Case study 12

River Eden land use impact study - Cumbria

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1. Catchment summary

Study location

The study is taking place in the Morland subcatchment (approximately 12.5km2 in size) within the River Eden watershed in Cumbria. It is an upland (233 metres above Ordnance Datum) grassland catchment with clay and sandy loam soils over largely carboniferous limestone.

The River Eden Demonstration Test Catchment (www.edendtc.org.uk) is a Defra funded research project. The Demonstration Test Catchment (DTC) network was set up by Defra to increase understanding of the effectiveness of measures based on Working with Natural Processes (WwNP) in helping to reduce the risk of diffuse pollution. Examples of such measures in the Eden catchment are shown in Figures 1–3.

Figure 1: Diffuse pollution mitigation in the Eden catchment

Source: JBA Consulting

Catchment summary

As a small agricultural catchment typical of a grassland catchment used for a mixture of beef and dairy production, there are issues with diffuse pollution in the area. During peak flow events, this can result in the transfer of large amounts of phosphorus, nitrate and sediment to the watercourse leading to reduced water quality. As warmer wetter winters and hotter drier summers (with more intense storms) are predicted to occur in greater frequency in the future, the effects and impacts of climate change and land use/management could have detrimental impacts on water quality in the catchment.

Study summary

The main aim of the work in the DTC catchments is to investigate the impacts of land use and climate change on hydrology phosphorus interactions to the year 2050. The project will use high temporal resolution DTC hydrology and water quality data (mainly phosphorus) to learn about the major processes controlling phosphorus transport in the catchments. The results will then be used to test and evaluate a range of water quality models – including Soil and Water Assessment Tool (SWAT), HYPE (HYdrological Predictions for the Environment) and Integrated Catchment Model Phosphorus (INCA P) – to assess model uncertainty in a non-stationary system. The focus is on assessing the impact of warmer wetter winters and hotter drier summers on hydrological events, including flood events, which can lead to high transport of phosphorus to rivers.

The study involves a critical assessment of some of the models that could be used to support decision making on WwNP measures to combat run-off generation and diffuse pollution. The uncertainty assessment will quantify the uncertainty in predictions of a number of models (SWAT, HYPE and INCA). This will include evaluation of whether the models are fit for purpose at simulating hydrology and water quality issues in the DTC catchments based on high quality data.

Community involvement

Setting up the DTC in the Eden catchment involved considerable work with local landowners, farmers and Catchment Sensitive Farming officers.

2. Data summary

Datasets and analysis techniques used

Datasets used included:

- Nextmap Digital Elevation Model (DEM)
- DTC high frequency water quality and hydrology data
- DTC high frequency weather data
- UK Met Office rainfall data – to supplement in situ weather data
- data for England from National Soils Resources Institute (NSRI) National Soil Map of England and Wales (NATMAP)
- Centre for Ecology and Hydrology (CEH) Land Cover Map (LCM) 2007

Data restrictions

The DEM data used in this work are from the Nextmap dataset and were only available on licence through the Natural Environment Research Council (NERC) Earth Observation Data Centre.

The DTC data were been collected initially for academic research but will be available through the Freshwater Biological Association (FBA) at a future date.

LCM2007 is copyright property of CEH and is available on licence through the EDINA service for academic research.

The NSRI dataset is the property of Cranfield University and is available for a small charge on licence for academic research. Higher charges apply for commercial licences.

3. Model summary

Catchment processes investigated

Surface water and small scale fluvial events are being considered in this project in terms of sources of flooding. The impacts are examined in terms of the changes to nutrient concentrations which can be considered against Water Framework Directive standards.

A range of events are being modelled to calibrate the different models. This modelling will be carried out in an uncertainty framework using the Generalised Likelihood Uncertainty Estimation (GLUE) framework (Beven and Binley 1992, Beven 2006).

Small scale WwNP measures such as ditch damming, flow path interruption and the use of additional storage to intercept known flow pathways are targeted more at reducing diffuse pollution than reducing flood risk. Hence performance in terms of flood attenuation is not being modelled directly in this project, although it would be possible to estimate from before and after modelling and monitoring.

The different models are being used to investigate how run-off generation and patterns will change under future climates and changes in land use (for example, pasture to arable) and land management (for example, changes in stocking densities) and the subsequent impact on river flows and quality.

The impact of climate and land use/management change on the mobilisation and transport of phosphorus from the land is also being investigated, as is how the frequency and magnitude of such events will change in the future.

Model assumptions

SWAT, HYPE and INCA have been set up and run for the Eden DTC subcatchments. It has been assumed that:

- the DEM, soil and land data provide a good representation of the characteristics of the catchments
- the weather data from 4 rain gauges provide a suitable representation of rainfall in the local area

This work utilised the GLUE framework to quantify the associated uncertainty in the 3 water quality models when used to simulate hydrology phosphorus interactions in the target Eden DTC subcatchments. The GLUE analysis uses the high frequency hydrological, meteorological and water quality data from the DTC. The catchments are set up in the models using NextMap DEM data, CEH LCM 2007 land use data and NSRI soils data.

Data and model outputs

- Continuous high frequency hydrological data (discharge) at 15 minute temporal resolution
- Continuous high frequency water quality data (phosphorus, nitrate, turbidity) at 30 minute temporal resolution
- High frequency weather data at 15 minute resolution

A suite of water quality models (SWAT, HYPE and INCA-P) are being calibrated and evaluated for the Eden DTC catchments providing discharge and phosphorus outputs along with uncertainty on these model predictions. The models will then run a range of climate and land use/management scenarios to assess the changes in discharge and phosphorus by 2050.

Model performance

Failure of the diffuse pollution WwNP measures (Figures 1 and 2) could arise if, for example, flushing of sediments occurred during a large event. The high frequency monitoring means that this effect would be picked up and could be explicitly modelled using the continuous simulation models that have been set up.

4. Lesson learnt

Choice of tools

The NutCat 2050 (Estimating nutrient transport in catchments to 2050) project (www.nutcat2050.org.uk) will assess whether the chosen models (SWAT, INCA-P and HYPE) are fit for purpose for simulating hydrological and biogeochemical cycles in the chosen catchments along with the associated uncertainty in the predictions using the GLUE methodology. Although the investigation is not yet complete, the open source nature of SWAT and HYPE has made the modelling transparent since, for these models, the full code is available and it can be downloaded and modified.

Figure 2: Sediment trap in the Morland catchment

Source: JBA Consulting

Figure 3: Small scale sediment trapping in the Eden catchment

Source: JBA Consulting

Catchment scale and typology

This work focuses on the catchment scale for which the calibration data are available (the 3 Eden DTC monitored catchments), although the Morland subcatchment is only 10km2. Semi-distributed models are being employed to investigate at the whole subcatchment scale so as to encompass as much detail of the catchment processes as possible while making the models run as computationally efficient as possible.

In relation to this, as the models work on a lumped approach, a scale limitation will arise when using them for flood risk applications. There will be difficulty in representing small scale features in models such as SWAT, HYPE and INCA. This involves some major assumptions when accounting for small scale flood retention features and nutrient mitigation measures in the models, often involving the calibration of large scale parameters which leads to inherent uncertainty.

In terms of timescales, it has been found to be crucial to 'warm up' the application rates of nutrients before modelling the period of interest because there can be a very long lag between seeing their impact. This means that the models will need to be run for long periods to understand the WwNP measures.

Wider benefits

The major objective is to model the effectiveness of WwNP measures to improve water quality. However, the models used in this approach can be employed to investigate the types of hydrological events that lead to flooding and the associated impact on nutrient transport. Both HYPE and SWAT have hydrological models needed to estimate rainfall run-off with which to drive the diffuse pollution fluxes.

Future research needs

This study utilises high frequency data to help identify areas where the current generation of water quality models are failing and have the most uncertainty in. Without high frequency monitoring data, the 'sampling error' in observations can be very large due to natural variability and so the calibration of models can be very uncertain.

The results of the GLUE procedure will help to identify whether each model is fit for purpose for application to a range of catchments. It will also highlight the parameters and processes where there is the most uncertainty in the model. This will allow model users and policy makers to make decisions as to which model is more appropriate to use for decision making in their catchment and also provide them with a measure of confidence in the predictions made by that model. This will aid in the decision making process for adaption to potential changes under a future climate.

This case study adds to previous research in the field of uncertainty in water quality modelling. It aims to build on applications of the GLUE approach to water quality models (Dean et al. 2009) by evaluating the models using high frequency DTC data.

5. Bibliography

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Project background

This case study relates to information from project SC120015 'How to model and map catchment processes when flood risk management planning'.

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