User guide to fine resolution (15 Minute) data

Version Number: 1.6

Document Description
This document is a user guide to the data produced at a 15-minute temporal resolution on the North Wyke Farm Platform (NWFP). The guide describes the NWFP design, instrumentation, data collection, quality control and management.

Associated Documents	**Description**
FP_UG.Doc.001_Estab&Develop	Establishment and continued development of the NWFP

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Change Record

Version Number	Date	Changes Made
1.1	10/03/2016	Minor typo and format changes: Capitalization of words in headings Appendix 1: justification of header and added colour
1.1	22/03/2016	Superscript degrees in longitude/latitude coordinates
1.1	29/03/2016	Change location names on Figure 1
1.1	30/03/2016	Figures 6 & 7 swapped round
1.2	04/04/2016	Appendix 4 altered for details on summary statistics
1.3	18/07/2016	Appendix 4 altered for further details on summary statistics (notes on missing data)
1.3	22/07/2016	Figure 3 changed due to typo in legend
1.4	06/09/2016	Conductivity changed to specific conductivity throughout.
1.5	01/03/2017	YSI EXO 2 sensor upgrades including addition of FDOM sensors Turbidity units changed from NTU to FNU Data transfer via fibre optic network Nitratax calibration units (p18) and units in Appendix 3 corrected. Units for flow corrected on p12, Table 2 and in Appendix 3. New YSI EXO 2 sensor specifications added to Appendix 3. Information added regarding changes to the latest quality controlled version of datasets and additional data added. This can be found in Section 7.1. New information added to Quality Control section and associated tables updated and rearranged. Appendix numbers have been changed. Appendix 5 added
1.6	04/12/2018	Document edited to reflect changes made to data available on the data portal (data version 3) - outlined in Section 7.1. Addition of different sensors & data available i.e. FDOM, Ortho-P. All references made to DOC measurements removed as data unreliable and thus unavailable. Field numbers added to Table 1. Additional reference for citation of data-sets added to Section 7.

Preface

The North Wyke Farm Platform (NWFP) represents a large investment by BBSRC in the future, to not only study, but also to improve grassland livestock systems. The NWFP is a national and global research asset linked to real-world farming. It is a world-class facility and a key member of the Global Farm Platform network http://www.globalfarmplatform.org/ which attracts researchers from different communities and disciplines seeking to develop sustainable ruminant production systems. It provides access to a range of in situ state-of-the-art instrumentation in the hydrologically isolated (sub-) catchments to better address key issues in sustainable agriculture related to:

- Replacement of N fertiliser with N-fixation by legumes - achieving a reduction in energy and Greenhouse Gas emissions for both environmental and economic reasons.
- Using plants to manage soils and hydrology in green-engineering solutions to flooding.
- Efficient phosphorus cycling in grassland systems.
- Resilience of soil biota and their functions in land-use change.
- Impact of grassland management on carbon cycling and storage.
- Water resource use efficiency.
- Systems modelling to design optimal grassland production systems.

The NWFP provides three farming systems in farmlets, each consisting of five component catchments comprising approx. 21 ha in total per farmlet. Each farmlet is managed using alternative approaches to livestock production from grassland. Measurements on water, air and soil are all recorded. Much of this data has a fine-scale (15 minute) temporal resolution, such as water flow and water chemistry data measured at a flume for each of the 15 catchments, which can comprise either single or multiple fields. As a UK National Capability, the data collected are made publicly available.

The main farming systems or 'treatments' on the platform are currently:

1) Permanent pasture: improvement through use of inorganic fertilisers (Green farmlet).
2) Increased use of legumes: replacing nitrogen fertilisers with biological fixation using sown legume and grass mixtures (Blue farmlet).
3) Planned reseeding: regular renewal, providing opportunities for introducing innovative varieties with desirable traits. Currently, high sugar and deep rooting grasses are studied (Red farmlet).

See more at: http://www.rothamsted.ac.uk/farmplatform

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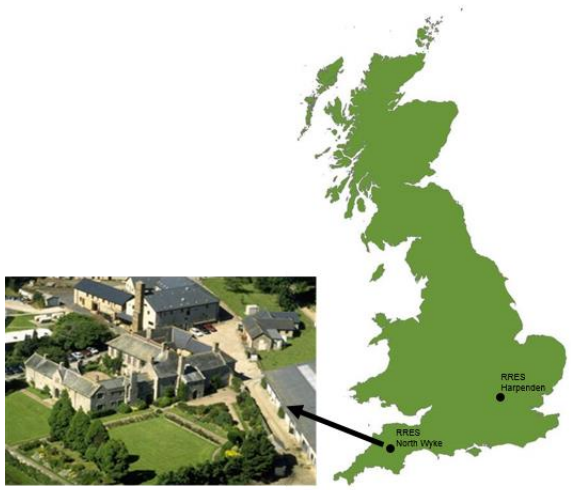
1 Introduction

The North Wyke Farm Platform (NWFP) was established during 2010 to 2011 and is a National Capability funded by the Biotechnology and Biological Sciences Research Council (BBSRC) to promote collaborative research, training and knowledge exchange on productivity and ecosystem responses to management practices of agricultural lowland grasslands in the UK. The platform uses state-of-the-art technology to capture data at appropriate scales of land management which can be used to model how agricultural grassland systems will respond to different management inputs and to help develop a better understanding of the underlying processes and mechanisms. This document is intended to be a user guide to the data produced at a 15-minute temporal resolution on the NWFP. The guide describes the NWFP design, instrumentation, and data quality checks.

2 Farm Platform Design

The NWFP is located on the Rothamsted Research, North Wyke Farm in the South West England (50^{0}46'10" N, 3^{0}54'05" W) with an average annual rainfall of 1031mm (for the 30-year period 1984 to 2013) (Figure 1). The NWFP is located on a ridge at 120 – 180 m above sea level, where the land slopes down on the west to the River Taw and on the east to one of its tributaries, the Cocktree stream. A prominent feature of the site is the presence of clay-rich sub-soils beneath the sub surface horizons. The soil is predominantly of two similar series, Hallsworth and Halstow, that comprise of a slightly stony clay loam topsoil (approximately 36% clay) overlying a mottled stoney clay (approximately 60% clay), derived from carboniferous culm measures [Harrod T.R and Hogan D.V, 2008]. Below the topsoil layer, the subsoil is highly impermeable to water and is seasonally waterlogged with most excess water leaving by surface and sub-surface lateral flow across the clay layer to be intercepted by the bounding drainage system at the edge of each sub-catchment (Figure 2). The clay-rich nature of the NWFP soils was a key factor in

Figure 1. Location of the NWFP



making this farm-scale experiment viable. The NWFP is comprised of three individual 'farmlets' of approximately 21 ha, each of which consists of five (sub-) catchments, with each catchment (15 in total) hydrologically isolated through a combination of topography and a network of 9.2 km of French drains (800 mm deep trenches containing a perforated drainage pipe backfilled to the surface with 20-50 mm clean granite, carbonate-free, stone chips) which were constructed at the edges of the catchments.

As of October 2015, six of the 15 catchments have field divisions, resulting in 21 fields in total across the NWFP. The name and size of the individual fields making up the sub-catchments are given in Table 1.

Catchments were allocated to each farmlet primarily based on:

- Historical farm practices.
- Expert knowledge of the physical properties of the North Wyke site.
- A required spatial connectivity between the five catchments of each farmlet.
- Farm/research operational requirements.

Over a two-year period, from 1 April 2011 to 31 March 2013, beef cattle and sheep grazing systems were operated under the same management guidelines on all three farmlets enabling productivity, water quality and water quantity parameters to be measured on the existing permanent grassland to provide a baseline prior to management changes. From 1 April 2013, two of the farmlets entered a "transition" phase, where they progressively moved towards the following treatments (Figure 3):

1. **Increased use of legumes**: replacing nitrogen fertilisers with biological fixation using sown legume and grass mixtures (Blue Farmlet).
2. **Planned reseeding**: regular renewal, providing opportunities for introducing innovative varieties with desirable traits e.g. high sugar grasses (Red Farmlet).
3. **Permanent pasture**: Sward improvement of the existing grassland through the use of artificial fertilisers (Green Farmlet).

For more detail see FP_UG.Doc.001_Estab&Develop which describes the establishment and ongoing development of the NWFP since its establishment in 2010.

Table 1. Name of catchment, field number, field and area contributing to each catchment flume on the three NWFP farmlets as of 2015.

Red Farmlet	Field Number	Field Names	Fenced area (ha)	Total Fenced area (ha)	Total Hydrological area (ha)
Catchment 1	NW001	Pecketsford	3.50	4.81	5.00
	NW038	Little Pecketsford	1.31		
Catchment 2	NW002	Great Field	6.65	6.65	6.79
Catchment 3	NW003	Poor Field	3.92	6.62	4.03
	NW004	Ware Park	2.71		2.81
Catchment 10	NW015	Lower Wheaty	1.82	1.82	1.94
Catchment 15	NW019	Longlands East	1.54	1.54	1.62
Total				**21.4**	**22.2**
Green Farmlet	**Field Number**	**Field Names**	**Fenced area (ha)**	**Total Fenced area (ha)**	**Total Hydrological area (ha)**
Catchment 4 Pre-Aug 2013†	NW006	Burrows	6.39	11.12	11.55
	NW005	Bottom Burrows	1.26		
	NW007	Top Burrows	3.47		
Catchment 4 Post-Aug 2013†	NW006	Burrows	6.49	7.75	8.08
	NW005	Bottom Burrows	1.26		
Catchment 5 Pre / Post Aug 2015‡	NW008 / NW045	Orchard Dean North	2.55	6.47	6.73
	NW008 / NW046	Orchard Dean South	3.92		
Catchment 6	NW009	Golden Rove	3.86	3.86	3.95
Catchment 12	NW016	Dairy North	1.78	1.78	1.87
Catchment 13	NW017	Longlands South	1.75	1.75	1.81
Total pre-Aug 2013				**25.0**	**25.9**
Total post-Aug 2013				**21.6**	**22.4**
Blue Farmlet	**Field Number**	**Field Names**	**Fenced area (ha)**	**Total Fenced area (ha)**	**Total Hydrological area (ha)**
Catchment 7	NW012	Lower Wyke Moor	2.60	2.60	2.71
Catchment 8	NW011	Middle Wyke Moor	4.32	7.02	7.33
	NW10	Higher Wyke Moor	2.70		
Catchment 9	NW013	Dairy South	6.45	7.75	7.91
	NW039	Dairy Corner	1.30		
Catchment 11	NW014	Dairy East	1.76	1.76	1.85
Catchment 14	NW018	Longlands North	1.72	1.72	1.78
Total				**20.8**	**21.6**
Total NWFP Area pre-Aug 2013†				**67.2**	**69.7**
Total NWFP Area post-Aug 2013†				**63.8**	**66.2**

†At the start of the Farm Platform, the Burrows Catchment 4 consisted of 3 fields, Bottom Burrows, Burrows and Top Burrows, which made up a total area of around 11 ha. As the Green farmlet (25 ha) was considerably larger than the Red farmlet (21.4 ha) and the Blue farmlet (20.8 ha), it was decided to remove the Top Burrows field, which has an area of 3.47 ha, from the Farm Platform, in order for all farmlets to be of a similar size. In order to isolate the Top Burrows field, additional French Drains were constructed to intercept and divert water draining from Top Burrows away from Flume 4. This work was completed 13 August 2013.

‡*See section 4.2 in Establishment and Development of the NWFP (FP_UG.Doc.001_Estab&Develop).*

Figure 2. Soil map and typical soil profile of the NWFP

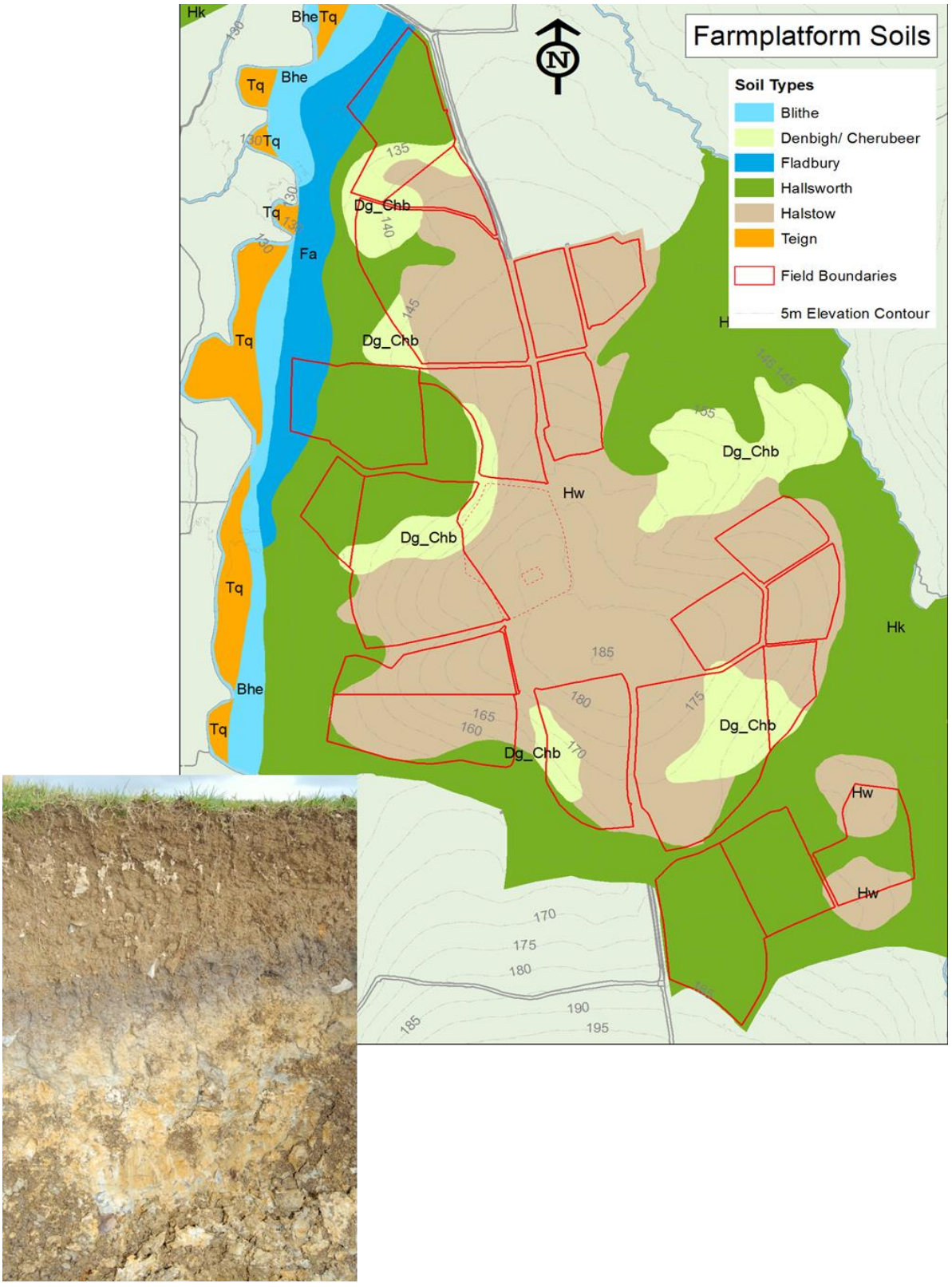


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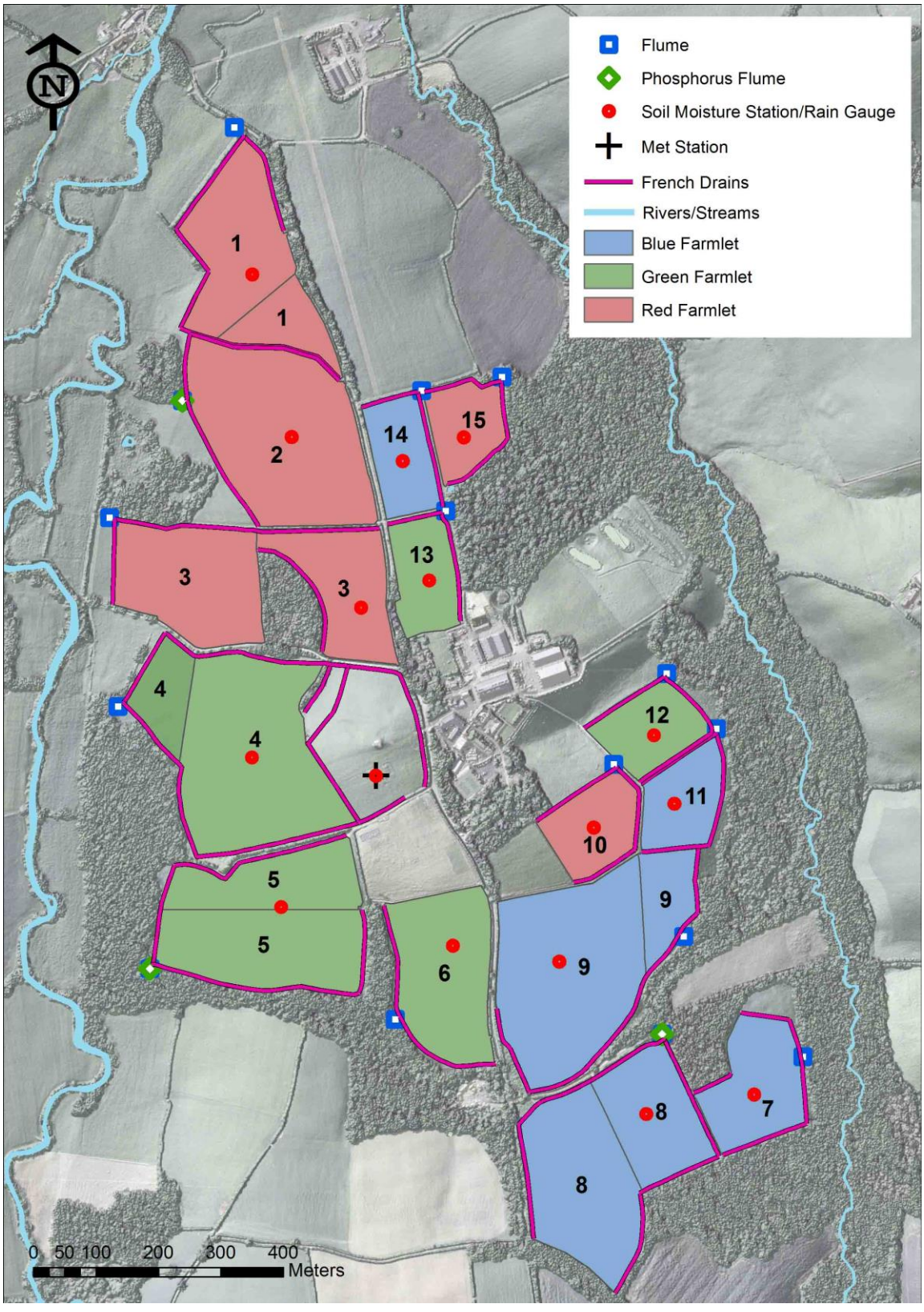
Figure 3. The North Wyke Farm Platform. Numbers represent catchment number.



3 Instrumentation

3.1 Telemetry

Central to the NWFP is the communication network that provides continuous data transfer from the *in-situ* sensors. Transfer of data from the catchment flume cabins is facilitated using NetDL1000 loggers [OTT hydromet, Loveland, CO., USA], that transmit via ftp over the fibre optic network. Data transfer from the soil moisture station sensors (Section 3.4) and meteorological sensors (Section 3.5) is via Adcon (Adcon, Austria) remote telemetry units (RTUs), which collect in-field data at configured intervals and transmit via UHF radio. Other telemetry components include:

1. A centrally located base-station (A850 Gateway) which manages the RTU network, receiving the data as well as having the capability to send commands back to the RTUs if required.
2. Software (AddVantage Pro), which collects, stores, processes and displays the data via its integrated web server.

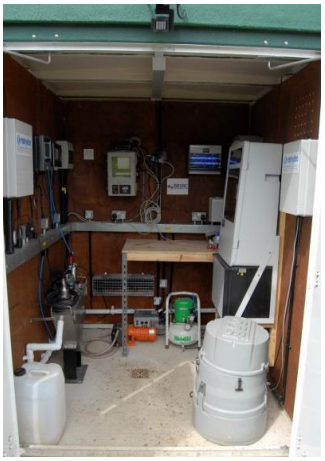
At present the NWFP, the telemetry network collects data from over 250 sensors every 15 mins.

3.2 Monitoring Hydrology

Each of the catchments drains to a single monitoring station supplied by two branches of each French Drain system which join in a confluence pit. The quantity of discharge from each catchment is measured through a combination of primary and secondary flow devices. The primary devices are H Type flumes [TRACOM Inc., Georgia, USA] with capacity designed for a 1 in 50-year storm event (Figure 4). Flumes are fixed engineered structures that intercept and channel free-flowing liquids in such a way that flow rate can be determined by a known relationship (rating curve) between the height of the liquid at a single specific location in the flume and its flow rate. The specific design of the H flume facilitates the accurate measurement of both low and high flows and is relatively self-

Figure 4. Example of an H-Flume

Figure 5. Interior view of one of the flume laboratories



cleaning since it allows the ready passage of sediment and particulate matter [ISCO open channel flow measurement handbook, 2008]. The choice in size of the flumes installed on the NWFP was determined by size of the catchment they are servicing and are 1'6" (450mm), 2'0" (600mm) and 2'6" (750mm); see Appendix 1. Pressure level sensors [OTT hydromet, Loveland, CO., USA] are the secondary devices that are used to measure the depth of water by means of an integrated controller and ceramic pressure-measuring cell. The output data are converted to flow (L s^{-1}) externally using the formulas given in Appendix 1.

Each catchment site has a cabin or flume laboratory (Figures 4 & 5) which houses telemetry devices, pumping equipment, and a by-pass flow cell which contains sensors to measure various water quality parameters, the specifications of which are described in Appendix 3.

3.3 Monitoring Water Quality

A complication with the *in-situ* measurement of water quality of discharge from land is that flow is discontinuous since it is linked to soil moisture conditions and rainfall events. Sensors often require permanent submersion in water to prevent them drying out. Thus, water from a sump in the conduit that supplies the flume from the confluence pit (Figure 6) is automatically pumped every 15 mins into the cabin and into a bespoke stainless-steel by-pass flow cell that holds 13 litres and houses the sensors (Figure 7). Water is pumped into and out of the base of the flow cell and this, coupled with the V shape design, ensures that there is no build-up of sediment or particulate matter either between samples or over time. Water is pumped into and out of the flow cell whilst flow conditions allow, but when flow drops below a critical threshold the pumping cycle stops and the volume of water in the flow cell is retained, thus keeping the sensors submerged. The pumping cycle is controlled through a combination of the data from the level sensor, the NetDL 1000 data logger, a programmable logic controller (PLC) and a bi-directional peristaltic pump. The level data is processed by the NetDL logger and a signal sent to the PLC according to the following conditions:

1. If a flow data point is equal to or greater than 0.2 L s^{-1}: Activate PLC programme

2. If a flow data point is equal to or less than 0.18 L s^{-1} the signal is switched off via the same process.

Figure 6. Water sampling point in conduit.

Figure 7. By-pass flow cell

The signal is connected to a PLC LOGO [Siemens AG, Munich, Germany] holding a programme which activates the pump [621VI\R, Watson-Marlow Inc., Massachusetts, USA] as well as controlling its speed and direction via a 4-20 mA connection. To prevent synchronization issues[1] with other instruments the PLC runs a sub-routine, a timer on a loop, only allowing the main programme to be activated for a 1 min period every 15 mins. Once activated the main PLC programme runs on a 900 sec cycle, first running the pump in reverse to empty the cell for 100 secs, then holding for 10 secs to allow previously sampled water to flow away before running forwards for a further 100 secs to refill the cell. The programme then holds for 680 secs before repeating. This cycle will continue until the PLC no longer receives a switch on signal, which will result in the previous sample being held in the by-pass cell until flow conditions rise above the 0.2 LPS threshold.

Flow conditions are checked every minute and the switching on and off of pumps controlled in-situ. The Net DL 1000 outputs a signal to the programmable logic controller (PLC) whenever the flow threshold is reached, triggering it to run its routine.

Within the flow bypass cells are 3 instruments, each synchronised with the pump filling cycle to take measurements shortly after a fill has completed every 15 mins (Figure 8). The first is a multi-parameter sonde [YSI [Xylem Inc Rye Brook, New York, U.S] Originally 6600V2 sondes were used that hold 5 sensors measuring 7 water quality parameters including

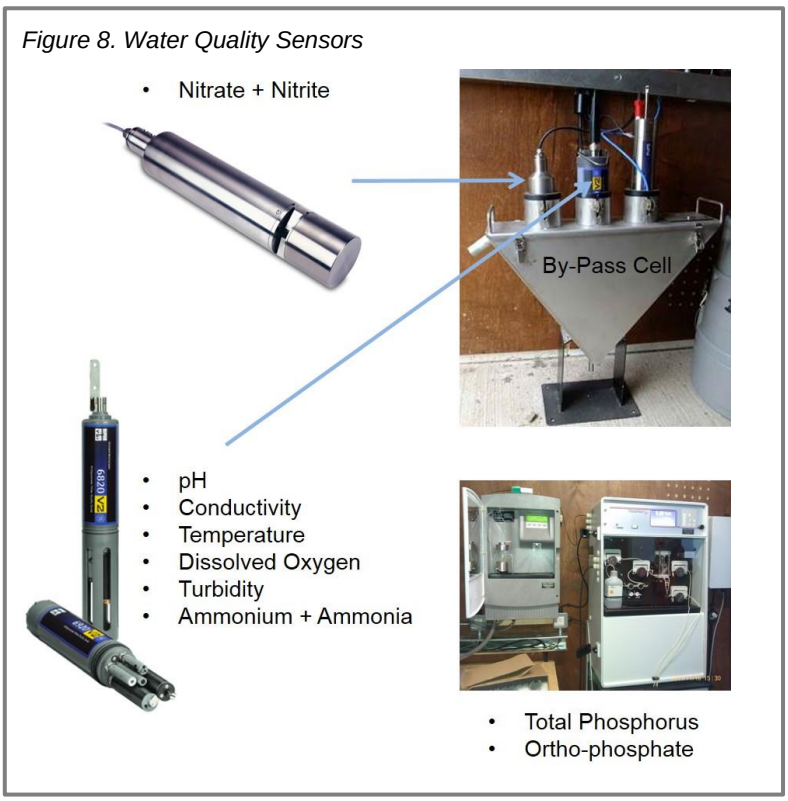
[1] Up until May 2016

dissolved oxygen and turbidity, measured by self-cleaning optical sensors; specific conductivity and temperature, pH and ammonium (NH4+) and ammonia (NH3), measured by an ion selective electrode (ISE)[1].

During May – September 2016 the YSI 6600 water quality multi-parameter sondes were upgraded to YSI EXO 2 sondes. In addition, fluorescent particulate dissolved organic matter (fDOM) sensors were added on the YSI platform as a proxy for dissolved organic carbon / total organic carbon (see Appendix 3 for sensor specifications). The sonde communicates directly with the NetDL loggervia an SDI-12 interface (Serial Data Interface at 1200 baud).

The NWFP has two complete sets of sensors for the EXO2 sondes, allowing one set to be calibrated in the lab while the other set is deployed in the field. The sets are rotated once every month, minimising downtime and ensuring continuous high data quality. Details on the updates for sondes are given in Appendix 3.

Figure 8. Water Quality Sensors



Combined nitrate-N and nitrite-N (NOx-N) are measured by a dedicated, self-cleaning, optical UV absorption sensor [NITRATAX Plus SC, Loveland, Colorado, USA]. Nitrate dissolved in water absorbs UV light at wavelengths below 250 nm, so by passing UV light through the medium and measuring the absorption using a 2-beam turbidity compensated photometer, the NOx-N concentration is calculated (Figure 8).

Total phosphorus (TP) and/or inorganic P (Ortho-P) are measured only at flume cabins on Catchments 2, 3, 5 and 8. A sample is collected from the sump by a separate device [SIGMATAX 2, Hach, Loveland, Colorado, USA)] which homogenises the sample using ultra-sound before passing it to a process photometer [PHOSPHAX sigma, Loveland, Colorado, USA]. The measurement of TP and ortho-phosphate on the NWFP is not a continuous

automated process, unlike the other water quality parameters, as the instruments need to be manually switched on and shut down according to flow conditions. The data are transferred to the same telemetry system via a 4-20 mA current loop, but the devices are manually switched on and off as required, typically to monitor individual storm events or when base flow conditions are adequate to leave the instrument running for extended periods. (Figure 8).

3.4 Monitoring Soil Moisture, Soil Temperature and Rainfall

Each of the 15 catchments has a soil moisture station (SMS) sited at a central location, consisting of an RTU, a combination soil moisture and temperature probe (SM) and a rain gauge (RG) [Adcon, Austria] (Figure 9). The SM1 probe measures soil moisture through capacitance at depths of 10cm, 20cm[2] and 30cm[3], and soil temperature at 15cm. However, only soil moisture data at 10cm are available on the data portal as data at the lower depths were deemed unreliable for this soil series. The direct connection to the RTU is via a SDI 12 interface and the raw data is converted to soil moisture using a lookup table developed from testing the sensor output in blocks of North Wyke soil at a range of conditions.. Data from the tipping bucket rain gauge are collected by the RTUs integrated pulse counter at a resolution of 0.2mm per tip. Changes in the soil moisture stations sensing technology are detailed in Appendix 3. The original SMS station for Catchment 4 was located within the MET compound, however, the change in area of Catchment 4 on 13 Aug 2013 (see the FP_UG.Doc.001_Estab&Develop document) resulted in the SMS station being located outside the catchment. A new SMS station was sited in the new Catchment 4 on 04/02/2015.

Figure 9. Soil moisture station with tipping bucket rain gauge

[2] Data not available on the Data Portal
[3] Data not available on the Data Portal

To provide a reliable dataset, the Catchment 4 data on the data portal start when the new SMS station was installed on 04/02/2015. The rainfall data have been included in the MET data and are available for download via the portal.

3.5 Meteorological Data

Two sets of instruments are co-located at the meteorological station shown in Figure 3 and these are:

1. Official UK Meteorological Office equipment.
2. NWFP dedicated equipment, with data collected since 29th April 2013.

The following meteorological variables are collected by the site-specific instruments: precipitation (mm) (installed in Nov 2011), air temperature (°C), relative humidity (%), wind speed (km/h), wind direction (in degrees) and solar radiation (W/m^2, installed in May 2014). NWFP meteorological data are collected at 15 min intervals. The tipping bucket rain gauge was phased out and replaced by a more accurate, Pluvio weighing RG installed in 12th April 2015 which can provide precipitation (mm) data at 1 min intervals (but currently not exported as such) and data for this is available from August 2013.

4 Calibration and Harmonisation

Many sensor calibrations or harmonisations directly relate to the quality control (QC) of the 15 -minute data. How this relates to the QC of the 15-minute data is detailed in Section 7.

4.1 Data Sondes

Up until May 2016 the NWFP used two complete sets of YSI 6600V2 sondes (incorporating Ammonium/Ammonia, Specific Conductivity/Temperature, Dissolved Oxygen, pH and Turbidity sensors), allowing one set to be calibrated in the lab while the other set was deployed in the field. The sets were rotated once every month, minimising downtime and ensuring continuous high data quality. When a set of sondes was returned from the field following a period of deployment, all sensors were checked in standards of known concentration and these data used to drift correct values during subsequent quality control procedures. Once drift checked the sondes were cleaned, pH sensors removed and placed in a pH 4 buffer, NH4 Ion Selective Electrodes (ISEs) removed and allowed to dry to prolong their lifespan. The

sondes were then stored in hydrated calibration cups for up to 1 month until they were calibrated prior to deployment.

From September 2016 onwards, water quality parameters are measured using YSI EXO 2 multi-parameter sondes. The different design of the sonde allows smart sensors to be plugged in and removed easily. Thus, 2 complete sets of sensors, rather than the whole sondes are now in use; one set deployed in the field whilst the other is calibrated and stored ready for use. An additional advantage is that a sonde in the lab can be mounted with multiple smart sensors of the same type for calibration, speeding up the process. The new calibration procedures are described below.

Ammonium/Ammonia ISE

Calibration: 2-point 1mg/l and 100 mg/l

Frequency: Monthly.

Replacement: Sensor modules replaced every 12 months

Additional info: 3-point calibrations are performed when new ISEs are used that includes a 1mg/l chilled standard. Following storage periods ISEs are re-hydrated by soaking for 24 hours in a 100 mg/l NH4 standard prior to calibration.

Specific Conductivity

Calibration: 1-point; 1413 µs/cm (Potassium chloride 0.01 mol/l solution)

Frequency: Quarterly (previously monthly)

Additional Info: Specific conductivity sensors also include a temperature sensor. This is checked as part of the calibration.

Dissolved Oxygen

Calibration: 1-point; 100% saturated air in a hydrated and aerated calibration cup.

Frequency: Quarterly (previously monthly)

Replacement: Membranes replaced every 18 months

pH

Calibration*:* 2-point; pH 7 and pH 4

Frequency: Monthly

Replacement: Sensors modules replaced every 18 months

Additional info: The pH sensor is integral to the performance of the Ammonium ISEs as the reference junction is shared by both sensors. pH sensors are replaced as soon as raw mV values drift outside the recommended manufacturers specification and decontamination following deployment is thorough.

Turbidity

Calibration: 2-point; 0 FNU[4] (RO water) and 124 FNU (previously 0 NTU and 126 NTU)

Frequency: Quarterly (previously monthly)

Fluorescent Dissolved Organic Matter

Calibration*:* 2-point 0 (RO water and 300 QSU (Quinine sulphate units)

Frequency: Quarterly

Additional info: None

4.2 Nitratax (NO_xN)

Nitratax UV absorption sensors remain *in-situ* and are calibrated monthly in the field. Sensor drift as a result of lens contamination is checked prior to cleaning the instrument lenses and wiper blades. Calculated values are used to back correct any drift.

Calibration: 2 point; 0 (RO Water) and 11.3 mg NO_{2+3}/l

Frequency: Monthly

Additional info: The instruments have an annual service including a 3-point factory calibration

[4] Formazin Nephelometric Units – changed from Nephelometric Turbidity Units (NTU). No conversion of the data values is necessary as a result of this change since the units are comparable. A full explanation for the change in unit of measurement can be found here:
https://www.ysi.com/ysi-blog/water-blogged-blog/2016/01/turbidity-measurements-tips-and-precautions

4.3 Phosphax (Total P & Ortho-P)

The Phosphax analysers perform their own daily calibration checks using a 2mg/l standard. The Phosphax takes about 15-minutes between sample collection and generation of a value. Furthermore, although the sampling interval is stated as 15 minutes by the manufacturers, in practice it is slightly more and so drifts from the point the machine is switched on. The time stamp given to data points is the time they were collected from the device by the logger and do not represent the sample time or the time the analysis completed. This will be at least 15-minutes after sample collection but could be as much as 30 minutes. An example of this would be if a sample was collected at 00:01, a data point would be available at 00:16 (and held on the devices current loop output) but not collected by the logger until the next 15-minute time period e.g. 00:30. The Phosphax has been set up so that every other analysis is either Total P or Ortho-P, thus each of these is measured every 30 mins.

4.4 Rain Gauges

Rain gauges are checked monthly in the field for basic functionality; and annually under laboratory conditions. A known quantity (500 ml) of water is dripped through them and the number of tips counted. If there is any difference between the expected and observed number of tips a correction factor is generated which can be applied to the data. Checks have been conducted annually since 02/04/2014. The decision was made not to correct the data, as the frequency of the checks made it difficult to determine the actual behaviour of the instruments in the field. The results of the checks are provided in Appendix 5.

4.5 Soil Moisture Stations

There are currently no specific calibration issues. However, following changes in the soil moisture sensing technology (Appendix 4), there exists an on-going data harmonisation issue between the use of new and old soil moisture sensors (see Section 7.1.1 & Appendix 2).

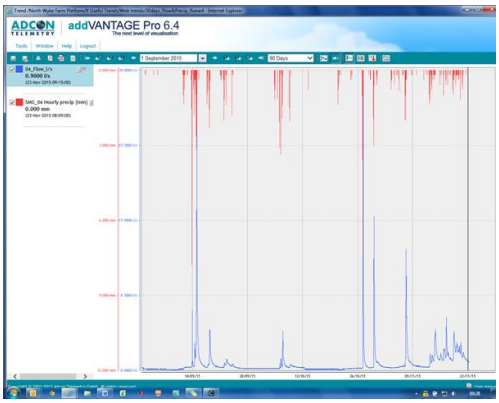
4.6 Met Data

There are currently no specific calibration issues. Issues with the Rain Gauge data, have already been discussed in section 4.4

5 Data Acquisition and Sensor Downtime Log

Raw data are collected from loggers in the field (NetDL1000 via FTP and Adcon RTUs via UHF radio) every 15 minutes and hosted by Adcon AddVANTAGE pro software, allowing for visualisation (Figure 10), data processing, automated control, event alarming and data export/distribution. An extension running within the software automatically creates and exports weekly CSV files for each parameter for archive and subsequent QC procedures.

Figure 10. Example of graphical display by the addVantage Pro software of hydrology and rainfall data for one of the catchments.



A log of all sensor downtime issues is maintained in MS Accesswhere input forms and restricted fields are used to ensure that the correct and required data is recorded. The information includes details on the location, the sensor, the start and end times the sensor was not functioning correctly, information about the problem and the required QC action (e.g. set recorded data as missing or add a 'unreliable' flag to the data). Exports from this worksheet are automatically used as part of the QC process. The sensor downtime log also serves of a useful reference when trouble shooting current sensor issues.

6 Quality Control and Associated Traffic Light System

Different levels of QC of the 15-minute data are possible. Each level of QC consists of a bespoke R (http://www.r-project.org) script on 4 weeks' worth of data at a time. The R script automatically and statistically processes data from the 15 SMS and RGs (3 variables at each), the 15 flume labs (14 variables at each) and the single Met site (6 variables).

Each 4-weekly set of data produces an outputted log-file (and associated reports) to enable any re-runs and further checks as required. Full details of the QC system, the current QC level, and the associated traffic light flagging system; together with how the QC is expected to evolve over time (via timely data releases) are given in Section 7. The QC system incorporates aspects of Sections 4 and 5, above.

7 NWFP Data Portal

The NWFP Data Portal (Figure 11) allows accessibility to the core NWFP data sets to not only Rothamsted but also the wider research community (https://nwfp.rothamsted.ac.uk/). The data are open access and free to download but users are required to register their interest.

- If you choose to use any of data-sets provided by the Farm Platform in a publication, please would you cite these papers:

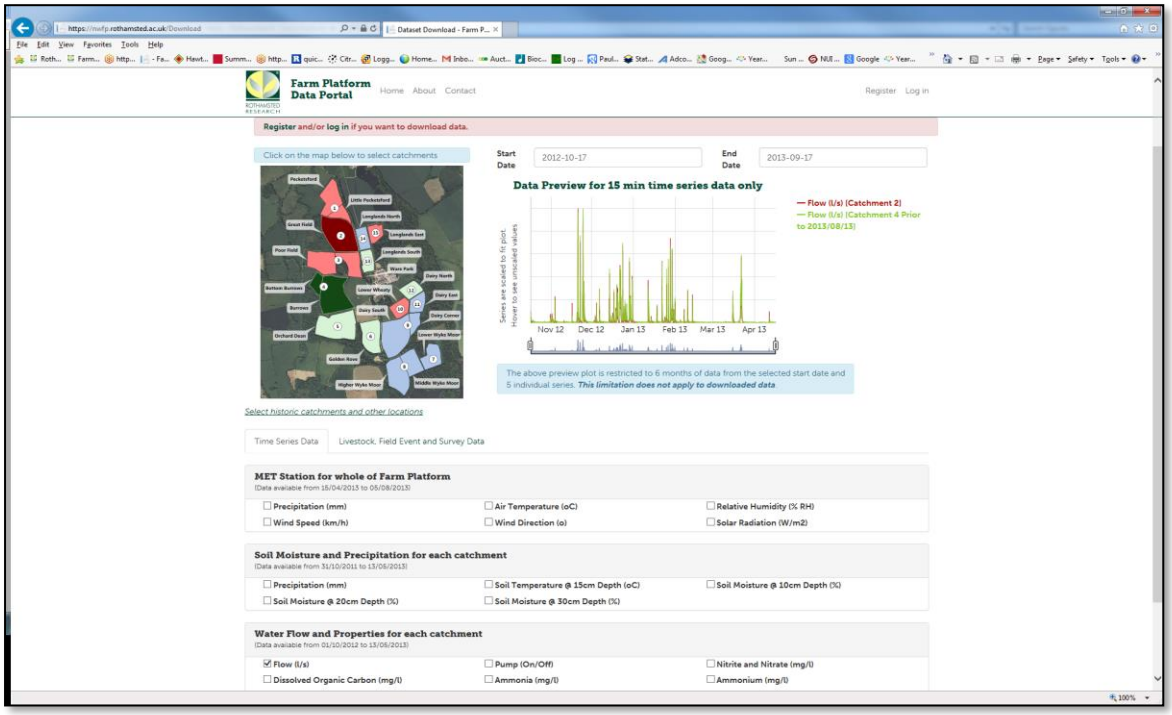
Orr R, Murray P, Eyles C, Blackwell M, Cardenas L, Collins A, Dungait J, Goulding K, Griffith B, Gurr S, Harris P, Hawkins J, Misselbrook T, Rawlings C, Shepherd A, Sint H, Tozer K, Wu L, Lee M (2016) The North Wyke Farm Platform: effect of temperate grassland farming systems on soil moisture contents, surface run-off and associated water quality dynamics. European Journal of Soil Science 67: 374-385.

Takahashi T, Harris P, Blackwell MSA, Cardenas LM, Collins AL, Dungait JAJ, Hawkins J, Misselbrook T, McAuliffe GA, McFadzean J, Murray PJ, Orr RJ, Rivero-Viera, MJ, Wu L, Lee MRF (2018) Roles of instrumented farm-scale trials in trade-off assessments of pasture-based ruminant production systems. Animal 12 (8): 1766-1776.

- In addition, please would you include the following paragraph in the acknowledgments section:

"The North Wyke Farm Platform is a UK National Capability supported by the Biotechnology and Biological Sciences Research Council (BBS/E/C/000J0100)"

Figure 11. NWFP Data Portal



7.1 Latest Version of 15 Minute Data on the NWFP Data Portal

On 01/12/2018 all existing Flume data was replaced with the latest quality controlled version and additional data have been added for the flumes, SMS and MET. Details of the QC data are given in Tables 2:6 below.

These changes affect the following 15-minute datasets:

Flume data: 01/10/2012 - 25/08/2018
SMS data: 18/01/2016 - 25/08/2018
MET data: 18/01/2016-25/08/2018 (Only Precipitation between 31/10/2011 – 29/04/2013).

7.1.1 Changes to the existing data since the last version (01/12/2018)

- **Flume Data**

  Flume data have undergone quality control and were flagged using the Sensor Downtime Log to identify potentially suspicious data. The previous version of these data on the Data Portal was drift-corrected, but these corrections have since been removed in order to be transparent with the data and to give the user the opportunity to apply drift correction using a methodology of their choice. Details of sensor drift can be found **here**, where all instrument drift data are still recorded

- **SMS 10 cm Data Harmonised**

  To harmonise the data collected from the 2 different firmware versions of the soil moisture probes, new conversion formulae were generated under experimental conditions and used to recalculate the data. The experiment was conducted as follows. A 1m^2 soil-block of Hallsworth series soil, as found on the Farm Platform, was moved undercover. The 2 firmware versions of the soil moisture probes were installed in the block. The soil-block was then saturated above field capacity and then allowed to dry naturally over a 6-month period. During this time, fortnightly measurements were taken from the probes and simultaneously a soil sample was removed from the block to coincide with the measurement depth(s). The soil sample was oven dried to measure the actual moisture content. The data from the probes and the oven dried samples were plotted against each other and fitted with a linear regression. No clear relationship was found for either the 20 cm or 30 cm depth results and thus these data from the probes were deemed unreliable for this soil series. Consequently, the 20 cm & 30 cm SMS data have been removed from the Data Portal, and only the SMS 10 cm data remainConversion formulae are given in Appendix 2.

- **Met-Data Precipitation**

  The tipping bucket precipitation data of the original Catchment 4 situated in the MET compound have been assigned to the MET dataset, until the arrival of the new Pluvio weighing rain gauge in the MET compound. As the precipitation collection started 1½ years before the other MET-data collection, only Precipitation data are available for

the period from 31/10/2011 – 29/04/2013. Potential issues of the Precipitation data were discussed in section 4.4.

7.1.2 Quality Control (QC) System for Data Release 32 – 01/12/2018

This section provides details on the QC for the 15-minute data released on 01/12/2018. Only a very basic level of QC was applied to these data. Future data releases will provide at least the same level of QC, but in general, the QC is expected to become more sophisticated. This sophistication can take a number of forms – from a QC that is more integrated within the database, through to a QC that identifies numerous types of outlying observations (e.g. local outliers, seasonal outliers, relationship outliers, etc.).

For this data release, the following sets of tables indicate the QC step that each parameter was subjected to, together with a rudimentary extended traffic light quality flag system (TLQF) for suspicious data.

In addition, during this latest QC process, data were flagged unreliable for certain periods based on records in the Sensor Downtime Log stating this. This could be from a few hours up to months. Data exceeding extreme upper or lower limits were set to NA. The number of impossible values set to NA and the number of possible outliers are available in the Reports. In the Data Portal, the measurements are flagged 'Outlier' if they fall outside the 'outlier' limits. These limits are listed in Table 7, Section 7.

Table 2. QC: Data from rain gauges and soil moisture stations (31/10/2011 to 25/08/2018)

NB. Soil Moisture for 20 cm and 30 cm have been removed from the Data Portal Download, as they were deemed highly unreliable after calibration checks (see above).

	QC Step	Rainfall	Soil Temperature	Soil Moisture 10cm	Soil Moisture 20cm	Soil Moisture 30cm
1	Data dimension check	Yes	Yes	Yes	NA	NA
2	Headings check	Yes	Yes	Yes	NA	NA
3	Time and time interval check	Yes	Yes	Yes	NA	NA
4	Data format check	Yes	Yes	Yes	NA	NA
5	Sensor downtime check (values set as 'NA')	Yes	Yes	Yes	NA	NA
6	Impossible values – via set upper/lower limits (values set as 'NA')	Yes	Yes	Yes	NA	NA
7	Data correction (according to sensor calibration - including sensor drift)	No	No	No	NA	NA
8	Relational check with all other same sensor readings	Yes	No	No	NA	NA
9	Check against alternative QC	Yes	Yes	Yes	NA	NA
10	Daily summary statistics output	Yes	Yes	Yes	NA	NA
11	4-weekly summary statistics output	Yes	Yes	Yes	NA	NA
12	Traffic Light Quality Flag (TLQF) assignment^	Acceptable	Acceptable	Acceptable	Not Set	Not Set
13	Reason for TLQF assignment (see below)	A	A	B	B	B

^ 7 levels: Not Set, Good, Acceptable, Outlier, Suspicious, Highly Suspicious, Reject.

Table 3. QC: Data from water flumes (01/10/2012 to 25/08/2018)

	QC Step	Flow	PLC Switch	Nitrate & Nitrite
1	Data dimension check	Yes	Yes	Yes
2	Headings check	Yes	Yes	Yes
3	Time and time interval check	Yes	Yes	Yes
4	Data format check	Yes	Yes	Yes
5	Sensor downtime check (values set as 'NA')	Yes	Yes	Yes
6	Impossible values – via set upper/lower limits (values set as 'NA')	Yes	Yes	Yes
7	Data correction (according to sensor calibration - including sensor drift)	No	No	No
8	Relational check with all other same sensor readings	No	No	No
9	Check against alternative QC	Yes	Yes	Yes
10	Daily summary statistics output	Yes	Yes	Yes
11	4-weekly summary statistics output	Yes	Yes	Yes
12	Traffic Light Quality Flag (TLQF) assignment^	Acceptable	Acceptable	Acceptable
13	Reason for TLQF assignment (see below)	A	A	C

^ 9 levels: Not Set, Good, Acceptable, Outlier, Suspicious, High Sensor Drift, Missing Sensor Drift, Highly Suspicious, Reject.

Table 4. QC: Data from water flumes (01/10/2012 to 25/08/2018)

	QC Step	Ammonia	Ammonium	Specific Conductivity	Dissolved Oxygen
1	Data dimension check	Yes	Yes	Yes	Yes
2	Headings check	Yes	Yes	Yes	Yes
3	Time and time interval check	Yes	Yes	Yes	Yes
4	Data format check	Yes	Yes	Yes	Yes
5	Sensor downtime check (values set as 'NA')	Yes	Yes	Yes	Yes
6	Impossible values – via set upper/lower limits (values set as 'NA')	Yes	Yes	Yes	Yes
7	Data correction (according to sensor calibration - including sensor drift)	No	No	No	No
8	Relational check with all other same sensor readings	No	No	No	No
9	Check against alternative QC	Yes	Yes	Yes	Yes
10	Daily summary statistics output	Yes	Yes	Yes	Yes
11	4-weekly summary statistics output	Yes	Yes	Yes	Yes
12	Traffic Light Quality Flag (TLQF) assignment^	Acceptable	Acceptable	Acceptable	Acceptable
13	Reason for TLQF assignment (see below)	D	E	A	A

^9 levels: Not Set, Good, Acceptable, Outlier, Suspicious, High Sensor Drift, Missing Sensor Drift, Highly Suspicious, Reject.

Table 5. QC: Data from water flumes (01/10/2012 to 25/08/2018)

	QC Step	pH	Sonde Temperature	Turbidity	fDOM
1	Data dimension check	Yes	Yes	Yes	Yes
2	Headings check	Yes	Yes	Yes	Yes
3	Time and time interval check	Yes	Yes	Yes	Yes
4	Data format check	Yes	Yes	Yes	Yes
5	Sensor downtime check (values set as 'NA')	Yes	Yes	Yes	Yes
6	Impossible values – via set upper/lower limits (values set as 'NA')	Yes	Yes	Yes	Yes
7	Data correction (according to sensor calibration - including sensor drift)	No	No	No	No
8	Relational check with all other same sensor readings	No	No	No	No
9	Check against alternative QC	Yes	Yes	Yes	Yes
10	Daily summary statistics output	Yes	Yes	Yes	Yes
11	4-weekly summary statistics output	Yes	Yes	Yes	Yes
12	Traffic Light Quality Flag (TLQF) assignment^	Acceptable	Acceptable	Acceptable	Acceptable
13	Reason for TLQF assignment (see below)	A	A	A	A

^6 levels: Not Set, Good, Acceptable, Suspicious, Highly Suspicious, Reject.

Table 6. QC: Data from water flumes (01/10/2012 to 25/08/2018)

	QC Step	Total Phosphorus	Ortho-Phosphorus
1	Data dimension check	Yes	Yes
2	Headings check	Yes	Yes
3	Time and time interval check	Yes	Yes
4	Data format check	Yes	Yes
5	Sensor downtime check (values set as 'NA')	Yes	Yes
6	Impossible values – via set upper/lower limits (values set as 'NA')	Yes	Yes
7	Data correction (according to sensor calibration - including sensor drift)	No	No
8	Relational check with all other same sensor readings	No	No
9	Check against alternative QC	Yes	Yes
10	Daily summary statistics output	Yes	Yes
11	4-weekly summary statistics output	Yes	Yes
12	Traffic Light Quality Flag (TLQF) assignment^	Acceptable	Acceptable
13	Reason for TLQF assignment (see below)	F	F

^6 levels: Not Set, Good, Acceptable, Suspicious, Highly Suspicious, Reject.

Table 7. QC: Data from Met station (31/10/2011 to 18/01/2016; Only Rainfall between 31/10/2011 – 29/04/2013)

	QC Step	Rainfall	Air temperature	Relative humidity	Wind speed	Wind direction	Solar radiation
1	Data dimension check	Yes	Yes	Yes	Yes	Yes	Yes
2	Headings check	Yes	Yes	Yes	Yes	Yes	Yes
3	Time and time interval check	Yes	Yes	Yes	Yes	Yes	Yes
4	Data format check	Yes	Yes	Yes	Yes	Yes	Yes
5	Sensor downtime check (values set as 'NA')	Yes	Yes	Yes	Yes	Yes	Yes
6	Impossible values – via set upper/lower limits (values set as 'NA')	Yes	Yes	Yes	Yes	Yes	Yes
7	Data correction (according to sensor calibration - including sensor drift)	No	No	No	No	No	No
8	Relational check with all other same sensor readings	Yes	No	No	No	No	No
9	Check against alternative QC	Yes	Yes	Yes	Yes	Yes	Yes
10	Daily summary statistics output	Yes	Yes	Yes	Yes	Yes	Yes
11	4-weekly summary statistics output	Yes	Yes	Yes	Yes	Yes	Yes
12	Traffic Light Quality Flag (TLQF) assignment^	Acceptable	Acceptable	Acceptable	Acceptable	Acceptable	Acceptable
13	Reason for TLQF assignment (see below)	G	A	A	A	A	A

^6 levels: Not Set, Good, Acceptable, Suspicious, Highly Suspicious, Reject.

7.1.3 Reasons for TLQF assignment

A. No obvious issues in the data and no reason to suspect any. Level of QC not sufficient however to be given a "Good" assignment.
B. Soil Moisture data are now complete as new sensor readings have been harmonised to old sensor readings. All 20 and 30 cm sensor readings currently set as 'NA', as the data were deemed unreliable after calibrations.
C. The data seem acceptable, however, for some limited periods the Nitrate/Nitrite data appeared highly erratic. So proceed with caution.
D. Ammonia is a derived variable from Ammonium and as such should be treated with caution. Where Ammonium data are absent, Ammonia values should be ignored. In general, on the FP, Ammonia values can be regarded as 0.
E. For Ammonium, the drift often appears severe, but no evidence has yet been found that these data are incorrect, apart from periods when the data have known issues.
F. For the Phosphax sensors, there are on-going issues with irregular time intervals. Here the data are not always sampled exactly every 15 minutes but always reported as this. (described in Section 4.3) Data comparison, however, have found the data from the Phosphax sensors to be reliable and the decision was made to no longer flag the data as Suspicious, but as Acceptable.
G. The MET/SMS Rainfall data has been deemed Acceptable as data from the tipping buckets are reliable. The only issue found is that Rain Gauge checks show a slight underestimation of rainfall (see section 4.4 for information on the Rain Gauge checks), however, the data were deemed acceptable.

7.1.4 Summary statistics data

Summary statistics (daily and 4-weekly) for each 15-minute parameter were determined as part of the QC. These summary data can be down-loaded from the "Farm Platform File Store" and not from the data portal. Please be aware that the summary statistics are calculated in a specific manner and as such, should be used carefully. They should not be considered as a substitute to a thorough investigation of the high resolution data from which they stem from. **Of note, is that all daily summaries run from 00:15:00 one day until 00:00:00 the next day. Similarly, all 4-weekly summaries run from 00:15:00 the first day until 00:00:00, 29 days later.**

For the SMS/RG/Met data this includes the following daily and 4-weekly summaries: means, medians, standard deviations, inter-quartile ranges, coefficient of variations, minimums, maximums, number missing, percentage missing, number of lower limit outliers, number of upper limit outliers, number of zero rainfall values, percentage zero rainfall values and rainfall sums.

For the flumes water data this includes the following daily and 4-weekly summaries: means, medians, standard deviations, inter-quartile ranges, coefficient of variations, minimums, maximums, number missing, percentage missing, number of lower limit outliers, number of upper limit outliers, number of zero flow values, percentage zero flow values and flow sums. **It is important to stress that the validity of any summary statistic is dependent on the number values it is calculated from. Thus the 'number missing' and the 'percentage missing' are key outputs, in this respect.** Here user should define their own '*reliability thresholds'*. For example, a user may decide to only use daily means for pH that have been calculated from at least 90% of the 96 15-minute values for any given day (i.e. if the 'percentage missing' is greater than 10%, then corresponding daily pH means are not considered reliable). For rainfall and flow sums, it may be safer to only use those found from 0% 'percentage missing'. An alternative and very important approach to these issues would be to return the 15-minute time series data and infill missing data.

The limits (or thresholds) that were used to identify simple distributional (lower limit and upper limit) outliers are given in Table 7, for each parameter in turn. All such thresholds were simply based on expert judgement of the NWFP 15-minute data; and were set to identify unusual or interesting low- and high-valued measurements. These thresholds were not statistically set or set according to some known threshold in the literature; and it was not the intention to do so.

Table 8. Lower and upper threshold limits used to identify simple distributional outliers

Parameter	Threshold for the detection of low-valued outliers	Threshold for the detection of high-valued outliers
Rainfall (mm)	0	5
Soil Temperature (ºC)	0	20
Soil Moisture 10/20/30 (%)	10	55
Flow (l s^{-1})	0	100
Water Temperature Flume (ºC)	0	25
PLC Switch (0/1)	0	1
Nitrite & Nitrate (mg/l)	0	20
Ammonia (mg/l)	0	20
Ammonium (mg/l)	0	50
Specific Conductivity (uS/cm)	30	1600
Dissolved Oxygen (%)	60	105
pH	3.5	8.5
Water Temperature Flow-cell (ºC)	0	25
Turbidity (FNU)	0	2000
Fluorescent Dissolved Organic Matter (µg/l QSU)	0	400
Total Phosphorus (mg/l)	0	1
Ortho-Phosphorus (mg/l)	0	0.25
Air Temperature (ºC)	-10	30
Relative Humidity (% RH)	40	100
Wind speed (km/h)	0	75
Wind direction (degrees)	0	360
Solar radiation (W/m^2)	0	1250

8 References

ISCO open channel flow measurement handbook, 6th edition, (Ed. Walkowiak D.K) (2008). Teledyne ISCO Inc., Lincoln, Nebraska, USA.

Harrod T.R and Hogan D.V (2008). The soils of North Wyke and Rowden. http://www.rothamsted.ac.uk/farm-platform-national-capability/data-portal-guides-and-information

Appendix 1. Formulae for conversion of water height to discharge rate for different sized flumes.

Catchment Number	Flume size (ft)	Formulae (H in meters)‡
1, 7, 10, 11, 12, 13, 14, 15	1.5	$L^{-s} = -0.00396436 – (0.07231968 * H^{0.5}) + (79.89379128 * H^{1.5}) + (900.3765227 * H^{2.5})$
2, 3, 5, 6, 8, 9	2.0	$L^{-s} = 0.022285358 – (0.55496382 * H^{0.5}) + (125.5275778 * H^{1.5}) + (939.5717311 * H^{2.5})$
4	2.5	$L^{-s} = 0.042446953 – (0.90725263 * H^{0.4}) + (108.676075 * H^{1.4}) + (937.5943603 * H^{2.5})$

‡Taken from Field Manual for Research in Agricultural Hydrology, Agriculture Handbook No. 224, U.S. Department of Agriculture, February 1972

Appendix 2. Formulae for conversion from scaled frequency unit (SFU) to soil moisture

Soil Moisture Sensor	Formulae
SM1 A51730, F/W 6.0	% soil moisture = SFU -18.8) / 1.808
SM1 A51730, F/W 6.2	% soil moisture = SFU+ 12.87) / 1.808

Appendix 3. Water, soil and meteorological parameters monitored at each of the fifteen catchments on the NWFP

Water properties	Method	Units	Range	Resolution	Accuracy
Stage Height (Data not released)	Bubbler flow meter	m	0.006 - 1.6		0.006 - 1.5m: ±0.003; 0.03 – 1.6m: ±0.006
	Pressure Probe	m	0 - 4	0.001	<± 0.05% full scale
Discharge	Equation	L s^{-1}			
Pump	Peristaltic Pump	On/Off	n/a	n/a	n/a
Nitrate and Nitrite-N	UV absorption sensor (Nitratax)	mg L^{-1}	0.1 - 100	0.1	±3% of the measured value ±1.0 mg L-1
Fluorescent Dissolved Organic Matter	UV fluorescence	QSU†	0 - 300	0.01	Linearity: R2 > 0.999 for serial dilution of 300 µg L^{-1} QS solution
Ammonia-N & Ammonium-N	Ion selective electrode (YSI 6600V2)	mg L^{-1}	0 - 200	0.001 - 1	±10% or 2mg N L^{-1}, whichever is greater
	Ion selective electrode (YSI EXO 2)	mg L-1	0-200	0.01	±10% or 2mg N L^{-1}, whichever is greater
Specific Conductivity	Ion selective electrode (YSI 6600V2)	mS cm^{-1}	0 - 100	0.0001 – 0.1	±0.5% + 0.0001
	Ion selective electrode (YSI EXO 2)	mS cm^{-1}	0 - 200	0.001, 0.01, 0.1	±0.5% of reading or 0.001 mS cm^{-1}, whichever is greater
pH	Ion selective electrode (YSI 6600V2)	n/a	1 - 14	0.01	±0.2
	Ion selective electrode (YSI EXO 2)	n/a	1 - 14	0.01	±0.1 pH units within ±10˚C of calibration temp or ±0.2 pH units for entire temp range
Dissolved Oxygen	Optical Sensor (YSI 6600V2)	%	0 - 500	0.1	0-200: ±2%; 200-500%: ±6%
	Optical Sensor (YSI EXO 2)	%	0 - 500	0.1	0 to 200%: ±1% of reading or 1% saturation, whichever is greater. 200 to 500%: ±5% of reading
Turbidity	Optical Sensor (YSI 6600V2)	FNU	0 - 1000	0.1	±2% or 0.3 FNU, whichever is greater
	Optical Sensor (YSI EXO 2)	FNU	0 - 4000	0 - 999: 0.01 FNU 1000 - 4000: 0.1 FNU	0-999: 0.3 FNU or +/- 2% of reading, whichever is greater 1000-4000 FNU: +/- 5% of reading
Temperature	Thermistor (YSI 6600V2)	°C	-5 - 50	0.01	±0.15
	Thermistor (YSI EXO 2)	°C	-5 - 50	0.001	-5 to 35: ±0.01°C 35 to 50: ±0.05°C
Total Phosphorus (in 4 catchments only)	Reduction method, IR-LED photometer	mg L^{-1}	0-5	0.1	±2.0%+0.05mg L-1

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Ortho-Phosphate in 4 catchments only)	Reduction method, IR-LED photometer	mg L^{-1}	0-5	0.1	±2.0%+0.05mg L-1
Soil properties & precipitation					
Precipitation	Tipping Bucket	mm	0 – 100 per hour	0.2	0-50: ±1%
Soil Temperature @ 15cm Depth	Thermistor	°C	-55 - 70	0.125	±0.5
Soil Moisture @ 10cm Depth	Capacitance sensor	%	0 - 100	0.1	±2.0
Met data – site wide					
Precipitation	Weighing	m/15-min	0.1 – 500 per hour	±0.01	±0.05
Precipitation	Tipping Bucket	mm	0 – 100 per hour	0.2	0-50: ±1%
Air Temperature	Thermistor	°C	-40 - 60	0.01	±0.1
Relative Humidity	Capacitance Humidity element	% RH	0 - 100	0.1	0-90: ±1.0 ; 90-100: ±2.0
Wind Speed	Anemometer	km h^{-1}	1.44 - 270	0.01	±0.8
Wind Direction	Magnetic Hall Element	Degrees	0 - 360	0.1	±2.5
Solar Radiation	Pyranometer	W/m^2	0 - 1600	0.1	±1.8%

† Quinine Sulfate equivalents (QSU µg L^{-1})

Appendix 4. Timeline for sensor deployment and upgrades

1	31/10/2011: Soil Moisture Stations/ Rain Gauges deployed (SM1 A51760 F/W v.283)
2	01/10/2012: Flume/ Water quality sensors deployed
3	27/05/2012: Soil moisture sensor replacement, Catchment 12 (SM1 A51730, F/W 5.7)
4	15/04/2013: NWFP met site deployed (1m mast, Top Burrows)
5	03/05/2013: Soil moisture sensor replacement, Catchment 15 (SM1 A51730, F/W 6.0)
6	15/09/2013: Soil moisture sensor replacements Catchments 1,5,7 (SM1 A51730, F/W 6.0)
7	28/01/2015: Soil moisture sensor replacements Catchment 9 (SM1 A51730, F/W 6.2, New sensor body design)
8	03/02/2015: New Soil moisture station and rain gauge installed in catchment 4, (SM1: A51730, F/W 6.2, New sensor body design)
9	12/04/2015: New OTT Pluvio rain gauge installed met compound (Top Burrows)
10	02/06/2015: Met site moved to new 3m pole. Wind sensors moved from 1m to 3m. Temp/RH 1.25m
11	24/06/2015: Soil moisture sensor replacements Catchments 1,2,3 (SM1 A51730, F/W 6.2, New sensor body design)
12	25/06/2015: Soil moisture sensor replacements Catchments 5,6, Met (SM1 A51730, F/W 6.2, New sensor body design)
13	02/07/2015: Soil moisture sensor replacements Catchment 7,11,12 (SM1 A51730, F/W 6.2, New sensor body design)
14	06/07/2015: Soil moisture sensor replacements Catchment 14 (SM1 A51730, F/W 6.2, New sensor body design)
15	06/07/2015: OTT Pressure level sensors installed in Catchment 7
16	10/07/2015: Soil moisture sensor replacements Catchments 8,13,15 (SM1 A51730, F/W 6.2, New sensor body design)
17	25/08/2015: Soil moisture sensor replacements Catchment 10 (SM1 A51730, F/W 6.2, New sensor body design)
18	07/09/2015: OTT Pressure level sensors installed in Catchment 1
19	09/09/2015: OTT Pressure level sensors installed in Catchments 2,3,4,5,6
20	11/09/2015: OTT Pressure level sensors installed in Catchments 10,11,12
21	14/09/2015: OTT Pressure level sensors installed in Catchment 13,14,15
22	15/09/2015: OTT Pressure level sensors installed in Catchment 8
23	16/09/2015: OTT Pressure level sensors installed in Catchment 9
24	04/02/2016: Phosphax's switched to measure TP and Ortho P simultaneously
25	May – September 2016 Flume loggers changed from Adcon A723 to OTT netDL with data transfer via fibre optic network.
26	May – September 2016 Water quality multi-parameter sondes (YSI 6600) upgraded to YSI EXO 2. Addition of FDOM (Fluorescent Dissolved Organic Matter) on YSI platform as proxy for DOC/TOC. Decommissioning of Trios PROPs.

Appendix 5. Correction factors calculated for precipitation data

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Downloaded precipitation values could be improved if multiplied by the corresponding catchment factor below.

	1 mm = X mm		
SMS	**Feb 2014**	**Aug 2015**	**Feb 2017**
1	1.124	1.157	5.787
2	1.131	1.116	5.580
3	1.147	1.121	5.605
4	1.142	1.147	5.734
5	1.087	1.147	5.734
6	1.109	1.101	5.507
7	1.068	1.152	5.760
8	1.082	1.163	5.814
9	1.055	1.059	5.297
10	1.083	1.190	5.952
11	1.076	1.020	5.102
12	1.100	1.142	5.708
13	1.122	1.131	5.656
14	1.065	1.078	5.388
15	1.060	1.106	5.531