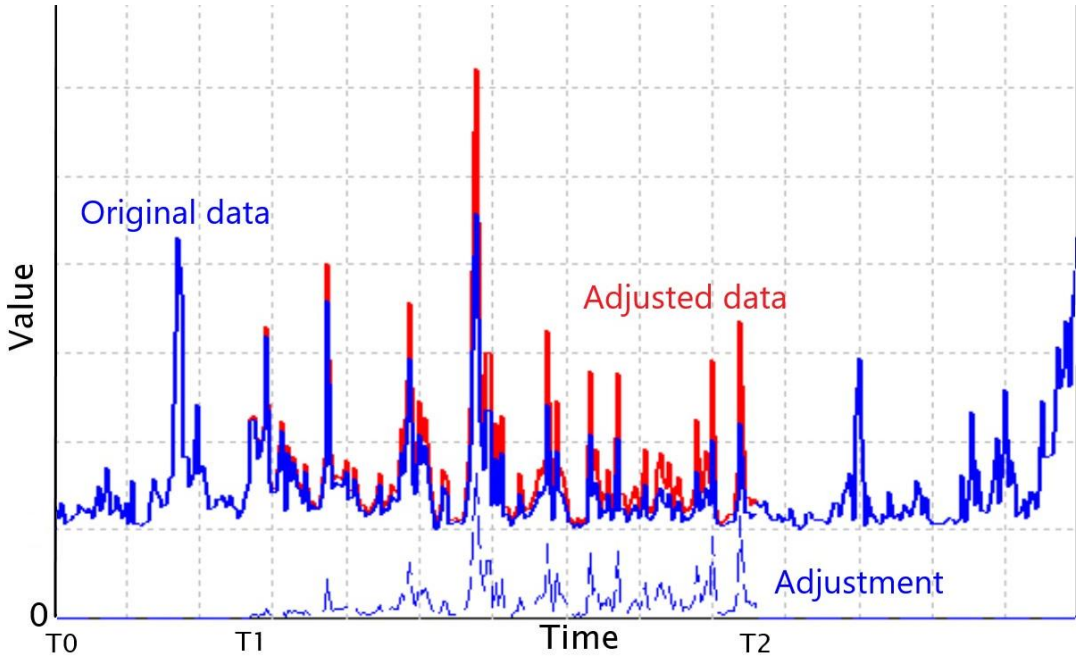


Figure J 4 - An example of a period of PM_{10} data experiencing linearly proportional amplitude (span) drift between T1 and T2 (blue line) with the adjusted data (red line) and showing the adjustment applied (dotted line), which increases linearly with time from 0% of the original value at time T1 to 100% of the original value at time T2.

3.4.3 Calibration drift

The response of most analysers tends to drift over time. If the drift involves some loss of linearity the simple drift adjustments described in Sections J 3.4.1 and J 3.4.2 are not appropriate. Instead, the instrument's overall response and calibration must be considered.

An instrument's response and/or calibration curves are confirmed or updated at each instrument check or calibration.

Affected data may be adjusted by applying a non-linear transformation to the values as determined from results of each routine validation (instrument calibration check). The

transformation may be applied as one or more equations, or by a look-up function, or as a rating curve.

Using rating curves

Response and/or calibration curves can be applied to data using a TSM's rating engine. Each curve is assigned a period of applicability (which may be open-ended) and can be gradually introduced (see Section 4.10).

For example: The adjustment shown in Figure J 4 could be achieved by smoothing (or phasing, transitioning, or blending, depending on the TSM software) between a rating defined as y' = y at time T1 and a rating defined as y' = 2y at time T2.

Because ratings may be curves, the TSM's rating engine can therefore be used to compensate for calibration drift when the calibration relations or the nature of the drift are not of a simple linear form.

Ratings are stored in and applied within the TSM, so their history is maintained by the TSM and changes to the data are automatically applied and traceable but do not overwrite the original data.

Note: Rated data are virtual unless specifically written to the database via a separate transformation process.

Ratings can be applied as an instantaneous change i.e. not gradually introduced, allowing the rating engine to also adjust for a sudden offset (see Section J 3.2).

For example: The adjustment shown in Figure J 2 could be achieved by applying a rating defined as y' = y – c at time T1 then a rating defined as y' = y at time T2.

For guidance on procedure for constructing ratings and associated metadata requirements see NEMS Rating Curves. For technical guidance on data entry, storage, and application of rating curves consult the relevant TSM user documentation.

Note: The scope of NEMS Rating Curves is limited to stage-discharge relations, but its procedural elements can be applied more generally to the calibration and application of other relationship models.

Note: Sections 8.4.1 and 8.4.2 of the Good Practice Guide (Ministry for the Environment, 2009) describe and illustrate the process of applying and transitioning between calibration curves when implemented as ratings (see Sections 4.9 and 4.10) but Section 8.4.2 mistakenly calls the process 'ramp correction'. Ramp correction is a TIDEDA (NIWA, 2000) term carried into Hilltop Software, that has become synonymous in NZ with linear baseline drift adjustment (see Sections J 3.4.1 and 4.4). A ramp correction as implemented in TIDEDA and Hilltop Software cannot adjust for non-linear baseline drift or amplitude (span) drift but can apply offset and/or time shifts (see Sections 4.2 and 4.3) and adjust for time drift (see Section 4.6). Care is needed when using the ramp correction tool (or equivalent in other TSM's) to not inadvertently adjust time when adjusting values.

Table J 3 – Guidance for resolving drift

Guidance for resolving drift		see Section(s)
Issue(s)	Measured values are biased by an increasing amount or proportion over time.	J 3.4
Evidence	Instrument zero and span checks, validation results, and coincident steps in the data. Drift may also be discernible in a plot of the data as trending baseline and/or unexpected gradual change in range.	Fig. J 3 & J 4 J 3.4 J 2.3.1 J 2.4.1 3.6
Solution(s)	Apply linear drift adjustment for linear with time baseline drift. Appy non-linear drift adjustment or multiple short-duration linear drift adjustments for non-linear baseline drift. Apply % of value linear drift adjustment for amplitude drift. Apply non-linear transformation(s) if loss of calibration linearity, by equation(s), function(s), or rating curve(s).	J 3.4 4.4 Fig. J3 & J4 4.5 4.9 & 4.10
Metadata	QC 500 or QC 400 depending on 'minor' or 'significant' change, and Data Processing Comment required explaining identified cause of drift and details of each drift adjustment applied (type, amount, and period of adjustment). QC 400 and Data Comment if loss of linearity is detected but transformation is not possible.	J 7.2 6.2.3 J 7.3.5 6.2.4.7 J 7.3.4 6.2.4.6

3.5 Spikes and noise

Treatment of spikes is determined by their association with negative values. If associated with negative values, see Section J 3.5.2. If not associated with negative values, invalidate any values that, with reasonable and documented justification, are considered spurious (see Section J 3.8.1).

Note: known or suspected cause for the spike in a Data Processing Comment (see Section J 7.3.5). Multiple instances of the same cause and treatment may be combined into a single Data Processing Comment timestamped at the first instance, to avoid overwhelming the commenting facility.

Noise is often due to measurement instability. TEOM instruments may exhibit noise when subject to vibration or when filters become significantly loaded. Provided noise is random it will have little, if any, effect on averaging and does not need to be mitigated. However, if the noise includes negative values see Section J 3.5.2.

3.5.1 Housing environment

Instruments sensitive to temperature and humidity require housing conditions and/or inlet temperatures to be controlled for the instrument to produce accurate and stable

measurements. Inadequate control, including power failure to the air conditioner or heating elements, will likely cause spikes and/or noise in the data until acceptable conditions are restored.

Use the records of instrument housing conditions (see NEMS Air Quality: Particulates v1.0.0 Section 3.1) to evaluate suspected spikes and noise in the PM_x data.

3.5.2 Negative values

Large negative spikes from an optical instrument are almost certain to be due to instrument fault and if so, shall be invalidated (see Section J 3.8.1).

Large spikes related to volatile moisture changes e.g. from BAM instruments, may be negative values only but may be high positive followed by large negative values. Outliers can significantly affect calculation of averages so unless the positive and negative pairs do sum to near zero, retaining them will induce some bias, therefore all large spikes, positive and negative, related to volatile moisture changes shall be invalidated (see Section J 3.8.1).

Noise that is within the uncertainty of measuring zero concentration may include negative concentrations.

Note: This is common for BAM and TEOM stations when measuring low concentrations and moisture is changing rapidly.

- If only the negative values are changed (to zero) or removed from the data, the distribution of the data is altered and becomes biased by the positive value noise.
- Applying an offset to move all values to zero and above (i.e. zero becomes the minimum value) introduces even greater positive bias.
- Either all values within the uncertainty range of zero must be retained or all removed to avoid this bias, assuming the distribution of the noise around zero concentration is random.
- In terms of ensuring sufficient data for NES-AQ averaging, retaining values is preferred.
- Removing values creates a censored dataset (see Section 1.1.5) where the limit of reporting is the upper bound of the uncertainty range for the measurement of zero concentration. This may be a more preferable form of the data for some end users.

Acceptable tolerances for small negative values caused by moisture can be in the range of 0 to -5 $\mu g/m^3$ when the true mass concentration is very low (0–5 $\mu g/m^3$) for both PM_{10} and $PM_{2.5}$ (see the relevant AS Standard for the measurement method).

Hourly average concentrations should not be routinely lower than -10 $\mu g/m^3$ and concentrations less than this should be invalidated (AS 3580.19:2020), (see Section J 3.5).

Note: The above tolerances may differ from those contained in some instrument manuals.

Table J 4 – Guidance for resolving spikes and noise

Guidance for resolving spikes and noise		see Section(s)
Issue(s)	Spurious values can bias averages. Noise is indicative of measurement instability, and possible bias if not random. Negative values may occur although physically not possible.	J 3.5
Evidence	Isolated value(s) significantly different from adjacent values, observable in a plot of the data. Presence of negative values. Variation between adjacent values is larger than is normal or expected from resolution of the instrument. Records of instrument housing conditions.	J 3.5 Fig. 30 Fig. 31
Solution(s)	Invalidate positive spikes that are justified spurious, and large spikes (both positive and negative). Use instrument housing condition records to evaluate measurement stability when sensitive to temperature and humidity. Invalidate noise that produces hourly averages routinely < -10 µg/m^3.	J 3.5 J 3.8.1
Metadata	QC 500 or QC 400 depending on 'minor' or 'significant' change, and Data Processing Comment explaining identified cause and method applied, OR Refer to missing data guidance as applicable. Comments may be aggregated if frequent and repetitive.	J 7.2 6.2.3 J 7.3.5 6.2.4.7 J 3.8

3.6 Incorrect scaling

3.6.1 Analogue instruments

Sensor output as current (Amps) or potential (Volts) requires conversion on the data logger to PM_x concentrations, or the relevant supplementary variable's measurement units, using a multiplier and possibly an offset. If the multiplier is incorrect, a scaling error arises that will show as span error and/or apparent calibration drift.

To correct the data, remove any offset applied, then divide by the incorrect scaling multiplier to obtain raw signal, then multiply the raw signal by the correct scaling multiplier, then apply an appropriate revised offset (i.e. recalculated using the raw signal and its correct multiplier).

If the necessary transformations are fully traceable and do not compromise precision, there is no effect on quality code.

3.6.2 TEOM instrument measurement bias

TEOM instruments have been shown to under-read compared to gravimetric methods despite their status as an equivalent method for PM_{10}. The differences:

- vary with season and location
- are more likely where wood smoke forms a large portion of the particulate matter

- are partially mitigated by operating the instrument at 40°C, and
- may be fully mitigated by fitting a filter dynamics measurement system (FDMS) (Ministry for the Environment, 2009).

When used for compliance monitoring, a correction factor should be applied to data from a TEOM not fitted with an FDMS. The correction factor shall be derived from a co-location study that is also an equivalency test (see Section J 4) and applied as a transformation after all other editing has been completed (see Section J 5.1.2).

Table J 5 – Guidance for resolving incorrect scaling

Guidance for resolving incorrect scaling		see Section(s)
Issue(s)	Scale and/or units of the data is/are wrong.	J 3.6
Evidence	Data inconsistent with expected range. Step-change occurs at time of configuration change. Routine checks indicate apparent span error and/or calibration drift.	J 3.6 J 3.3 J 2.3
Solution(s)	Apply conversion equations, to equivalent precision, if measurements are in the wrong units. If TEOM without FDMS used for compliance, apply equivalency correction factor i.e. convert to PM_x Equivalent. For instrument configuration errors, apply transformations reversing the applied instrument configuration parameters to obtain raw signal, then apply the correct configuration parameters to the recovered raw signal, OR Assess impact of configuration error(s) and if not significant or misleading, file data with lower quality code and comment, OR Delete affected data and treat as missing.	J 3.6 J 4 J 1.3 J 1.4 4.7 Fig. 28 J 7.2 J 3.8
Metadata	If the correction required is explicitly reversible and fully traceable, quality code is unaffected, but a Transformation Comment is required. QC 400 and Data Comment detailing assessment if configuration error is assessed as not significant, OR Refer to missing data guidance as applicable.	J 7.3.6 6.2.4.8 J 7.2 6.2.3 J 7.3.4 6.2.4.6 J 3.8

3.7 Time faults

Time disparities may occur between an instrument's internal data logger and the external data logger if their clocks are not well synchronised. Provided the two datasets are retrieved, identified, stored, maintained, and archived separately any disparity poses few, if any, problems.

However, if record from one is used to fill a gap in the other, any time difference between the two sources of more than one recording interval shall be addressed by applying a time shift (see Section 4.3) to the secondary (backup) data.

The amount of time shift applied shall be included in the Data Comment (see Section J 7.3.4) that is required when backup data are included in a primary record (see Section J 3.8).

Time drift adjustment is rarely needed with modern electronic loggers (see Section 4.6). If logger date/time does not agree with actual date/time it is more likely the logger has stopped and there is a gap in the record, possibly unmarked, needing to be identified and addressed.

Most time-series management software has the ability to make time adjustments simultaneously with value adjustments. There is risk when using drift adjustment tools that time is unintentionally adjusted and time faults are introduced into the processed data. This is relatively easy to detect in fixed interval data by analysing the timesteps or inspecting the timestamps.

Table J 6 – Guidance for resolving time faults

Guidance for resolving time faults		see Section(s)
Issue(s)	Timestamps are inaccurate or conflicting. Undetected gaps may be present. Faults may be introduced by drift adjustment.	J 3.7
Evidence	Logger date/time is different from actual at inspection. Simultaneous records are out of sync. Fixed interval data have incorrect or missing timesteps.	J 3.7
Solution(s)	If wrong time zone, apply time shift then address any missing record created at the start (or end) by the shift. Keep asynchronous simultaneous time series separated unless using one to fill a gap in the other, in which case apply a time shift to the backup as needed. Mark gap if clock stopped. Apply time drift adjustment if clock slow or fast (rare).	4.3 4.6 Fig. 19 Fig. 27 J 3.8
Metadata	Data Processing Comment required explaining identified cause and providing details of the amount and period of adjustment of any shift or drift adjustment applied. QC 100 if data are missing and a Data Comment. Otherwise, 'minor' or 'significant' modification criteria apply for final quality code.	J 7.3.5 6.2.4.7 J 7.3.4 6.2.4.6 J 7.2 6.2.3

3.8 Missing data

The NES-AQ (2011 amendments) require for PM_{10} in a 12-month period:

- A minimum data capture rate of 95% after deducting instrument downtime for maintenance and calibration, and
- At least 75% data captured to be valid when calculating averages.

NEMS Air Quality: Particulates v1.0.0 follows the Ministry for the Environment Guides (2009, and 2011 (updated 2014)), which have:

- interpreted the NES-AQ (2011 amendments) requirements
- provide example calculations according to their interpretation, and
- extend the validity requirement to all averaging intervals.

Note: The Ministry for the Environment Guides omit the word "captured" when restating the NES-AQ data validity requirement so that 75% of the data in the averaging interval must be valid rather than 75% of the data captured in the averaging interval.

A measurement cycle may be interrupted by:

- power loss
- missing filter tape
- an instrument error
- instrument automatic zero and span checks
- operator intervention for cleaning, maintenance, and calibration.

Data can also be lost if:

- telemetry communications fail and there is no on-site data logger able to be manually downloaded
- on-site data logger storage is exceeded before data are retrieved
- communications fail between the monitoring instrument and external data logger and the data has not also been logged on the instrument (see Section J 3.8.2).

3.8.1 Invalidating data

Adequate mechanisms shall be employed to prevent non-representative (invalid) data being included in any averaging required by the NES-AQ.

Each agency should ensure that they evaluate and invalidate data in a consistent way.

Invalid data may be collected in the following situations:

- when flow rate is outside the specified control limits
- during instrument calibration and maintenance, including the time needed for stabilisation of the instrument afterward
- failure to meet relevant PM_x criteria in Table 5 of AS 3580.19:2020 (critical criteria for pollutant measurement data validation), and

- significant failure to meet relevant PM_x criteria in Table 7 of AS 3580.19:2020 (operational criteria for pollutant measurement data validation).

  Note: Under AS 3580.19:2020, significance of the failure is assessed in terms of impact on overall uncertainty of the PM_x measurement(s).

Depending on the database management system 'invalidating' may be achieved by deleting the spurious value(s) and inserting a gap marker, replacing them with NULL, or applying a code or tag e.g. NaN, to exclude them from averaging and further analysis. Spurious values may be included in the NES-AQ "meaningful data" data capture test but must not be included in the corresponding valid data test (see Section J 3.8).

Applying a NEMS quality code of QC 100 to invalidate data is not sufficient on its own. The most certain prevention is to delete the offending data, mark the period removed as missing, and quality code the now missing period as QC 100 (verified missing data).

Note: The preserved original data and any pre-processing records allow recourse to all initial measurements if required.

Note: Some systems can exclude 'bad' data from analysis on the basis of NEMS quality code, but others cannot, so simply assigning QC 100 to invalidate values (rather than removing them then assigning QC 100 to the resulting gap) is not recommended.

If deleting values from a multi-item dataset, ensure other variables are not corrupted in the process.

An agency should avoid changing its chosen method of invalidating values within a dataset and should use the same method for all their PM_x data. If change of method (including a change of code or tag) is unavoidable, a Stationarity Comment (see Section J 7.3.7) describing the change shall be filed, timestamped to when the method was changed.

Decisions to invalidate data should be peer reviewed (AS 3580.19:2020 section 2.6). The reason for invalidating the data and the persons responsible for the decision and review shall be noted in the data processing records.

Deletion of any data shall be identified and justified in one or more Data Processing Comments (see Section J 7.3.5). Multiple instances of the same treatment and justification may be combined into a single Data Comment timestamped at the first instance, to avoid overwhelming the commenting facility.

Data Comments about instrument calibration and maintenance are not expected to include the maintenance and calibration history, which are the subject of associated Equipment Comments (see Section 6.2.4.4) and Operational Comments (see Section 6.2.4.5) as required.

3.8.2 Infilling missing record

Backup from secondary data storage may be used to infill a gap in a primary record e.g. from an instrument's internal data logger when the external data logger has failed. Time discrepancies may need to be accounted for (see Section J 3.7).

Infilling using synthetic data, including interpolation across more than one recording interval, shall not to be undertaken for regulatory or archiving purposes. Infilling with synthetic data may be done separately if continuous data without gaps is required for dispersion modelling but is outside the scope of this NEMS and not addressed further.

Child quality codes (see Section J 7.2.2) are recommended to distinguish the reasons for missing data, e.g. planned versus unplanned maintenance (see NEMS Air Quality: Particulates v1.0.0 section 6.2.1), to minimise repetitive required comments (see Section 6.2.1).

Table J 7 – Guidance for resolving missing data

Guidance for resolving missing data		see Section(s)
Issue(s)	Data are missing (not collected or subsequently removed).	J 3.8
Evidence	Expected timestamps are not present in the original data. A gap marker may be filed. Data plot has features absent, (e.g. loss of daily peaks). Investigation confirms data were not logged and/or not collected, OR data have been intentionally removed.	J 2.3 4.16 3.6 & Fig. 9 J 3.8.1
Solution(s)	Use at-site backup data where available. Synthetic data, including interpolation across missing recording intervals, not permitted for regulatory or archiving purposes but may be done separately if dispersion modelling.	J 3.8.2
Metadata	Quality code as applicable to the backup record, or QC 100 if left as missing. Data Comments are required explaining identified cause and providing details of decisions made and use of backup data where applicable. Child quality codes recommended to minimise repetitive comment of reasons for missing data.	J 7.2

4 Equivalency Testing and Co-location

Measurement of particulate concentrations is method and source dependent (NEMS Air Quality: Particulates v1.0.0 Section 4).

While most instruments are capable of precise measurement provided air temperature, relative humidity, and flow rate are well controlled, different methods use different properties of particles to determine concentration, and instruments cannot be calibrated with known concentrations of the mix of particles that may be encountered

at any site. To relate measurements from different instruments to each other and/or to reference methods, relationships derived from paired measurements must be applied.

Without these relationships, data acquired by instruments employing different methods are not comparable, even if deployed at the same site.

4.1 Definitions

4.1.1 Equivalency testing

Equivalency testing means measurements from one method are compared with those from a reference method as defined in AS/NZS 2580.9.17:2018 Demonstration of equivalence for ambient PM monitoring methods (see Section J 1.8.5).

Relationships derived and applied produce concentrations expected to be equivalent to those from the reference method (see Sections J 2.4.2 and J 2.4.3).

Demonstrated equivalency is required for continuous PM_x data to achieve QC 600 (NEMS Air Quality: Particulates v1.0.0 Introduction) (see also Section J 7.2.3).

4.1.2 Co-location study

Co-location means two or more different methods used at the same site, compared, and correlated, with relationship(s) derived and applied so their records can be combined for site-specific long-term trend analysis. Co-location is used when intending to change methods at a site and may also be used to relate PM_{10} with $PM_{2.5}$ at a site for quality control (see Section J 2.3.2) and regulatory purposes.

These studies may also be known as comparability assessments (NEMS Air Quality: Particulates v1.0.0 Section 4.3).

4.2 Test or study data

Reference methods used in equivalency testing are gravimetric. Filters are manually collected, then submitted to and weighed in a testing laboratory. Sample handling and laboratory quality assurance procedures must exist and be followed to ensure results are reliable, available, and accessible (see Section J 6).

The reference samples used in equivalency testing can be drawn from a variety of locations provided certain conditions are met with respect to particle mix and source, sample size and range, and frequency (see NEMS Air Quality: Particulates v1.0.0 Section 4.1).

Co-location data must be collected at the same site for a period of 12 months or more. The paired data may be from two or more continuous instruments. A reference instrument may be used but is not required (see NEMS Air Quality: Particulates v1.0.0 Section 4.2). Continuous data must be cleaned and verified prior to regression analysis and stored in a way that separates and distinguishes each series and prevents possible corruption of either dataset.

If the test data collected are exported to make use of national standardised analysis and reporting templates (currently in preparation), export configuration must ensure the data are correctly represented when input to the templates (see Section J 1.5 and Appendix J.2).

4.3 Deriving the relation

Each relation shall be derived using the 24-hour averages of the paired data.

If the co-location or equivalency data are within the uncertainty of the instrument and data collection system, then no adjustment should be made to the data and therefore deriving any relation is unnecessary.

Where a relation is required, ordinary least squares regression will normally suffice unless the relation is:

- unequivocally non-linear, and non-linear regression is needed, or
- includes valid outliers, in which case orthogonal or standardised major axis (SMA) regression should be considered (Scarrott, 2010).

Guidance on use of regression analysis may be adapted from Appendix 2. Bear in mind that relationships, and therefore the factors, are possibly seasonal.

A relation once derived will have an associated period of applicability.

- For equivalency relations, the period is up to ten years from the representative date of the analysis (see NEMS Air Quality: Particulates v1.0.0 Section 4.1.5) or repeat test, whichever is sooner.
- For co-location relations, the period will be either the duration of the record collected from the instrument being replaced, or open-ended from the date of installation of the replacement instrument.

  Note: It will usually be more practical to adjust the finite period of record already collected from the instrument to be replaced.

Note: At time of writing this Annex, guidance specific to PM_x is being prepared by industry specialists and this and related sections of this Annex may be revised once the guidance document PM Equivalency testing and co-location guide (in preparation) is available.

4.3.1 Uncertainty of the relation

Uncertainty of the relation is one of a suite of goodness of fit indicators that may be used to assess acceptability of a regression result.

Goodness of fit measures appropriate to the statistical method used to derive the relation must be included in the required Transformation Comment (see Section J 7.3.6) and in the records of the analysis permanently stored with the site calibration metadata (see Section J 4.4).

Note: At time of writing this Annex, NEMS acceptance criteria for regression analyses performed for equivalency testing or site-specific co-location are included in the scope of

the PM Equivalency testing and co-location guide (in preparation). In future, reliability of the relation may modify the quality code of data transformed using the derived relation.

4.4 Metadata

When equivalency testing or co-location is undertaken, an analysis history must be maintained, accessible, and preserved.

Note: Suitable repositories are the site file, a calibration database (with the manufacturer's calibration information), or a document or asset management system.

The analysis history shall contain the following:

- whether equivalency test or co-location study
- purpose of test or study
- brief description of test or study environment, including:
- location(s)
- particulate source(s), and
- reasons for site selection (and/or chosen representation of airshed)
- instruments used in test or study
- period of test or study data collection
- reference method used for equivalency test, including method of analysis of samples
- standard(s) or guidance used, and exceptions as applicable (e.g. equivalency not undertaken in each climate zone, contrary to AS/NZS 3580.9.17 (NEMS Air Quality: Particulates v1.0.0 Section 4.1.2))
- input data details e.g. hourly or daily averages, fixed or running, and
- justification for not deriving a relation (see Section J 4.3), or
- the relation(s) and method(s) used to derive them, including details of:
- explanation of assumptions
- regression method e.g. simple least squares or orthogonal, X on Y or Y on X, linear or non-linear, and
- the code or application used to analyse the paired data e.g. in-house Excel spreadsheet or NEMS approved toolbox R script.
- result and means of assessing acceptability of the relation(s), including:
- assessment of outliers
- observations and descriptions of any unusual or exceptional conditions impacting the relation(s), and
- assessment of uncertainty of the relation(s).
- anything else useful to sharing equivalency testing results.

The following additional metadata shall be compiled and preserved when applying the relation(s):

- source of relation(s) applied (e.g. agency study or shared resource)
- method used to apply the relation(s)
- range and period of applicability of each relation
- explanation of extrapolations beyond the relationship range
- method used to transition between successive relations, and
- any other known or suspected limitations of the relation(s) that may affect use of the transformed data.

If nationally standardised analysis and reporting templates are not used the agency undertaking the testing must, in addition to all other metadata, document the following:

- design of the test (see NEMS Air Quality: Particulates v1.0.0 Section 4.1)
- required quality assurance records, and
- how and where the documentation and results are to be stored.

4.5 Applying the results

Results of equivalency tests or co-location studies shall be applied as a transformation to the measured data after all other editing has been completed (see Section J 5.1).

NEMS Air Quality: Particulates v1.0.0 Section 5.7.2 requires co-location and equivalency testing to output a single 24-hour correlation factor, which shall be applied to the highest resolution data and be recorded in the metadata.

Note: At time of writing this Annex, expected results of equivalency testing or site-specific co-location and their application are within scope of the PM Equivalency testing and co-location guide (in preparation), which will provide the most up to date guidance for equivalency testing and co-location in NZ and replace the above requirements.

In the case of co-locations, agencies may choose whether to transform retrospectively (i.e. transform the measured data already collected from the instrument to be replaced) or going forward (i.e. transform the ongoing new measured data from the replacement instrument) but do need to ensure they apply the correct form of the relation for their choice.

Note: If using a rating engine to apply the transformation(s), going forward is more transparent and efficient. Ratings can be modified, and new ratings added, all are stored and traceable in the TSM, and application is automatic and virtual (i.e. 'on the fly' as data are accessed) (see also Section J 3.4.3). However, applying in retrospect is a finite period once-only transformation.

Transitioning (see Section 4.10) shall not be applied to equivalency or co-location transformations. There is therefore potential for a change of instrument at a site, where each instrument has a different non-site-specific equivalency relation, to result in a step in all forms of the data (measured, PM_x STP, and PM_x Equivalent) (see Section J 3.3.1). Applying co-location relations should not create a step-change because achieving a homogenous series (i.e. preservation of stationarity) is the purpose of the study.

5 Post-processing

5.1 Transformations

Refer to Section 4.7 (linear transformation) or Section 4.9 (non-linear transformation) as applicable for guidance on the use of data transformations.

Each transformation applied requires a comment (see Sections J 7.3.6 and 6.2.4.8)

5.1.1 PM_x STP data

If not done on the instrument before data are captured, conversion to STP must be done on the data logger or by the data collection system or by transformation after data verification and editing. If done automatically using user-programmable code, the program code must be tested, documented, controlled, and preserved.

If not automatically applied, transformation to STP is needed after data processing (verification and editing) is completed. Refer also to Appendix J.1.

5.1.2 PM_x Equivalent data

Transformation to reference (by way of equivalency testing) is needed after data processing (verification and editing) is completed to obtain PM_x Equivalent values.

For transparency and audit purposes, equivalency transformations to PM_x Equivalent should not be automatically applied.

5.1.3 Averaging

Averaging shall not include any data collected during maintenance or calibration of the instrument. Depending on the data processing system employed, such data may need to be removed during data verification and processing (see Section J 3.8.1).

Schedule 1 of the NES-AQ defines the averaging periods required to be derived from the continuous PM_x data.

- Hourly means are required to be preceding interval on the hour calculated from the mean of not more than 10-minute means, collected not less than once every 10 seconds.

  Note: The above seems to require running means of up to 10-minutes duration, updated at least every 10 seconds, (i.e. six or more times per minute). However, in the Users' Guide (Ministry for the Environment, 2011) mention is only of fixed interval 10-minute means in each hour, (i.e. six values per hour), although it is noted that monitoring is required to be "continuous" in order to calculate 24-hour means.

- 24-hour means are required to be preceding interval to midnight (i.e. midnight is 24:00 day ended, not 0:00) calculated from the hourly means.

Some industry recognised TSM's have facilities to automate this process and perform the necessary gap-handling provided the underlying time series of recorded data is correctly configured (see Section J 1.5). Preference should be given to using these facilities when available to avoid potential data transcription and/or transfer errors.

NEMS Air Quality: Particulates v1.0.0 Section 5.7.4 requires instantaneous data to be used to calculate hourly averages, when possible. However, some cautions apply:

- Instantaneous continuous data has specific meaning as a data type when data are stored in a TSM.
- The data type assigned to the data in the TSM determines what interpolation method is applied between the stored values, which then determines how the data are averaged.
- When using a TSM the data type must be carefully chosen to reflect how the values stored were derived by the instrument so that averages are calculated correctly (see Section J 1.5 and Appendix J.2).

Note: AS 3580.19:2020 requires hourly averages to be calculated from "the arithmetic mean of all available measurements taken within the hour", which assumes the measurements are stored as discrete (i.e. non-interpolating) fixed interval data.

If an organisation codes its own application(s) to produce the averages, including scripts that run from inside the database or TSM storing the recorded data (e.g. Hilltop virtual measurements) the code shall be formally documented, tested, controlled, secured against unauthorised change, and regularly backed up.

5.1.4 Co-location

Transformations that apply the empirical relation derived from a co-location study assist with maintaining stationarity of a record when instruments and/or methods change (see Section J 4.1.2).

Refer to Section J 4 for detailed guidance on deriving and applying co-location relations and associated metadata requirements.

The transformation is not regarded as data editing for quality coding purposes because it is required to be applied after all editing is completed (see Section J 4.5). Quality code of verified and processed data is therefore unaffected by subsequent application of a co-location relation.

Note: The quality coding matrix criteria (NEMS Air Quality: Particulates v1.0.0 Table 8) include transformation of data on the basis of equivalency testing but not co-location.

Note: At time of writing this Annex, guidance is being prepared by industry specialists on co-location studies and their application. This and related sections of this Annex may be revised once the PM Equivalency testing and co-location guide (in preparation) is available. In future, reliability of the empirical relation may modify the quality code of the data transformed.

6 Laboratory Processes

Gravimetric PM_x reference methods require filters to be weighed in a temperature and humidity-controlled environment, usually provided by a dedicated balance room within a laboratory to which the filters are transported (NEMS Air Quality: Particulates v1.0.0 Sections 4.1.1 and 4.4).

Each filter to be manually weighed constitutes a sample. Procedures are required to ensure filters are not mislaid, degraded, or contaminated and all results are received, checked, and appropriately archived. Records are required to verify stringent quality control of the filters before and after use, instrument housing conditions and air flow, and the balance room environment.

The following sections are a summary of the key requirements when using a laboratory to measure and report PM_x concentrations. More detailed procedure may be developed from AS 3580.19:2020, and by adapting the guidance in Annex I Discrete Water Quality Data Processing for the manual collection of samples, submission of those samples to an off-site laboratory for analysis, and storage and preservation of the results and quality management records.

6.1 Tracking the status of samples

The monitoring agency must record which samples were sent where, when, by whom and with whom, e.g. by recording courier tickets (tracking numbers) against the sample identifier(s), and have some documented process to monitor:

- timely notification of receipt of a shipment by the laboratory
- timely return of the completed Chain of Custody form
- receipt of analysis results
- when the results are checked, quality coded, and archived, and
- formal 'closure' of the sampling event, or
- cancellation/abandonment of the sampling event with no data to archive.

The monitoring agency must also document how orphan results are managed and resolved, i.e. analysis results wrongly identified, attributed, and/or reported, and/or from samples not able to be identified.

6.1.1 Chain of custody form

This form travels with the filters to the laboratory providing the laboratory with information about their origin and what test(s) to perform.

The laboratory assesses timeliness and condition of the filters on arrival and records receipt of them and any issues on the same form, a copy of which is then returned to the monitoring agency, providing assurance that filters were not lost or compromised on the way.

All AS Standards for manual monitoring methods specify:

- maximum period between sampling and final filter weighing, and
- maximum temperature during sample transport.

Non-conformance does not invalidate a result but QC400 shall be assigned to it and a Data Comment filed (see Section J 7.3.4) quantifying the exceedance and providing reason for it (AS 3580.19:2020).

Completed forms must be retained at least until all expected results are received from the laboratory, fully processed and quality coded, the metadata has been compiled, and all are permanently archived and backed up.

Office procedure should include a bring-up system to follow up forms submitted but not returned promptly. Preferably prior to submission, but at least on the form's return:

- reconcile it with the corresponding field visit records
- resolve any anomalous information, e.g. date and time, sample ID's, conditioning requirements and status
- notify the laboratory to correct their information if necessary.

Known issues affecting filter collection, handling, and condition should be noted on the field visit record and/or the chain of custody form by the sampling and/or laboratory personnel.

A chain of custody form may be resubmitted with any request for retest, also noting the date of the request and who made it, and any comments in reply from the laboratory.

Note: AS 3580.19:2020 requires samples not destroyed during analysis to be archived to allow for reanalysis if needed. Recommendation for low volume sampler filters is retention for at least five years, stored at less than 4°C for the first year.

6.1.2 Sample identification

A sample identifier is used to associate each uniquely pre-labelled filter with its field visit and laboratory records, including chain of custody and laboratory results report.

If sample identifiers are associated with sites and sampling events when generated, the sample identifiers may also be used to automatically file electronic laboratory results into the database on receipt.

6.2 Laboratory results

6.2.1 Quality assurance

Laboratory calibrations, validations, and other quality control practices e.g. balance room controls and filter preparation, and curation of the associated records, form part of the laboratory's internal quality management system, which may be independently accredited. When using an external contracted laboratory, a monitoring agency's ability to view and query these records if required should be incorporated into the laboratory service contract.

The laboratory service contract or agreement, details of accreditation and/or other means of quality management and completed chain of custody forms are required metadata and must be preserved.

The laboratory is expected to validate all manual data entry contributing to their official laboratory report prior to releasing the report and results.

Field and laboratory blanks are used every twenty genuine samples to check for variation in results due to filter handling (see NEMS Air Quality: Particulates v1.0.0 Annex D).

Despite extensive quality processes, errors, usually of human origin, may still arise. Laboratory results should be reviewed within two weeks of receipt (see Section J 6.2.3).

Agencies making use of laboratory results must ensure procedures exist and are implemented to ensure any error found is identified, and corrected wherever possible, at every instance of the result being stored, including at the source laboratory, to prevent future transfers of results reintroducing the error.

6.2.2 Reporting and archiving results

Official laboratory reports are considered to be original records. The results supplied must be fully traceable within their internal system(s) and via the chain of custody.

Laboratories normally report results to a representative number of significant figures, however, to be useful for developing equivalency and co-location relationships the raw unrounded measurement value with its associated uncertainty of measurement (UoM) is preferred. This may be a departure from their standard practice and will require prior arrangement.

If an agency opts to obtain the raw (uncensored, unrounded) laboratory data, the agency must also document (and implement):

- how it will ensure raw and rounded and/or censored versions of the data are not muddled
- how integrity of both versions will be managed in the database
- how each version will be identified, and
- which version will be supplied for publication or to a data user.

The laboratory that performed the measurement, the method used, and any relevant laboratory comments must be stored with each filter result. The laboratory name and method may be codified provided the coding scheme is formally documented and maintained by the archiving agency.

Methods for storing the results of field and laboratory blanks and their metadata must be carefully designed to ensure their consistent treatment and retrieval as required while preventing unintended corruption, omission, overwrite, conflict and/or loss of actual data.

6.2.3 Results review

Data files to be imported (e.g. CSV, XML, or JSON) are usually transferred from the laboratory separately from the laboratory report, which is typically supplied as an electronic document (e.g. a pdf).

- Check each import for gross errors (e.g. unexpected termination, skipped or missing fields, or data corruption).
- Periodically check the integrity of the import against the original data (i.e. the field sheet and/or the laboratory report).
- After a software update and/or template change, thoroughly check the first one or two subsequent imports to ensure they have operated as expected.

Reconcile results with their original and quality assurance records. The checks should include, but are not limited to:

- confirm the intended sample information was received by the laboratory and acted upon
- information on the chain of custody form corresponds with the laboratory report and the measurement results metadata
- site, date, and time information is correct
- the measurement environment was appropriately controlled
- field and/or laboratory blanks indicate no filter handling problems
- If a laboratory blank limit is exceeded, results for all sample filters weighed in the same batch shall be invalidated (see Sections J 3.5 and J 3.8.1) unless clear and unequivocal evidence demonstrates the cause of exceedance was limited to the blank.
- If a field blank limit is exceeded, results for all sample filters weighed in the same batch shall be quality coded QC 400 and a Data Comment filed explaining the exceedance.

  Note: The above requirements are consistent with AS 3580.19:2020.

- supplementary values used to adjust results to STP are consistent with the balance room records
- flow rate(s) agree with the field visit records and calibration is current
- orphaned records are resolved wherever possible
- repeat results are appropriately handled, depending on whether they are the result of mistaken duplicate reporting, information amended and resupplied by the laboratory, or the reweighing of filters.

7 Metadata

7.1 Description

7.1.1 Site metadata

The site metadata detailed in Section J 2.2 is required to be collated. maintained, and retained indefinitely. Site metadata can be readily maintained and preserved in, and accessed from, a Site History Record (see Section J 1.8.2).

The following information about the airshed in which the site is located is also recommended to be included in the Site History Record (see Section J 1.8.2):

- airshed name (as gazetted), and
- rationale for site selection, including, but not limited to:
- whether chosen as representative of other locations in a non-contiguous airshed, or
- one of several monitors in the airshed, and
- whether used for consent compliance monitoring.

If gravimetric sampling is undertaken, records of balance checks and balance room climate controls (see NEMS Air Quality: Particulates v1.0.0 Annex D) shall be included with the site's instrument and calibration records.

7.1.2 Time-series metadata

- Time-series metadata are described in general in Section 6.2. For air quality particulate data, the following recommendations and requirements also apply:
- Note any limitations with the site and summarise them in the Site/Initial Comment (see Section J 7.3.1). Potential issues include:
  - obstructions impeding air flow
  - surrounding surfaces that may absorb or adsorb particulates
  - potential for interference (physical, electrical, or extraneous emissions)
  - any non-conformity to the standard requirements for the site classification.
- Maintain a record of changes around the monitoring site, which may be temporary or permanent, and could render the data collected not representative or invalid. For example:
  - construction or demolition activity
  - altered traffic flows or congestion patterns
  - road works, including sealing of previously unsealed road
  - growth or removal of surrounding vegetation.

Summarise temporary changes in a Data Comment (see Section J 7.3.4) and permanent change in a Stationarity Comment (see Section J 7.3.7).

- If the site is no longer representative of the monitoring purpose it may be relocated, in which case the change of location shall be updated in the Site History Record (see Section J 1.8.2) and the Site/Initial Comment (see Section J 7.3.1) and explained in a Stationarity Comment (see Section J 7.3.7). Under some circumstances (see NEMS Air Quality: Particulates v1.0.0 'The Standard") a new site may be required.
- If a new site is established, note the association between the old and new sites in the Site History Record (see Section J 1.8.2) and the Site/Initial Comment (see Section J 7.3.1) for both sites.

7.2 Quality coding

- Quality code for PM_x data is set by four different but related sets of criteria:
  - the quality coding flowchart
  - the Quality Coding Matrix
  - blanket provisions, and
  - data editing actions and adjustments.

The quality coding flowchart and Quality Coding Matrix may be found in NEMS Air Quality: Particulates v1.0.0 Section 6.2.

Where the provisions and requirements for quality coding contained in this section conflict with those in NEMS Air Quality: Particulates v1.0.0, this Annex shall prevail.

7.2.1 The Quality Coding Matrix

The Quality Coding Matrix uses information about the site, instruments, configuration, and servicing to differentiate between a maximum possible quality code of QC 400, QC 500, or QC 600 for the data collected between each inspection. This assessment should, for quality assurance preventive action purposes, be completed before departing the site, but if not, becomes the first step of quality control during data processing.

By applying the Quality Coding Matrix at the time of data collection it is possible to assign initial quality codes higher than QC 200 to unprocessed data. This can be misleading because data editing actions may result in periods of data acquiring a different code (see Section J 7.2.3).

Adjusting measured values to standard temperature and pressure (STP) is included in the Quality Coding Matrix assessment. It is not regarded as data editing for quality coding purposes.

7.2.2 Child codes

Use of child codes is required for measured data quality codes (QC 400 to 600) and recommended for other quality codes (NEMS Air Quality: Particulates v1.0.0 Sections 6.1.1 and 6.2.1). They codify site classification and may be used to differentiate between different causes of missing data e.g., scheduled maintenance or unplanned outage (see Section J 3.8).

An organisation shall formally document their child code schema, including their basis for selection and application of child codes beyond those stated in NEMS Air Quality: Particulates v1.0.0 Table 9.

7.2.3 Blanket provisions

Maximum quality code for PM_x Equivalent data is QC 600 (or relevant QC 600 child code greater). Other forms of PM_x data cannot be assigned QC 600 regardless of their quality matrix score (see Section J 7.2.1). To quality for QC 600 requires:

- use of equipment specified in Schedule 2 of NES-AQ, or EU or USEPA approved instruments (NEMS Air Quality: Particulates v1.0.0 Sections 2.2.1 and 6.1.3)
- adjustment to STP (NEMS Air Quality: Particulates v1.0.0 Sections 2.5 and 5.1), and
- equivalency testing and transformation to equivalent values (i.e. to PM_x Equivalent).

Maximum quality code for PM_x STP data is QC 500 (or relevant QC 500 child code greater) regardless of their quality matrix score. Furthermore, if adjustment to STP is not performed by the PM_x instrument during its measurement process, PM_x STP data:

- cannot have quality code higher than the quality code assigned to the required supplementary data, if the supplementary data are fully processed and quality coded
- may retain QC 400 or QC 500 as assigned to the PM_x data by the quality coding matrix and/or any data editing applied, provided the required supplementary data acquire QC 200 (not assigned a final quality code)
- shall be assigned QC 200 (of unknown quality) if the required supplementary data retain QC 0 (original, non-verified)
- shall be assigned QC 300 (estimated from limited measured data) if ambient air temperature and/or barometric pressure is approximated (see Section J 1.6).

Note: The above requirements apply to the parent quality code. A numerically greater child code of that parent code may still be used to indicate the site classification once the parent code has been established.

For quality coding of supplementary measurements see Section J 1.6.

7.2.4 Data editing actions and adjustments

The quality code of any data collected may be affected by subsequent editing actions and adjustments made to the data. Minor modifications reduce quality code to QC 500 and significant modifications reduce quality code further to QC 400. Refer to Section 6.2.3 for explanation of 'minor' and 'significant'.

Further guidance on how and when quality code must change as a consequence of data processing is provided in Section J 3 of this Annex.

Data that are a result of transformations applying relationships derived from equivalency testing or co-location studies are not considered synthetic data (QC 300) because they are traceably applied to data that were measured, in a manner consistent with adjustment to a primary network reference or field calibration respectively.

The following are templated examples of comments for air quality particulate stations.

7.3 Example PM10 and PM2.5 comments

Type: Site
Measurement: PM10 (or PM2.5)
Initial comment for the air quality particulate monitoring station <site name or ID>. Located at *<map co-ordinates and type1>* in the *<airshed name>* airshed, monitored for *<site purpose>*. NZ site classification is *<site category and scale>* and status is *<non->* polluted. Situated at altitude *<elevation>* m and *<briefly describe situation e.g. for traffic, <distance>* m from *<road name(s)> <with traffic volume <x>* vehicles per *<period e.g. hour or day>*.>, or for a background site, in an open rural grassed area *<distance>* m (or km) from *<e.g. farming or industrial activity, or housing, nearest road and/or town>*>. *<Related consents are: <list consenting agency(ies) and consent number(s)>.>*
Additional information: Inlet is located *<brief description of inlet placement and environment>*. Data are affected by *<site limitations and influences>*. *<Site evaluation is available from <reference>.> <This site replaces (or is replaced by) <site name or ID>.> <The monitoring agency is: < agency name (if different to recording agency)>.>* Values stored are as measured and verified (or adjusted to standard temperature and pressure (PM10 (or PM2.5) STP) or adjusted to standard temperature and pressure and for equivalency (PM10 (or PM2.5) Equivalent). *<Some (or All) quality control (and/or data editing) is automated; refer to the relevant Data Processing Comments.> <Data are stored as a censored series.>*

In addition to providing essential metadata for current and future data users, these comments can fulfil the data processing reporting requirements of AS 3580.19:2020 Sections 3.3.1 and 3.4.

Data for each particle size are required to be stored in a separate time series and a separate complete comment set is required for each time series, which will result in some duplication of information when both particle sizes are measured simultaneously at the same site.

Every comment must be assigned a fully specified timestamp and be associated with the relevant data (the time series of PM_{10} or $PM_{2.5}$ measurements) via some form of 'Site' and 'Measurement' database key combination. The database keys are usually specified in some form of record header not shown here.

7.3.1 Site/Initial Comments

Type: Site
Measurement: PM10 (or PM2.5)
The following is also measured at this site: <list variables, including any backup PM recorder and/or other particle size(s) measured, other pollutants, and separately logged supplementary and complementary data e.g. meteorological variables>; <This record is used to derive <list variables e.g. hourly averages, daily averages, etc.>>.
The local recording authority is: <name of recording/archiving agency>.

Update the Site/Initial Comment when details change so that it always conveys the site's current status and purpose. A Stationarity Comment (see Section J 7.3.7) shall also be filed, timestamped at the date and time any change occurs, noting what has changed and why, to maintain a traceable history in the time-series metadata of all such changes.

7.3.2 Equipment Comment examples

A comprehensive equipment comment shall be filed each time the instrument type at a site is changed. The equipment comment shall include the instrument type, brand and model and a brief description of its general principle of operation.

Note: Each type of analyser has a different underlying theory of operation, which results in different measured values at the same location for the same particulate concentration.

Type: Equipment
Measurement: PM10 (or PM2.5)
Instrument <*make, model and serial number*> installed on <*dd-mm-yyyy hhmmss*> is a <*state type (see Schedule 2 of the NES-AQ)*> with nominal accuracy of <*accuracy specification*> and resolution of <*increment and units*>. The instrument is installed in <*brief description of instrument housing and facilities e.g. portable insulted hut, detached shed with air-conditioning (or temperature and humidity control) etc. as applicable.*>.
Sampling inlet is <*distance*> m above ground and <*distance*> m from <*state supporting structure(s) e.g. wall or roof*> with clear sky angle of <*x*> degrees, unrestricted air flow of <*x*> degrees and <*x*> m from the nearest obstruction.
Instrument calibration is valid for <*calibration period*>. The instrument and installation are serviced <*servicing frequency*>. <*Zero and span are checked (and adjusted) <check frequency*>.> <*Sensor output is converted to recorded concentrations by <details of any transformations applied at the time of data capture or collection e.g. scaling multiplier and/or offset*>.> Data are logged to a <*describe main logger features e.g. how powered, compact (or otherwise e.g. PLC), multi- or single input, programmable etc.*> data logger, recording <*briefly describe data logging and sampling regime*>. <*Backup data are logged to <describe facility e.g. the instrument's internal data logger*>. Data are collected by <*method and frequency e.g. hourly telemetry polling and occasional manual download*>.

To avoid comments becoming too long and complex, create separate comments for co-located instruments, noting that the instrument is co-located and for what period and purpose.

Type: Equipment
Measurement: PM10 (or PM2.5)
Equivalency test reference data from <*dd-mm-yyyy*> (to <*dd-mm-yyyy) is obtained by <describe method(s) and instrument(s) used e.g. gravimetric analysis of 24-hr samples collected from a <make and model of reference instrument.>> <Add other relevant information such as range and number of samples; cross-reference to laboratory results and sample metadata; location if not co-located; how the reference data are supplied (e.g. collected by the recording agency, or by another party if not co-located); and where the reference data are stored*>.

7.3.3 Operational Comment examples

Type: Operational
Measurement: PM10 (or PM2.5)
Sampling inlet repositioned on *<dd-mm-yyyy hhmmss>* to *<describe relative location to previous>* to/because of *<provide reason>*. Inlet is now *<distance>* m above ground and *<distance>* m from *<state supporting structure(s) e.g. wall or roof>*.

Type: Operational
Measurement: PM10 (or PM2.5)
Sampling inlet exposure changed due to *<provide reason e.g. removal of a tree, changes to enclosure fencing, new obstructions such as a building etc.>* noted on *<dd-mm-yyyy hhmmss>* (and assumed (or confirmed) effective from *<dd-mm-yyyy hhmmss>*). Clear sky angle (and/or air flow) is more (or less) obstructed (or restricted) than before.

Type: Operational
Measurement: PM10 (or PM2.5)
Calibration of *<list component(s)>* completed within required frequency of *<x>* months on *<dd-mm-yyyy hhmmss>*. All were within specification tolerance and no adjustments were made.

Type: Operational
Measurement: PM10 (or PM2.5)
Overdue calibration of *<list component(s)>* completed on *<dd-mm-yyyy hhmmss>* and all were within specification tolerance and no adjustments were made.

Type: Operational
Measurement: PM10 (or PM2.5)
<List component(s)> failed scheduled calibration on *<dd-mm-yyyy hhmmss>*. Instrument was serviced and passed calibration on *<dd-mm-yyyy hhmmss>*. Data collected is likely compromised (or considered invalid) from *<dd-mm-yyyy hhmmss>*; refer to the relevant Data and/or Data Processing Comments.

Type: Operational
Measurement: PM10 (or PM2.5)
Site found vandalised beyond repair on *<dd-mm-yyyy hhmmss>*. No valid record from *<dd-mm-yyyy hhmmss>*. Site temporarily closed.

Type: Operational
Measurement: PM10 (or PM2.5)
Annual servicing and calibration completed successfully on *<dd-mm-yyyy hhmmss>*.

Type: Operational
Measurement: PM10 (or PM2.5)
Instrument was moved on *<dd-mm-yyyy hhmmss>* to *<where in relation to previous>* because *<provide reason for relocation>*.

When the above comment is filed, update the Site/Initial Comment, and file an associated Stationarity Comment that retains the previous location information changed by the update to the Site/Initial Comment (see Section J 7.3.7).

7.3.4 Data Comment examples

Type: Data
Measurement: PM10 (or PM2.5)
PM10 (or PM2.5) concentrations from *<dd-mm-yyyy hhmmss>* (to *<dd-mm-yyyy hhmmss>*) are measured by *<instrument name or type>* on a *<state time interval>* (or continuous) cycle. Values stored are *<describe how derived e.g. 10-minute averages>* logged at the end (or beginning) of each interval. *<Logged values are adjusted to standard temperature and pressure by the PM10 (or PM2.5) instrument (or on the data logger, or by the data collection system, or during data processing).> <Hourly averages are calculated from the logged values.> <Daily averages are calculated from the hourly averages.>* Refer to the relevant Equipment Comment for PM10 (or PM2.5) instrument and installation details.

Type: Data
Measurement: PM10 (or PM2.5)
Air temperature from *<dd-mm-yyyy hhmmss>* (to *<dd-mm-yyyy hhmmss>*) is measured by the PM10 (or PM2.5) analyser (or an independent sensor at site) and logged at *<state recording interval>* intervals. *<Refer to the relevant Equipment Comment for sensor details.>* The air temperature data are used to adjust measured PM10 (or PM2.5) values to standard temperature and pressure on the PM10 (or PM2.5) instrument (or on the data logger, or by the data collection system, or during data processing). The air temperature data are *<describe whether or not reviewed and/or edited and/or verified and/or archived as supplementary data or as primary data under the relevant site, time series and metadata identifiers>*.

Type: Data
Measurement: PM10 (or PM2.5)
Data may be affected by a temporary change in the monitoring environment from *<dd-mm-yyyy hhmmss>* to *<dd-mm-yyyy hhmmss>* due to *<describe event e.g. construction, demolition, roadworks, altered traffic flow, removal of vegetation, large fire etc.>*, *<x>* km (or m) *<compass direction>* of (or surrounding) the monitoring site.

Type: Data
Measurement: PM10 (or PM2.5)
Missing record from *<dd-mm-yyyy hhmmss>* to *<dd-mm-yyyy hhmmss>* due to *<identified cause of recording failure>*. *<Add any other relevant information>*.

Type: Data
Measurement: PM10 (or PM2.5)
Barometric pressures from *<dd-mm-yyyy hhmmss>* (to *<dd-mm-yyyy hhmmss>*) are measured at site and logged at *<state recording interval>* intervals (or obtained from *<site name>*, site number *<network number, ID or code>*, grid reference *<map co-ordinates and type >*, *<altitude>* masl, operated by *<recording agency>*). *<Add other relevant information such as barometer type, range, units, precision, and accuracy>* (or Refer to the relevant Equipment Comment for sensor details).> The barometric pressure data are used to adjust measured PM10 (or PM2.5) values to standard temperature and pressure on the instrument (or on the data logger, or by the data collection system, or during data processing). The barometric pressure data are *<describe whether adjusted for altitude, and/or reviewed and/or edited and/or verified and/or archived as supplementary data or as primary data under the relevant site, time series and metadata identifiers>*.

Type: Data
Measurement: PM10 (or PM2.5)
Backup record used from *<dd-mm-yyyy hhmmss>* to *<dd-mm-yyyy hhmmss>* due to *<identified cause of primary recording failure>*.

Type: Data
Measurement: PM10 (or PM2.5)
From *<dd-mm-yyyy hhmmss>* (to *<dd-mm-yyyy hhmmss>*) an offset of *<x>* $\mu g/m^3$ is added to measured values when they are logged to avoid negative concentrations.

Add a comment such as the following example to the end of the 'old' data and the start of the 'new' data when there is a significant change of method that initiates a new dataset, i.e. in the example, attach the comment to the last data before the change and the first data after the change. Corresponding Equipment and Stationarity Comments are also needed (see Sections J 7.3.2 and J 7.3.7).

Note: In most modern TSM's and environmental DBMS, more than one time series can be stored under the same site name or ID.

Type: Data
Measurement: PM10 (or PM2.5)
PM10 (or PM2.5) values from *<dd-mm-yyyy hhmmss>* to *<dd-mm-yyyy hhmmss>* are quality coded QC 400 (compromised) because the concentrations of PM2.5 exceed the concentrations of PM10.

Type: Data
Measurement: PM10 (or PM2.5)
Measurement method changed on *<dd-mm-yyyy hhmmss>* from *<describe relevant details of old method that have changed e.g. instrument, sampling regime, inlet temperature, etc.>* to *<describe corresponding relevant details of new method>*. The data from each method are stored separately and should not be considered homogenous. *<See the relevant Equipment Comments for instrument details.>*

Type: Data
Measurement: PM10 (or PM2.5)
Measurement method changed on *<dd-mm-yyyy hhmmss>* from *<describe relevant details of old method that have changed e.g. instrument, sampling regime, inlet temperature, etc.>* to *<describe corresponding relevant details of new method>*. Data prior to *<dd-mm-yyyy hhmmss>* have been transformed on the basis of a *<x>* month co-location study so that all data can be considered homogenous. See the relevant Transformation Comment for co-location relationship details. *<See the relevant Equipment Comments for instrument details.>*

7.3.5 Data Processing Comment examples

Type: Data Processing
Measurement: PM_{10} (or $PM_{2.5}$)
Intermittent negative values (*or* Large spikes) caused by *<identified cause e.g. volatile moisture or instrument fault>* deleted (*or* edited to zero) between *<dd-mm-yyyy hhmmss>* and *<dd-mm-yyyy hhmmss>*. Edited by *<name>* on *<date of processing>*.

Type: Data Processing
Measurement: PM10 (or PM2.5)
Time shift of -1 hour is applied to convert period logged in NZDT from *<dd-mm-yyyy hhmmss>* to *<dd-mm-yyyy hhmmss>* to NZST. Error due to *<give reason e.g. incorrect clock reset at logger restart>*. Edited by *<name>* on *<date of processing>*.

Type: Data Processing
Measurement: PM10 (or PM2.5)
Supplementary barometric pressure data collected at site (or name of location if not at site) is adjusted from *<dd-mm-yyyy hhmmss>* to *<dd-mm-yyyy hhmmss>* by *<method and parameters e.g. offset shift of <x> <units>*, linear drift adjustment of *<x0> <units>* to *<x1> <units>* etc.> to compensate for *<identified cause e.g. calibration drift>*. PM10 (or PM2.5) data are adjusted to standard temperature and pressure using the adjusted barometric pressure values. Edited by *<name>* on *<date of processing>*.

Type: Data Processing
Measurement: PM10 (or PM2.5)
Data from *<dd-mm-yyyy hhmmss>* to *<dd-mm-yyyy hhmmss>* is corrected for scaling error caused by incorrect conversion of raw sensor signal to PM10 (or PM2.5) concentrations. Incorrect logger parameters applied from *<dd-mm-yyyy hhmmss>* were multiplier *<m>* and offset *<C>*. Correct logger parameters are multiplier *<m'>* and offset *<C'>* as applied on the logger from *<dd-mm-yyyy hhmmss>*. Corrected values (Y') are obtained by applying the linear equation Y' = [(Y – *<C>*) x (*<m'/m>*)] + *<C'>* to the incorrectly scaled (Y) values. Edited by *<name>* on *<date of processing>*.

Type: Data Processing
Measurement: PM10 (or PM2.5)
Data from *<dd-mm-yyyy hhmmss>* to *<dd-mm-yyyy hhmmss>* adjusted by *<method and parameters e.g. offset shift of <x>* µg/m^3, linear drift adjustment of *<x0>* µg/m^3 to *<x1>* µg/m^3 etc.> to compensate for *<identified cause e.g. calibration drift>*. Edited by *<name>* on *<date of processing>*.

Similar 'automation' comments must be provided each time any relevant detail changes, from change to an action threshold through to a change of organisational procedure and/or software. Cross-reference relevant Equipment and Operational Comments as required to avoid unnecessary duplication. File a corresponding Stationarity Comment if change of methods potentially disrupts stationarity of the data.

The level of detail required in 'automation' comments depends on the extent to which the comments are necessary to ensure traceability of changes made to the raw measurements (see Sections 3.1.1 and 8.2).

Type: Data Processing
Measurement: PM10 (or PM2.5)
From *<dd-mm-yyyy hhmmss>* (to *<dd-mm-yyyy hhmmss>*) automated quality control (and/or editing) is applied to this data. Actions include: *<briefly describe each action in specific terms e.g. Range Test: concentrations >* x µg/m^3 not accepted (or, removed (and gapped)); Gap Test: gap flagged if timestep > 24 hrs; Neighbour Test: error flagged when PM2.5 exceeds PM10 > (or Actions are documented in *<provide reference to processing system documentation that contains specific detail of the tests applied to this data e.g. the site file, quality management system etc.>*), applied *<describe where in the process, with respect to what is original data, e.g. on the data logger (or telemetry system, etc.) prior to archiving as original data, or, after original data have been preserved but before near real-time web publication etc.>*, using *<provide name(s) of software and version and briefly describe how the actions are specified and/or configured in the system, and/or provide reference to where the code is permanently preserved, configuration files or screenshots are retained or similar>*.

7.3.6 Transformation Comment examples

Type: Transformation
Measurement: PM10 (or PM2.5)
Data archived from *<dd-mm-yyyy hhmmss>* (to *<dd-mm-yyyy hhmmss>*) were obtained by transforming measured PM10 (or PM2.5) by the correlation factor *<x>*, derived by *<method e.g. least squares regression>* of *<n>* paired values of PM10 (or PM2.5) from *<dd-mm-yyyy hhmmss>* to *<dd-mm-yyyy hhmmss>* measured simultaneously by the original *<instrument make and model>* and the co-located *<instrument make and model>*. Range of the correlation is *<range & units of the paired values>* and maximum deviation from the derived relation is *<deviation & units>*. *<Add other goodness of fit statistics as applicable, e.g. regression coefficient R^2>*. The resulting archived time series is in terms of the original (or co-located) instrument. Refer to relevant Equipment Comments for the instrument and installation details. Applied by *<name>* on *<date of processing>*.

The above comment may need some modification when used, depending on whether future data is sourced from the co-located instrument with the original data

transformed (once only), or future data collected from the co-located instrument is transformed to be consistent with data from the original instrument.

Type: Transformation
Measurement: PM10 (or PM2.5)
Data from *<dd-mm-yyyy hhmmss>* to *<dd-mm-yyyy hhmmss>* are transformed by a correlation rating to adjust for loss of calibration linearity. *<Name of software>* rating points are (original, adjusted) *<list the rating point pairs>*. (or Rating equations are *<state equation and range for each segment>*.) Instrument was replaced on *<dd-mm-yyyy hhmmss>*. Edited by *<name>* on *<date of processing>*.

7.3.7 Stationarity Comment examples

Type: Stationarity
Measurement: PM_{10} (or $PM_{2.5}$)
Instrument was moved on *<dd-mm-yyyy hhmmss>*. Prior location was *<add the details that were in the Site/Initial Comment before it was updated to reflect the change>*. Refer to the Site/Initial comment for current location details and the relevant Operational Comment for the reason for the relocation.

Type: Transformation
Measurement: PM10 (or PM2.5)
PM10 (or PM2.5) Equivalent values archived from *<dd-mm-yyyy hhmmss>* (to *<dd-mm-yyyy hhmmss>*) were obtained by transformation of measured PM10 (or PM2.5) using the linear (or nonlinear) relation *<provide equation>* derived by *<method e.g. least squares regression>*. The relation is derived from *<n>* paired values of PM10 (or PM2.5) measured by *<instrument make and model>* and reference values obtained by *<describe method>* from *<dd-mm-yyyy hhmmss>* (to *<dd-mm-yyyy hhmmss>*) with range *<range & units of reference values>* and maximum deviation from the derived relation of *<deviation & units>*. Range of the derived equivalent values is *<range & units>*. *<Add other goodness of fit statistics as applicable, e.g. regression coefficient R^2>*. Applied by *<name>* on *<date of processing>*.

Type: Stationarity
Measurement: PM10 (or PM2.5)
Instrument type changed on *<dd-mm-yyyy hhmmss>* from a *<type replaced>* to a *<new type>* causing a *<x>* µg/m^3 step-change in recorded baseline concentration. The data have not been adjusted to eliminate the difference. Location and monitoring purpose are unchanged. Refer to relevant Equipment Comments for the instrument and installation details.

Type: Stationarity
Measurement: PM10 (or PM2.5)
Regulation banning installation of domestic wood burners was introduced in *<describe locality e.g. town, city, district, region, airshed>* on *<dd-mm-yyyy hhmmss>*.

Type: Stationarity
Measurement: PM10 (or PM2.5)
Regulatory ban on open-hearth domestic fires introduced in this airshed from *<dd-mm-yyyy hhmmss>*. *<Add any references to the regulation and supporting documents>*.

Include similar comments to the above when long-term bans are lifted, consents for significant emissions expire, or new consents are granted, noting emissions offsets where applicable. Record routine and regular but temporary seasonal fire bans in Operational Comments.

Type: Stationarity
Measurement: PM10 (or PM2.5)
Change of *<name and/or description of algorithm, method, or environment e.g. obstructions>* on *<dd-mm-yyyy hhmmss>* that may disrupt stationarity of the record. *<Add any other relevant detail and/or refer to relevant Equipment and Operational Comments as applicable>*.

Stationarity Comments can also be used to capture and collate historical information.

8 Quality Assurance

8.1 Peer review of data processing

The requirements of Section 7.2 of this Standard, and the following review requirements of AS 3580.19:2020, apply:

- manual review of anomalous data flagged by automated systems, prior to any invalidation of that data (AS 3580.19:2020 Section 2.5.3)
- annual review of automated calculations, to ensure they have not changed (AS 3580.19:2020 Section 3.3.1).

8.2 Data audit

The requirements of Section 7.3 of this Standard apply, except those aspects related to synthetic data, and routine use of independent references e.g. deviation plots.

Further to those requirements, the following from AS 3580.19:2020 shall be included in the information required for an audit:

- relevant audit and inter-laboratory comparison outcomes when laboratory measurements have been used in data production (AS 3580.19:2020 Section 2.5.2)
- a summary of compliance with site criteria (NEMS Air Quality: Particulates v1.0.0 'The Standard')
- a summary of all routine and annual equipment servicing and housing performance, and calibrations, relevant to the instrument and installation since last audit (see NEMS Air Quality: Particulates v1.0.0 'The Standard' and AS 3580.19:2020 Tables 5 and 9), and

- a summary of equivalency testing and/or co-location studies carried out and/or applied to the measured data.

9 Preservation of Record

The requirements of Section 8 of this Standard apply. This section provides additional guidance and interpretation of those requirements.

In the following sections "suitably archived" means archived in a manner consistent with Section 8 of this Standard, plus any additional guidance in this Annex contained in, or referenced from, the relevant section.

9.1 Original data

Original PM_x data as defined by the agency (see Section J 1.8.6) may be PM_x STP, i.e. corrected automatically to standard temperature and pressure (STP) either on-board (the instrument), or during data capture or collection.

- If corrected to STP by the instrument, the PM_x STP values are also the raw (as measured) data.
- If corrected to STP during data capture (e.g. on the data logger) or data collection (i.e. manual import or telemetry), storing and retrieving the raw (as measured) data as an additional dataset is possible and recommended.

Some data processing systems may work on the original file and retain information on changes made, which is acceptable provided the original data can be retrieved when required, in perpetuity.

Note: The original data may be required at a later date should the processed and archived final dataset be found to be in error, corrupted, or lost.

Official laboratory reports and completed chain of custody forms, relevant when equivalency testing, are considered to be original records (see Section J 6).

9.1.1 Forms

All forms completed in the field during site and instrument inspections, assessments, servicing, and calibrations, and/or by a laboratory when processing samples, are considered to be original records.

- Paper records may be permanently retained as uniquely identified, indexed and accessible scanned, or verified as correctly transcribed, electronic copy.
- If an electronic form is used, information captured may be stored on a field device to be imported or sync'd on return to the office or uploaded directly from the field to the agency's database via internet and/or cellular networks.

- All information collected using an electronic form shall be permanently retained in an accessible form as original record.
- If transmission from the field device (of the completed form or all information captured on the form) is fully automatic (i.e. on connection and 'hands-free') and completes without fault, the file on the field device need not be permanently retained.
- The integrity of the transfer process shall be thoroughly checked when devices and/or software is changed, and then periodically thereafter, to ensure it is working as expected with no data corruption or loss.
- If transfer of information from the field device is not fully automated the field file must be retained until transfer of the original records is confirmed complete and correct.

9.1.2 Supplementary data

An original version shall be preserved of any supplementary data that is, or may be, edited (see Section J 1.6).

9.1.3 Complementary data

An original version shall be preserved of any complementary data (see Section J 1.7) that is manually transcribed or is, or may be, edited. In most cases this will relate to observations and measurements transferred from completed forms (see Section J 9.1.1) or to continuously monitored meteorological variables (for which a NEMS Standard is in preparation).

9.2 Final records

9.2.1 Time series and time-series comments

A time-series record generated from another database serving as the recognised PM_x data archive need not be permanently retained unless it is, or was, used for regulatory purposes.

Time-series comments (see Section J 7.3) must be archived and retained indefinitely in any case, so they are available if a time series is generated, and as an easily retrievable, reportable, and standardised metadata summary.

9.2.2 Multiple data series

Multiple data series are possible for the same site, particle size, instrument, and period.

Further to the guidance and examples in Section 3.1 of this Standard, the final processed and verified $PM_{2.5}$ or PM_{10} data may be stored as:

- the measured values
- PM_x STP (i.e. corrected to STP, see Section J 1.3.1), and/or
- PM_x Equivalent (i.e. equivalency relation applied, see Section J 1.3.2).

In addition to the above:

- when equivalency testing, gravimetric results are stored for an overlapping period, and
- during a co-location study, a second set of multiple data series are stored for the same site and for an overlapping period, but from a different instrument.

Each data series shall be uniquely identified, tracked, and managed to ensure integrity of each is preserved and all data stored are traceable to their source.

Moving a site

If a site is moved more than a few metres it shall be a new site (see NEMS *Air Quality: Particulates* v1.0.0 Section 1.1), with all records managed and archived as for a new site.

If change in the measurement environment at the existing site is the reason for site relocation, ensure this is noted in the Site Closed and Site/Initial comments of the old and new sites respectively so that end users of the data are aware that the two records will likely not be homogenous despite the new site being intended as a replacement for the old.

Note: A period of simultaneous monitoring at both sites after the change that necessitated the relocation may establish a good relationship between them, but that relationship does not apply to the previous measurement environment.

9.2.3 Records of data processing

The requirements of Section 6.2.2 of this Standard apply.

The following must be included in the data processing records:

- all completed quality coding matrices (see Section J 2.1 and NEMS *Air Quality: Particulates* v1.0.0 Section 6.2)
- justification for all data editing and invalidations
- the program code (versioned and dated) if conversion to STP is automated by a user-programmable facility, and
- details of all transformation of data using co-location and/or equivalency relationships (see Section J 4.5).

9.2.4 Supplementary data

All supplementary data (see Section J 1.6) shall be suitably archived and retained indefinitely, with their metadata, including quality code where applicable.

9.2.5 Complementary data

Complementary data are metadata that shall be verified and permanently archived (see Section J 2.2). Section J 1.7 recommends suitable storage options.

Complementary data used to assist with verifying or invalidating PM_x values shall be described in the PM_x time-series comments, including any editing applied to the complementary data if the complementary data do not have their own metadata.

Other complementary data that are helpful to interpret the PM_x data shall be, as a minimum, identified in the PM_x time-series comments.

Ensure required actions arising from annual obstruction assessments (see NEMS *Air Quality: Particulates* v1.0.0 Section 1.3.11) are transferred to the site maintenance work programme.

Photos and video

To be useful, photos and video must be curated to maintain control of quality and quantity. As a minimum, photos and video must be able to be:

- identified by site and date/time taken, and
- retrieved by site, date/time, and/or purpose e.g. obstruction assessment.

Photos or video used to assess obstructions around the site over time (see NEMS *Air Quality: Particulates* v1.0.0 Section 1.3.11) and stored in an image archive should be cross-referenced to the records preserved of each relevant assessment (see Section J 9.1.1).

9.2.6 Metadata

Refer to Section 8 of this Standard and Section J 7 of this Annex.

9.3 Quality assurance records

Quality assurance records may take a variety of forms, be in a variety of formats, and not necessarily stored in the same system with the air quality PM_x data and/or its immediate metadata.

For example, these records may be stored instead in a formal quality management system and/or an asset management system operated by the recording agency and/or one or more contracted parties (e.g. monitoring agency, instrument servicing agency, or testing laboratory).

9.3.1 Records of instruments

All certificates, forms, assessments, and associated information related to instrument calibration, validation, condition checks, servicing, and replacement shall be preserved, indexed, searchable, and permanently retained in an accessible form. An asset management system or instrument database may be used for this instrument history.

Include calibration and servicing information provided by the manufacturer, or servicing agent if different from the manufacturer, and test and service records created by the monitoring agency, in the instrument history.

It is useful to also maintain a readily accessible collated timeline of these events for each instrument, to help with verifying correct assignment of quality codes to data obtained using the instrument.

Note: Although the purpose of the event timeline is for internal operations, time-series Equipment Comments (see Section J 7.3.2) and Operational Comments (see Section J 7.3.3) can be a convenient way to provide and maintain it in the absence of suitable reporting functions from the asset management system or instrument database.

9.3.2 Checks of automated quality control and quality assurance

All records of regular checks of automated quality control and/or quality assurance algorithms shall be suitably archived and retained indefinitely (see Sections J 1.8.6 and 3.6.1).

9.3.3 Records of audits

The following records of data audits shall be suitably archived and retained indefinitely:

- a copy of the audit report (see Sections J 8.2 and 7.3), and
- a summary of any recommendations and actions arising from the audit.

9.3.4 Records of equivalency testing

Preservation of quality assurance records associated with, or arising from, a laboratory's internal activities is the responsibility of the laboratory (see Section J 6.2.1).

Field and sample records, and official laboratory reports, are required to be preserved indefinitely as original records (see Section J 9.1).

All equivalency testing metadata shall be suitably archived and retained indefinitely (see Section J 4.4).

9.4 Documents

The following documents must be stored indefinitely, maintained with editing and version control, and if electronic be backed up regularly, as essential air quality particulate metadata:

- the monitoring objectives and sampling design (see Section J 1.8.1)
- templates and/or blank forms (see Section J 1.8.3)
- laboratory contracts (see Section J 6.2.1)
- site assessments and screening surveys (see Section J 1.8.1)
- site access agreements (see NEMS *Air Quality: Particulates* v1.0.0 Section 1.3.1), and
- data access agreements, waivers, and/or copyright restrictions that constrain dissemination of the data.

9.4.1 Electronic document stores

Electronic document stores are now common. They may be:

- a corporate facility that is part of the same database used to store the measured PM_x data
- a corporate facility that is separate from the measured PM_x data, or
- a document store facility within the dedicated system that is also storing the measured PM_x data, e.g. within a time-series manager.

If an agency uses one or more electronic document stores for air quality particulate metadata, include a description of what is stored where, and procedures for their use, maintenance, and the indefinite preservation of the documents stored within them, in the formal documentation of the data management system (see Section J 1.8).

10 Data exchange

10.1 Data acquisition

Air quality particulate monitoring stations may be operated by an agency that is not the recording agency, with data transferred manually or automatically to the recording agency. Automatic push or pull of data is recommended to reduce human error,

What data are being transferred, and in what form, shall be agreed and fully documented to ensure data are received, stored, and ultimately interpreted appropriately.

Record of the site setup(s) and data transfer protocols must be collated and maintained and provided to the recording agency to incorporate in their site/station history/file and summarise in the site metadata.

Procedure shall be developed, documented, and implemented to ensure:

- data transfer between agencies is controlled and traceable
- automated systems are tested on or before commissioning and regularly checked, with test results logged and retained
- it is clear to both parties who has responsibility for:
- data verification
- initial quality coding
- preservation and permanent storage of original data, and
- collation and permanent storage of metadata.
- data types are aligned, or suitable tested, controlled, and traceable transformations are applied, and
- data subsequently changed are reported back to the collector.

10.2 Data supply and publication

The final dataset is the quality assured dataset, including quality coding. This is the dataset to supply to Ministry for the Environment and other clients, and to be used for publications, whether on the web or in reports. This dataset shall be retained indefinitely.

10.3 Data migration and integration

Data migration and/or integration into another database requires planning and careful execution to avoid data corruption and/or loss.

Agencies should consider the following aspects:

- Previous migration(s) may not have been complete, or the data migrated may have contained errors, or the migration process may have introduced errors.
- Preservation and security of, and future access to, legacy data that cannot or will not be incorporated into the new system.
- Any migration or integration must not corrupt data. For air quality particulate data, special attention should be given to any averaging applied and data types used and required.
- Fields in the old system may contain data that is not 'true to label', i.e. they have been used to store data they were not designed and/or named for.
- The need to re-establish links to essential metadata that is not stored with the data, e.g. site histories, monitoring programme and data management system documentation, equivalency test or co-location study records, and instrument records including calibration and validation history.
- Extra care is needed when using spreadsheets as intermediaries. Field overflows, cell formatting controls, and date formats can all introduce problems.
- Migrating to a temporary or test version of the new system, with planned quality control checks carried out between the old and new, e.g. by randomised comparisons and/or running standard reports on both systems, before release of a production version of the new system in which all issues identified on the temporary or test system are resolved.
- Resourcing of a period of user feedback and fault fixing on the new system as part of the migration and/or integration plan.

11 References

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Appendix J.1 Adjusting Concentrations to Standard Temperature and Pressure

Concentrations measured as mass per unit volume are sensitive to ambient temperature and pressure variations but can be standardised by adjusting measured values to standard temperature and pressure (STP). Standard temperature and pressure for New Zealand are 0°C (273.15 K) and 1 atmosphere (1013.25 hPa).

For particulate matter the US Code of Federal Regulations (1994) instructions are to calculate the average flow rate over the sampling period then correct it to reference conditions (i.e. STP) using the following equation before calculating the weight-volume concentrations.

$$Q_{std} = Q_{av}\left(\frac{P_{av}}{T_{av}}\right)\left(\frac{T_{std}}{P_{std}}\right)$$

where:

Q_{std} = average flow rate at STP (L/minute)

Q_{av} = average flow rate at ambient conditions during the sampling period (L/minute)

P_a = average barometric pressure during the sampling period, or average barometric pressure for the sampling site (hPa)

T_{av} = average ambient temperature during the sampling period, or seasonal average ambient temperature for the sampling site (K)

P_{std} = standard pressure of 1013.25 hPa

T_{std} = standard temperature of 273.15 K (0°C)

Worked example:

24-hour sampling

Sampling flow rate 16.7 L/min.

Ambient temperature 15°C

Ambient pressure 990 hPa

PM_{10} filter load of 4.0 mg

then:

Actual volume sampled = (16.7 × 60 × 24) ÷ 1000 = 24.048 m^3

Adjusted volume sampled = 24.048 × (990/288.15) × (273.15/1013.25) = 22.273 m^3

Measured PM_{10} concentration = 4000/24.048 = 166.3 µg/m^3

Adjusted PM_{10} STP concentration = 4000/22.273 m^3 = 179.6 µg/m^3

Barometric pressure and altitude

Barometric pressure change with altitude is given by:

$$P_{atm} = P_{ref}(1 - 2.25577 \times 10^{-5} h_{alt})^{5.25588}$$

where:

$P_{atm} =$ barometric pressure at altitude (hPa)

$P_{ref} =$ reference barometric pressure (hPa)

$h_{alt} =$ altitude difference in metres (m)

With a reference pressure of 1013.25 hPa (standard pressure at sea level), the pressure at an altitude of 400m would be 966 hPa.

At an elevation another 400m higher, the pressure would be 966 × 0.953 = 921 hPa.

Appendix J.2 Effect of Data Type on Data Averaging

Data type is an essential feature of time-series management systems (see Section 1.1).

Choice of data type for PM_x data must be made carefully to ensure the data collected is represented correctly and the various averages required for reporting are calculated correctly.

The following graphs show the effect of data type on the calculation of hourly averages from 10-minute data. For PM_x reporting, daily averages are then calculated from the hourly averages and annual averages are calculated from the daily averages.

In Figure J 3 the data elements (values and their timestamps) are numerically identical but represented differently.

In one case, values are instantaneous measurements at 10-minute intervals with straight-line interpolation between successive elements creating the continuous series from which values at any time may be extracted from along the line.

In the other case, each value is the average over the preceding interval. At any time within each 10-minute interval the value extracted will be the same, i.e. the average for that interval.

For example, from Figure J 3 the PM_{10} value at 08:25:00 would be interpolated as 64.5 $\mu g/m^3$ from the instantaneous series but 80 $\mu g/m^3$ from the average in preceding interval (histogram) series.

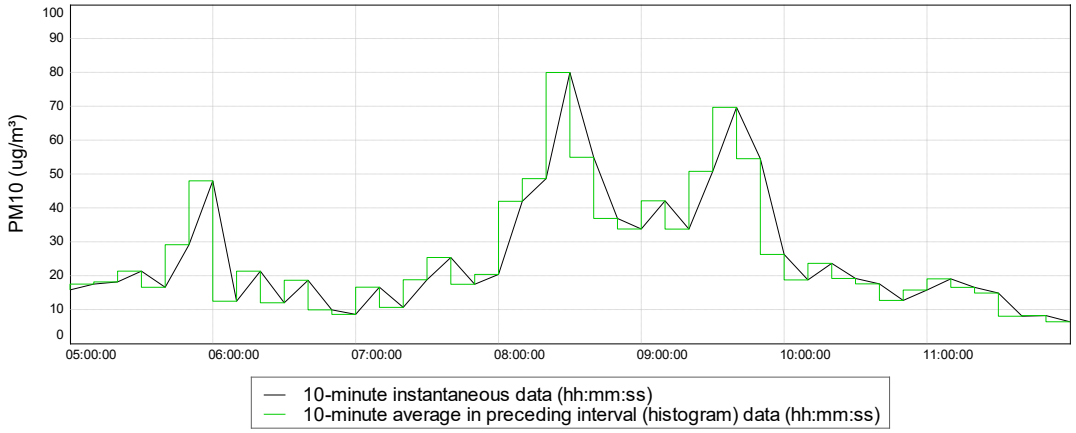


Figure J 5 – 10-minute data values stored as data type instantaneous (black trace) compared with the same values stored as data type average in preceding interval (histogram) (green trace).

Because the instantaneous series is continuous, with values able to be interpolated within each 10-minute interval, it is possible to calculate an average for each interval from the instantaneous data. The time-series engine integrates under the line then divides by the duration of the averaging interval, which in this case is ten minutes. Figure J 4 shows that this produces a different set of 10-minute averages than those measured and represented as 10-minute averages in the first place.

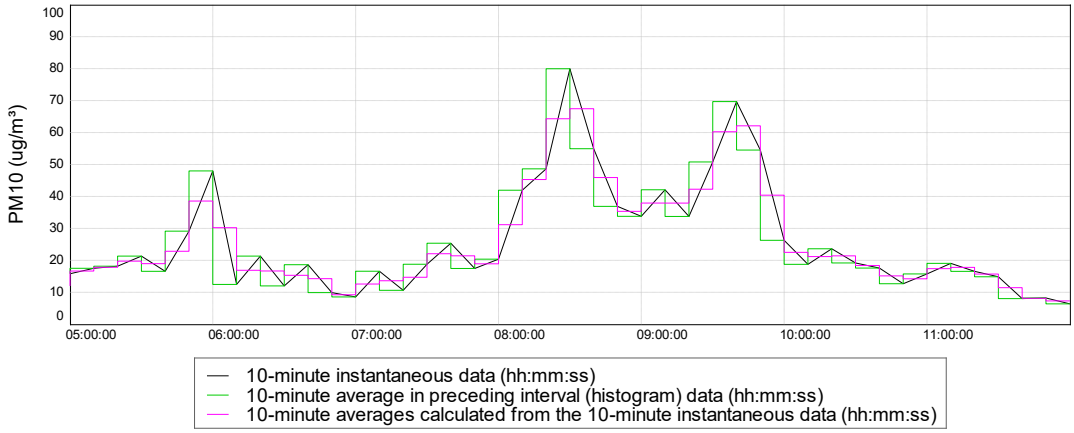


Figure J 6 – 10-minute data values stored as data type instantaneous (black trace) compared with the same values stored as data type average in preceding interval (histogram) (green trace), and with 10-minute averages calculated from the 10-minute instantaneous data (magenta trace).

To calculate hourly averages from the 10-minute data the time-series engine applies the same integration algorithm but, in this case, the averaging interval is one hour. Figure J 5 shows the hourly averages calculated from the instantaneous 10-minute data. Figure J 6 shows the hourly averages calculated from the average in preceding interval (histogram) 10-minute data. Figure 7 shows the two sets of hourly averages compared, with differences apparent.

Daily averages calculated from the hourly values would also then differ, as would annual averages calculated from the differing daily values.

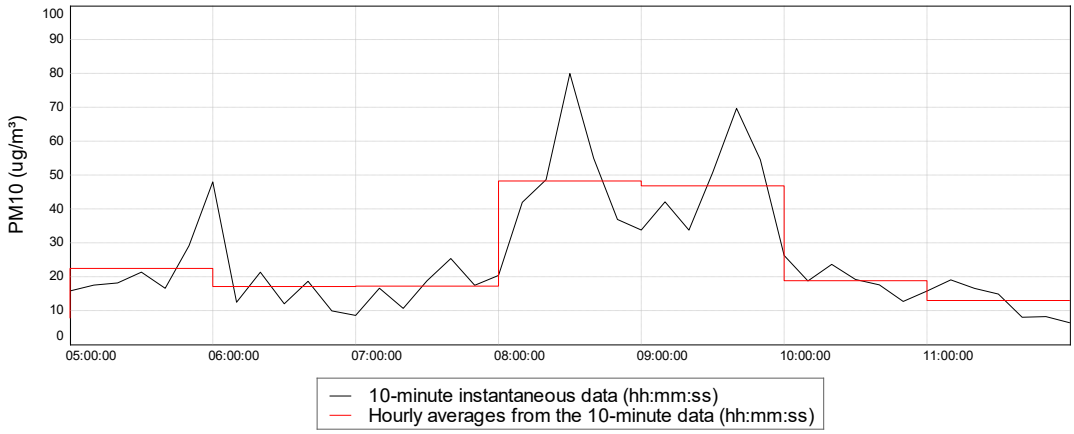


Figure J 7 – 10-minute data values stored as data type instantaneous (black trace) and the hourly averages calculated from that data (red trace).

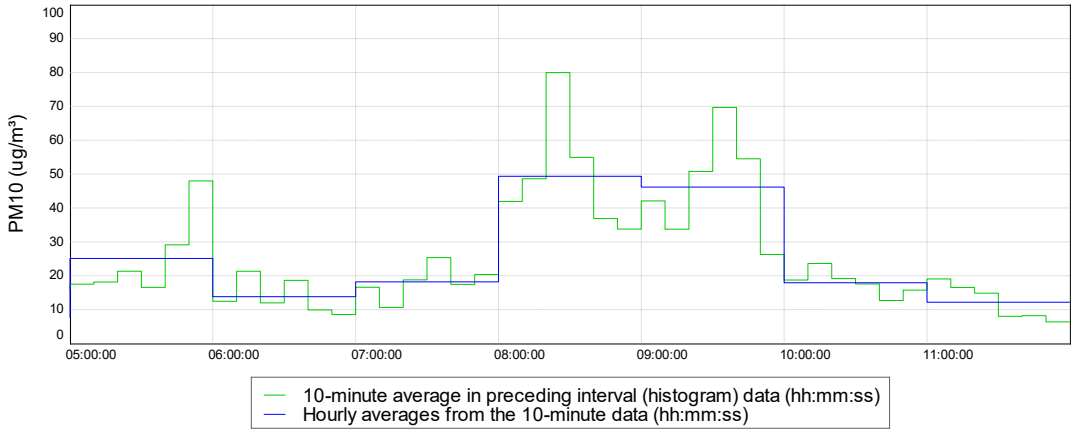


Figure J 8 – 10-minute data values stored as data type average in preceding interval (histogram) (green trace) and the hourly averages calculated from that data (blue trace).

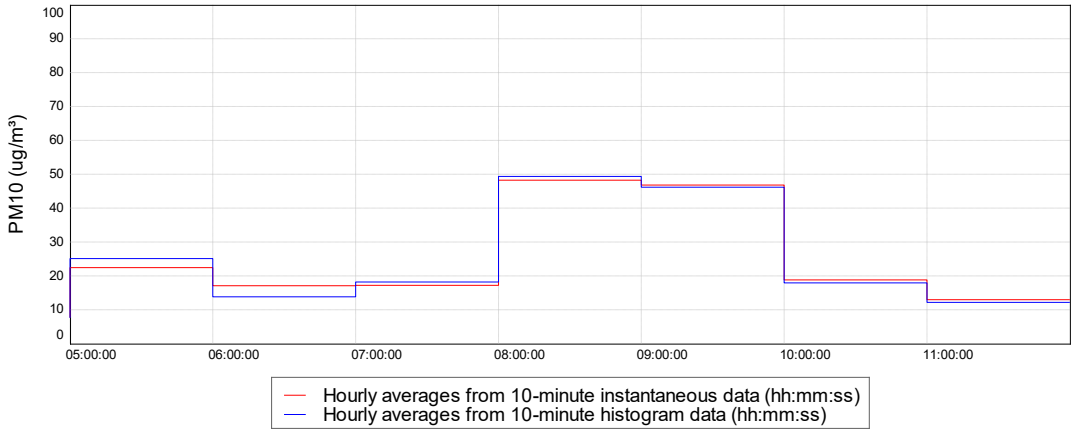


Figure J 9 – Hourly averages calculated from 10-minute values stored as data type instantaneous (red trace) compared with hourly averages calculated from the same 10-minute values stored as data type average in preceding interval (histogram) (blue trace).