The North Wyke Farm Platform: Methodologies used in the remote sensing of the quantity and quality of drainage water

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Abstract. The North Wyke Farm Platform (NWFP) for agri-environmental research in temperate grassland was established in the UK in 2010 (Orr *et al*. 2011). Here we describe the instrumentation and methodologies used to monitor the quantity and quality of drainage water at a total of 15 H-flumes draining 5 sub-catchments within three farmlets. Each of 15 flume laboratories is supplied with 3 kW of mains power and connected to both fibre optic and UHF (Ultra High Frequency) radio networks for data exchange. The radio data network also provides telemetry for rain gauges and soil temperature/moisture probes located away from the flumes and within the catchment blocks. Water flow is measured using bubbler flow meters and when flow is above a defined threshold level, water is pumped into bespoke 13-litre stainless steel bypass cells on a 15-minute cycle using bi-directional peristaltic pumps. A range of sensors located within the bypass cells measure the following water quality parameters: nitrate, ammonium, dissolved organic carbon, temperature, conductivity, turbidity, pH and dissolved oxygen. Total phosphorus and ortho phosphorus are measured at one flume in each farmlet. Networked auto-samplers are also provided at each flume site for the measurement of other water quality parameters as required. All data are logged and sent to a dedicated server at a 15 min resolution while a web front end allows advanced visualization capabilities and remote control of the entire system. The system is configured to allow for flexibility and future expansion to a wider range of parameters.

Keywords: Remote sensing, instrumentation, drainage, agriculture, productivity, sustainability.

Introduction

The North Wyke Farm Platform (NWFP) is a unique national capability for agri-environmental research and knowledge exchange for the UK grassland sector. Located in South West England ($50^0$46'10"N, $3^0$54'05"W) with average annual rainfall of 1056 mm and at a height of between 180 m and 126 m (Ordnance Datum Newlyn) it comprises 3 farmlets, of approximately 22 ha in size, which have been designed to test the productivity and environmental sustainability of contrasting temperate grassland farming systems. The systems are discussed in detail by Murray *et al*. (2013). The 3 farmlets have each been further divided into 5 sub-catchments (15 in total) and each is hydrologically isolated through a combination of topography and a network of French drains (800 mm deep trenches containing a perforated drainage pipe backfilled to the surface with stone) which have been constructed at the edges of the sub-catchments. A prominent feature of the site is the presence of clayey sub-soils beneath the sub surface horizons (Harrod and Hogan 2008) which results in the surface and subsurface flows moving laterally and being intercepted by the bounding drainage system. Each sub-catchment drains to a single location, allowing both the quantity and quality of the drainage water to be analysed through a combination of primary measurement structures within the flow channel and additional online sensors. Each of the 15 measurement sites incorporates an H flume, a pre-chamber for the collection of samples, a power and IT cabinet terminating mains power and fibre optic cables, and a flume laboratory housing pumping equipment, a by-pass cell, telemetry devices and sensors. The construction of the NWFP infrastructure was discussed in detail by Orr *et al*. (2011).

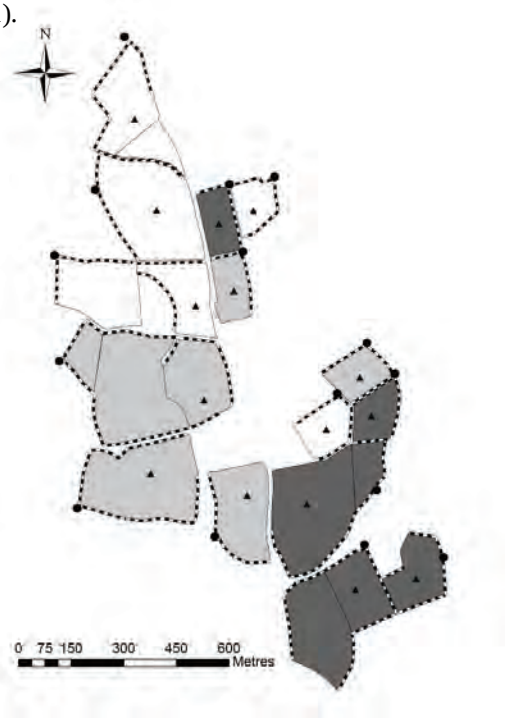

Figure 1. Map showing the layout of the NWFP. Grey scales indicate the 3 farmlets, (--) French drains, (●) monitoring sites, (▲) soil moisture sites

Instrumentation

Telemetry

At the heart of the NWFP is a wireless UHF radio telemetry network (www.adcon.at), consisting of 3 main parts: (1) Remote telemetry units (RTUs), which collect data from instruments in the field at configured intervals and transmit via UHF radio; (2) A centrally located base-station (A850 Gateway) which manages the network, receiving the data as well as sending commands back to the RTUs; (3) Software (AddVantage Pro), which collects, stores, processes and displays the data via its integrated web server. At present the NWFP has a network of 45 RTUs connected to 108 instruments collecting data on 198 environmental parameters every 15 mins.

Flow measurement

The quantity of run-off from each sub-catchment is measured through the combination of primary and secondary flow devices. The primary devices are H-flumes (www.tracomfrp.com), ranging in size from 450 to 750 mm, with capacity designed for a 1 in 50 year storm event. These hydraulic structures channel the discharge through a sharp edged opening where the rate of flow through this restriction is related to the water height at a specified measurement location. (ISCO open channel flow measurement handbook 2008). A secondary flow measurement device (4230 bubbler flow meter, www.isco.com) is then used to measure the water height within the flume and convert this measurement to a flow rate. The device releases bubbles of pressurized air at a constant rate down a tube fixed in a stilling well. A transducer within the device measures the pressure required to maintain the bubble rate and this pressure is proportional to the liquid level.

Filling the bypass cell

A complication with measuring agricultural run-off is that flow is not continuous but rather linked to soil moisture conditions and rainfall events. Also, the sensors within the bypass cell are vulnerable to drying out and must remain wet at all times. The NWFP system accounts for this by automatically pumping water into a stainless steel by-pass cell (13 L) every 15 mins (where the sensing of water quality parameters occurs), when flow conditions allow but holds the previous sample when flow is below a threshold. This is achieved through a combination of the data from the flow meter, the telemetry network, a programmable logic controller (PLC) and a bi-directional peristaltic pump. The flow meter outputs its data as an analogue pulse to a RTU. This data point is transmitted via UHF radio through the Gateway before being passed to the AddVantage Pro software where it is tested against a condition. If flow is equal to or greater than 0.2/L/sec (LPS) a radio signal is sent back to the RTU in the field where a switch on signal is activated. If the flow data is equal to or less than 0.18 LPS the signal is switched off via the same process. This signal is connected to a PLC LOGO,(www.siemens.com) holding a programme which activates the pump (621VI\R, www.watson-marlow.com) as well as controlling its speed and direction via a 4-20 mA connection. To prevent synchronization issues with other instruments the PLC runs a subroutine, 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 from the RTU, which will result in the previous sample being held in the by-pass cell until flow conditions rise above the 0.2 LPS threshold.

Sensing water quality

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. The first is a multi-parameter sonde (6600V2, www.ysi.com) which holds 5 sensors measuring 7 parameters. Dissolved oxygen and turbidity, measured by self-cleaning optical sensors; conductivity and temperature, pH and ammonium (NH_4^+) and ammonia (NH_3), which are measured by an ion selective electrode (ISE). The sonde communicates directly with the RTU via an SDI-12 interface (Serial Data Interface at 1200 baud). The NWFP has two complete sets of these sondes, allowing one set to be calibrated in the lab while the other set is deployed in the field. These sets are rotated once every month, minimising downtime and ensuring continuous high data quality.

Combined nitrate N (NO_3 N) and nitrite N (NO_2^- N) (NO_x-N) are measured by a dedicated, self-cleaning, optical UV absorption sensor (NITRATAX Plus SC, www.hach-lange.co.uk). 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 NO_x-N concentration is calculated. The data is passed to a visual display unit (SC1000) and output to the RTU via a 4-20 mA analogue current loop.

Dissolved Organic Carbon (DOC) is measured using a submersible UV-transmissiometer (ProPS WW www.trios.de) which operates using a similar principle to the UV absorption sensor listed above. A fundamental difference is that the full measured absorption spectrum in the UV (190 – 360 nm) is transmitted by the probe to software in an attached unit where an algorithm, based on principle component analysis, calculates the individual concentrations of various UV absorbers. Although the software algorithm installed in the NWFP units is optimized for the measurement of DOC, the device could, in theory, be optimized for the in situ measurement of any prominent UV absorber. Data is transferred to the RTU via a 4-20mA loop.

Total phosphorus and/or ortho phosphate are measured at three of the fifteen flume laboratories, one per farmlet, using a process photometer (PHOSPHAX sigma, www.hach-lange.co.uk). A sample is collected by a separate device (SIGMATAX 2) which homogenises the sample using ultra-sound before passing it to the PHOSPHAX sigma unit. The device mixes the sample with reagents to form a complex which is reduced by ascorbic

acid to phosphomolybdic blue. The intensity of this colour is measured by an internal photometer and is proportional to the orthophosphoric content of the sample. The measurement of total P and ortho P 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 is 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.

Other instruments

Each measurement site is also home to an online autosampler for the unattended collection of up to 24 physical samples (model 3700, www.isco.com). These devices are connected to the telemetry network, so can be triggered remotely or set to trigger according to set thresholds within any parameter on the system. Typically this would be flow, with the samplers set to collect samples on the rising and falling limbs of a hydrograph during a storm event. However, it is equally possible to set the samplers to trigger when a given NO_x-N or total P concentration is reached. The collection of physical samples allows analysis of parameters that are not being continuously measured as part of the system but also allows samples to be collected for quality assurance and calibration of the online instruments.

At a central location within each of fifteen subcatchments is located a soil moisture station (SMS) consisting of an RTU, a combination soil moisture and temperature probe (SM1) and a rain gauge (RG1) (www.adcon.at). The SM1 probe measures soil moisture through capacitance at depths of 10, 20 and 30 cm and soil temperature at 15cm. The direct connection to the RTU is via a SDI 12 interface and the raw data is converted to soil moisture % for the given clay soil type by an extension running within the AddVantage Pro software. Data from the tipping bucket rain gauge is collected by the RTUs integrated pulse counter at a resolution of 0.2mm per tip.

Discussion

The NWFP monitoring system is unique in both scale and scope for a managed land-based capability and brings together a number of technologies that allow the impact of farming systems to be studied in greater detail and resolution than ever before. The power of the NWFP lies in control over the farming operations that define the systems and control over the technologies that monitor their impact. New sensors can be easily integrated or existing ones configured to measure different parameters; data capture rates can be altered, equipment can be triggered when thresholds are reached whilst all being visualised and controlled from any web-connected computer in the world. The three P analysers can measure either total P or ortho P as required and can be moved to different locations, whist the infrastructure allows for additional analysers to be installed at all 15 flume laboratories in the future. The UHF radio network has scope for the incorporation of many more sensors whilst the inclusion of the fibre optic network offers further opportunity for expansion as new sensing technologies emerge.

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