New Technologies Enable High Resolution Monitoring

For over twenty years, the Environment Agency has employed a general quality assessment (GQA) scheme to assess river water quality in terms of chemistry, biology and nutrients. GQA has helped drive environmental improvements by dealing with the main sources of pollution, such as discharges from sewage treatment works. However, in line with the catchment based approach of the European Water Framework Directive (WFD) and in tandem with advances in technology, the Agency is now adopting a more sophisticated approach to monitoring which involves a much greater use of high resolution continuous monitoring and 'sensor-web' based technologies.

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The Agency's Matt Loewenthal has been responsible for monitoring the River Thames and its tributaries for around 20 years. During that time he has developed and commissioned an array of monitoring and communications technology that has provided a deep insight into the quality of one of the world's most famous rivers. Today, Matt is a technical lead for the National Water Quality Instrumentation Service (NWQIS), which was created to improve the quality and efficiency of water quality monitoring across England and Wales. Whilst the NWQIS fulfils the field monitoring requirements of the Environment Agency, it also provides expertise, services and data to other parties in both the public and private sectors.

NWQIS has developed a wide range of high resolution, sensor-web based, monitoring systems utilising multi-parameter water quality monitors, many of which are transportable so that they can be relocated when necessary to the sites of most interest. The core of each system is a YSI sonde that has been developed to provide long term accurate data for all of the most important water quality parameters. This approach is has now been rolled out to hundreds of sites across the Environment Agency.

However, the remainder of this article will explain how advances in technology have enabled high resolution continuous water quality monitoring in a large research project involving the monitoring of the rivers Eden, Wensum and Avon.

The Demonstration Test Catchments (DTC) Project

In line with the objectives of the European Water Framework Directive (WFD), a national £6.2million project is under way to identify sustainable agricultural practices that would limit or reduce detrimental effects on groundwater and river water quality while maintaining food production and the profitability of farm businesses.

Initiated by Defra and the Environment Agency, the project involves three Demonstration Test Catchments based at the river Eden in Cumbria, the river Wensum in Norfolk and the river Avon near Salisbury. Each of the DTCs is now collecting high resolution data from a network of water quality monitoring stations, most of which were designed and installed by the NWQIS.

Prof. Bob Harris is Secretariat for the DTC project. He says, "Since we started in 2010, a large number of partners and stakeholders have been enlisted, the monitoring equipment has been installed and we are busy compiling comprehensive baseline data. The installation of the monitoring equipment has been a great success and I would like to express my gratitude to the NWQIS team and to AT Engineering for helping to make that possible."

All three of the DTC consortia are now collecting large volumes of 24/7 data; most of which will become freely accessible. Their individual websites give more detail: www.edendtc.org.uk, www.wensumalliance.org.uk and www.avondtc.org.uk.

Background

The main objectives of the WFD are: no deterioration in water quality, the achievement of good ecological status in surface waters, and a good status for groundwater. With almost three quarters of the UK's land surface in agricultural production, diffuse pollution from farming activities has a major effect on the quality of water resources and associated ecosystems. However, the relationship between agriculture and the environment is extremely complex so the DTC project seeks to produce evidence to test the hypothesis that we can cost-effectively reduce the impact of agriculturally-derived diffuse pollution on ecology

and the delivery of ecosystem services through the implementation of multiple on-farm measures.

DTC Objectives

The DTC programme aims to test the efficacy of both novel and existing measures which can be integrated into farming practice without disproportionately impacting food production. The evidence base for existing measures will be drawn together from work already being undertaken within the Demonstration Catchments and elsewhere within the UK and Europe. The DTC project has three main objectives:

- To provide sound evidence for policy makers that specific measures and changes to farming practice can beneficially affect water quality
- To develop practical measures for controlling sources and pathways as part of a catchment management approach
- To create sustainable, transparent research platforms with clear visibility for all stakeholders

Underlying the objectives of the project is a need for the work to be knowledge based, adaptive (learning by doing) and participatory. An important feature of Integrated Catchment Management is therefore to involve all stakeholders and to better understand the relationships between different socio-ecological factors. In other words; it should be possible to determine the best possible agricultural practices to reduce diffuse pollution, but the implementation of such measures will only be effective with the cooperation of stakeholders. The DTC project therefore involves over 40 research institutions and other groups such as the Environment Agency, river trusts as well as farmers and land owners.

The Catchments

The three DTCs were chosen for their variable natural features, agricultural land use and the past research or level of monitoring and management – all three are enhanced monitoring catchments under the England Catchment Sensitive Farming Delivery Initiative (ECSFDI).

Research

Each DTC has employed the 'Before-After Control-Impact' (BACI) approach to the monitoring of water quality, which compares a manipulated stream with a non-manipulated stream before and after implementation of a mitigation measure. Data recorded pre-mitigation provide a baseline against which post-mitigation monitoring can be compared. The control stream provides additional spatial reference that can be used to factor out confounding effects of changes in land use, rainfall, flow etc.

The monitoring programme has 4 main objectives:

- Identifying the status quo (characterisation or source identification)
- Understanding the system (flow pathways and biogeochemical transformations)
- Predicting the consequences of management options
- Verifying the success/failure of interventions to the system (source control or pathway modification) once an option is chosen and in place

The NWQIS designed and commissioned two high-specification walk-in monitoring stations at the catchment outlets for each of the three DTCs. These include automatic samplers, YSI multiparameter sondes and analysers for phosphate, nitrate and ammonium. In addition, NWQIS has also designed and commissioned smaller stations (without the ammonium, nitrate and phosphate analysers) at each of the DTCs: 4 at Wensum, 2 at Eden and 2 at Avon.

Water flow is being recorded by a combination of pressure transducer level monitors and SonTek/YSI Argonauts which combine multi-beam doppler technology with channel profile data to provide instantaneous discharge values.

Water quality and flow monitoring data are being supplemented by ecological measurements and laboratory analysis of soils and sediment.

The Eden DTC is based near Penrith in Cumbria and provides an opportunity to study the effects of upland, predominantly livestock, farming on water resources and the local ecology. Prof. Phil Haygarth from the Centre for Sustainable Water Management at Lancaster University is project leader, he says "This is a tremendously exciting opportunity to find answers to the problem of diffuse pollution; an issue of global importance. We've got the best monitoring equipment available, but importantly we have brought together, for the first time, a wide group of individuals with an impressive array of skills in addition to representatives from the local communities – it's all about pooling our knowledge and resources to find new solutions."

The Eden catchment includes forest areas, pasture, moorland and bog, and features both extensive and intensive farming. The project has been split into three sub-catchments covering a combined area of around 10 km^2; one area will be used as a control and the other two will be used to investigate the effects of mitigation – changes to agricultural practices.

Staff from the NWQIS have installed continuous (every 15 minutes) water quality monitors at each of the sites. These employ a YSI multiparameter sonde in a flow-through chamber to measure conductivity, temperature, pH, dissolved oxygen, turbidity and Chlorophyll-a. Each site is also fitted with telemetry so that live data can be transmitted to the project's web site.

Larger, more comprehensive monitoring stations have been installed at the outlets for the Morland and Pow sub-catchments, which, in addition to the autosampler and YSI multiparameter monitors, also include analysers for phosphate, ammonium and nitrate. Dr Clare Benskin is responsible for the water quality

monitoring work and says "The continuous monitoring equipment is performing extremely well and is providing valuable baseline data, which is being complimented by monthly spot samples that are collected manually and transferred to the laboratory for analysis."

Laboratory analysis is undertaken for samples taken from autosamplers at each water quality monitoring site, and from boreholes, river sediment and soils. Clare and her colleagues also study ecological indicator organisms such as algal diatoms.

The Wensum DTC is located in a catchment that drains an area of north Norfolk about 40 km west-east and 25 km north-south with relatively low-lying topography. Almost the entire river and stream habitat is considered to be 'unfavourable and declining' mostly due to sediments, bank poaching and diffuse water pollution. The main river channel currently has 'poor' ecological status (and is also predicted to be 'poor' status in 2015). 40% of the water bodies in the catchment are at risk of reaching 50 mg/l nitrate (i.e. failing drinking water quality standards for nitrate). 27% of the water bodies in the catchment are at risk of failing phosphorus standards.

Reflecting a 'ground upwards' approach involving land owners and managers, as well as farming and environmental organisations, government agencies and researchers, the Wensum DTC has established the 'Wensum Alliance' of interested parties, which is led by Prof. Kevin Hiscock and Prof. Andrew Lovett from the School of Environmental Sciences at the University of East Anglia in Norwich.

Lister Noble, a Norfolk farmer, is responsible for farm liaison work at the Wensum DTC. It was his responsibility to enlist the involvement of farmers and land owners in the catchment. He says "It was necessary to make it clear that the project is not seeking to attribute blame; it is trying to find ways to improve the environment. Encouragingly, the farmers that we approached responded very positively because they could see the need to protect habitats and avoid nutrient wastage whilst maintaining agricultural viability."

The monitoring and mitigation work in the Wensum catchment is being conducted in an area of arable farmland including the source of one of the Wensum tributaries, so it is envisaged that improvements in the management of the land near the head water will have an impact on the water quality at the catchment outlet.

Prof. Hiscock says he has been very pleased with the monitoring equipment: "It has proved to be very reliable and our maintenance programme has worked well because we utilise spare YSI sondes on a 6-week rotation, which can be calibrated before going to the field site. So far, the main challenge has been maintaining the stream channel to facilitate flow measurement for sediment and solute flux calculations."

The Hampshire Avon DTC catchment comprises mixed agriculture and is focusing on using target sub-catchments on clay (River Sem), greensand (River Nadder) and chalk (Rivers Ebble and Wylye). In addition, the River Tamar has been adopted as an official satellite to the Hampshire Avon sentinel DTC. This provides an opportunity to assess the water quality and freshwater responses to mitigation

strategies funded by South West Water via the Payment for Ecosystem Services scheme being implemented by the Westcountry Rivers Trust. The Tamar satellite is monitoring the effects of mitigation measures at Caudworthy Water with a control site on the river Neet.

As with the other DTCs, baseline data is currently being collected from a network of continuous monitoring stations. There are a total of seven surface water monitoring sites on the Hampshire Avon and four on the Tamar. On the Hampshire Avon, five sites have autosampler monitoring stations and two sites have high spec monitoring stations. On the Tamar, three sites have autosampler monitoring stations and one site has a medium spec station (sampler, YSI multiparameter sonde, but no phosphate and ammonium analysers). Project leader Prof. Adrian Collins says, "The DTC platform provides a fantastic opportunity for collaborative research and one element of the ongoing work is developing an integrated toolkit for detecting change in response to on-farm targeted mitigation of diffuse pollution."

In addition to the monitoring equipment, the Avon DTC Alliance members have installed 400 porous pots in 29 fields across the target sub-catchments. These will be sampled on a bi-monthly basis during the winter of each year to measure nitrogen leaching in soil water. An ecological monitoring plan is also underway, recording macroinvertebrates, macrophytes, diatoms and fish.

High resolution monitoring

Traditional environmental monitoring often involved the collection of either samples that represented a moment in time or samples that are a composite taken over a period of time. In contrast, the latest monitoring and telemetry technology can provide data that are almost 'live' – high resolution data.

The DTC project specified high resolution monitoring equipment because of the many advantages that it brings. For example, spot sampling is laborious and inherently expensive; however, its greatest drawback is the potential for missing water quality incidents. As Matt Loewenthal from the NWQIS explains "Both

sensing and telemetry technology have advanced considerably in recent years, which means that we can now generate continuous reliable data from remote sites. For example, we have a network of water quality monitoring stations spread over the entire catchment of the river Thames, delivering continuous data to the Environment Agency's offices in Reading. As a result, we are immediately aware of any water quality deterioration and this is a major help in protecting water quality as well as looking for long-term trends."

The experience that the NWQIS has gained over many years in the development of real-time water monitoring networks was a significant factor in the success of the DTC installations. However, YSI's Ian Thompson believes that advances in monitoring technology have also been a major factor in enabling the creation of continuous or high-resolution field data: "For decades our development teams have been focused on finding ways to increase maintenance intervals, so that customers have to spend less time in the field and more time at their desks reviewing better quality data. Predominantly this has been achieved through: lower power usage; better sensor technology to reduce the need for recalibration, and improved resistance to fouling."

The WFD is also contributing to the pressure for high resolution data because it specifies short-term targets for improvements in ecological status, which means that member states have to find solutions as quickly as possible. Therefore, if solutions are to be knowledge based and supported by strong evidence then high resolution data are essential.

All of the DTCs have been delighted with the high resolution data that are being generated. For example, the Wensum DTC has been recording baseline data since March 2011 and Prof. Hiscock has already found that the data are providing greater insight into pollution sources and pathways: "We have recorded conductivity peaks following road gritting activity during cold snaps and autumn application of salt to sugar beet fields and these have come through as separate 'events' – firstly, via land drains and then later via the soil, and this means that we will be able to develop better models and more quickly understand the effects of mitigation measures."

Mitigation

The DTCs all have different topography, geology, soil types, climate and land use, so mitigation measures have been designed to suit each specific area. However, the following table summarises the main mitigation measures:

Catchment	Mitigation
Avon Eden	Livestock yard Infrastructure
Avon Eden Wensum	Integrated manure and fertiliser planning
Avon Eden	Farm track re-surfacing
Avon Eden Wensum	Rural sustainable drainage systems
Avon Wensum	Extension of current buffer strips
Wensum Avon	Reduced cultivation
Wensum	Cover crops
Avon	Stream bank re-fencing
Wensum Eden	Tree planting watercourses
Wensum Eden	Biobed to treat sprayer spill/wash

The DTC monitoring infrastructure is also being used to test additional measures that are being funded through other sources. These include: improved maize management; feeder ring management; separation of clean and dirty water in yards; improving slurry storage facilities; sediment trapping in farm drains; sediment ponds; and grassland aeration to remove compaction.

Looking forward

The participants of the DTC project are confident that they will be able to deliver the project's objectives and YSI's Ian Thompson says "Experience in other countries has demonstrated that the provision of live, web-based, local water quality data encourage communities to take a greater interest in their environment and in the factors that affect it, so I am confident that the stakeholder engagement activities that the DTCs have undertaken will deliver sustainable benefits in the future."

Prof. Harris says "An overarching goal of the DTC project is for communities to develop solutions to diffuse pollution that meet their own specific circumstances and that they learn from each other and serve as examples to communities in other catchments. If we can achieve that," he says, "we will have gone a long way toward helping develop a way to achieving the goals of the Water Framework Directive."

However, the WFD has set a 2015 target for 'good ecological status', which coincides with the end of the DTC project, so it is unlikely that the deliverables of the DTC project will have had sufficient time to have made an impact on the WFD 2015 target.

Nevertheless, it has been Matt Loewenthal's experience that, for example, the YSI monitors typically provide a ten year working life so, once the DTC project reaches the end of its 5 year plan, the monitoring infrastructure will still be in place, so it is hoped that funding will be available to continue the work.