LM0308: Catchment Management for Water Quality

Case Study 5: Uncertainty in ecological responses to water quality control measures at the river basin scale.

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Purpose: To demonstrate the attribution of sources of errors and their effects in estimating the ecological response to mitigation methods aimed at nutrient reduction.

Policy driver(s)	Water Framework Directive (ecological quality), Farm Payment Schemes, New Environmental Land Measures Scheme
Enduser(s)	Catchment Managers e.g. those developing River Basin Management Plans and Catchment Based Approach Hosts
Pollutant(s)	Phosphorous and Nitrogen
Measures	Catchment scale measures that can represented in SAGIS and/or INCA-P - Land use change, on-farm measures (from Farmscoper), shading from trees, flow augmentation (at low flows) and final effluent improvements
Scenario if appropriate	River Thames under current climate conditions, baseline and mitigation options (including low-flow mitigation) will be run with a number of model combinations.
Outcome / output	An assessment of the effects of different sources of uncertainty on our estimation of biological effects (algal growth) in a river system. How does this uncertainty compare with the magnitude of the impact of mitigation measures on nutrient concentrations and biological response? How does uncertainty in impact mitigation translate into costs and/or benefits?
Scale / Location	Catchment/ River Thames above Runnymede, SE England Area: 10,000 km^2, 7% Urban, 68% Agricultural Issues: P concentrations, algal blooms, point and non-point pollution sources
Risks	For future applications to all UK catchments, the following datasets must be available as a minimum: mean daily flows, EA, SEPA, NEIA water chemistry data, land cover map, final effluent concentration data, daily precipitation and air temperature.

Risks	The model used to generate the estimate of the hydrologically available rainfall and soil moisture deficit needs to be available. A reliable calibration of the branched version of INCA-P is achieved. For wider and un-restricted use of SAGIS the underlying flow data from Wallingford HydroSolutions needs to be made freely available[1].

Background / Narrative:

There are many sources of uncertainty in trying to predict the results of a particular intervention action in the catchment on the quality of water in a receiving water body. These include uncertainties in the measured data (used for generating loads and assessing model performance), in models used to in-fill measured data (temporally and spatially), in the effectiveness of a particular mitigation measure and in the river models that deliver the final result. This case study will try to estimate where these uncertainties lie for the case of assessing the effectiveness mitigation methods that reduce P (and N) loads to rivers in reducing their concentration and potentially modifying the ecological response e.g. algal growth. How do the uncertainties in the modelling process compare with the actual changes predicted? How can we reduce uncertainty?

Basic approach:

A multi-model approach will be used in this case study in which the models will be run separately and in sequence. The aim is to estimate the uncertainty in the biological response of the river system that results from (1) possible errors in estimates of input loads (2) uncertainty caused by using different models to provide the input instream loads and (3) uncertainty in the effectiveness of mitigation methods. The model chains will allow us to drive one model, QUESTOR, with the input loads from the other models (SAGIS and INCA-P) and compare these with the loads generated from measurement of flows and water chemistry. This will be done for baseline cases representing current conditions. Following this, a range of mitigation options for reducing chemical contaminations and augmententing flows will be explored.. Only gross mitigation options can be readily included. With INCA-P we can look at changes in land use and fertiliser additions on N and P loads reaching rivers reaches. With SAGIS we can look at annual and seasonal reductions in N and P loads across the catchment or from parts of the catchment. It is possible to use FARMSCOPER to specify the percentage changes expected due to a more specific range of farm-scale interventions as is being done in other case studies. All models can consider improvements in sewage works' final effluents.

The study will focus on Phosphorus (but will include also include N) as the driver of biological change. We will develop metrics to define biological change, but it will likely include changes in predicted P and N concentration and algal growth and associated dissolved oxygen (DO) and Biochemical oxygen demand (BOD) change. In a previous study for Defra, the metric we used was days in excess of "unacceptable" threshold concentrations of BOD, DO and chlorophyll-a . Comparing changes in this metrics between the modelled baseline and the modelled scenarios shows the direction and magnitude of change.

[1] There would be no restrictions to those who already hold a licence for LowFlows Enterprise. This would include the Environment Agencies and many Water Companies.

Models to be used:

- SAGIS
- INCA-P
- QUESTOR

Data to be used:

This project will focus on the Thames catchment and this defines the spatial extent of all the data. The data will be for (where possible) existing, calibrated model runs set up for recent periods.

- Inputs
  - QUESTOR dataset 1:
    - Time series of flow and water quality at the boundaries of the existing QUESTOR model simulation and for any STP discharges directly to the river system. These are taken from the National River Flow Archive (NRFA), and the Environment Agency GQA data supplemented by the CEH Thames initiative data.
    - Solar Radiation data time series at one location in the catchment.
    - Observed river quality and flow data (same source as above) for model performance evaluation.
    - Set of model parameters from the model calibration.
  - QUESTOR dataset 2: Contaminant chemical loads to each river stretch or collection of river stretches from the SAGIS Model.
  - QUESTOR dataset 3: Contaminant chemical loads and to each river stretch or collection of river stretches from the INCA Model.
  - SAGIS dataset 1: Driving data base set: Sewage treatment works discharge quality and flows, naturalised river flows, EA WIMS water quality data, diffuse inputs (PSYCHIC/NEAP-N) – **data already included in SAGIS model databases**.
  - SAGIS dataset 2: A number of different datasets (a-e) one for each set of driving data that corresponds with the mitigation measures scenario modelled (see below). Change in the driving data based on predicted changes due to selected mitigation options (N and P).
  - INCA-P dataset 1: Driving data base line:
    - Daily time series of precipitation, air temperature, mean daily flow, and streamwater nitrate and phosphorus concentrations, land cover, fertiliser inputs, sewage work flows and N and P concentrations. These data will be consistent with SAGIS model set-up.
    - Set of model parameters from the model calibration.
  - INCA-P dataset 2: A number of data set (a-d) as INCA Dataset 1, but modified to account for P mitigation options

- Outputs
  - QUESTOR all data sets resulting from the different driving data will be comprised of predicted concentrations of chemicals related to oxygen levels and nutrient species. Temperature, pH and biological variables (phytoplankton, macrophytes and benthic algae). Output at daily time steps. Many plotting options: river profiles, time series or distributions)

- SAGIS
    - All data sets resulting from the different driving data will be comprised of (i) Predicted concentrations for 28 chemicals at a selectable spatial scale (e.g. 1km interval). (ii) Chemical inputs source tracking – 'within sector' contribution from specific upstream sources. (iii) Input load and concentration source apportionment summarised by water body. (iv) Data visualisation – chainage plots showing concentration profile by source along the length of a river.
    - Additional data outputs will be created to act as inputs to INCA and QUESTOR to generate the input files described above.
- INCA-P
    - all data sets resulting from the different driving data will be comprised of Simulated daily mean flows and streamwater TP, TDP, PP, SRP and suspended sediment concentrations. Phosphorus process flux estimates for catchment processes such as, P weathering and estimates of P transport via different flow pathways.
    - Additional data outputs will be created to act as inputs to QUESTOR to generate the input files described above.

- Validation
  - QUESTOR and SAGIS have been already calibrated for the base line driving data set. It is not intended to re-calibrate the models for the other driving data sets, but to see the response of those calibrated models to other sources of driving data.
  - INCA will require water flows and water chemistry data at selected points in the river to perform a calibration of the branched version. These data will come from the NRFA and from the Environment Agency GQA data.
  - Validation data are in all cases based on measured stream water daily mean flows and spot samples of streamwater chemical concentrations. Usually these come from the NRFA and the Environment Agency GQA dataset.

Other requirements:

- Work with Paul Whitehead to adapt new version of INCA (in stream phytoplankton) parameterized to include diatoms, cyanobacteria, green algae, etc.
- Contact Chris Burgess to identify any synergies
- Make contact with Adie Collins and Pam Naden to identify any possible synergies re: Defra-funded project WQ0223: Developing a field tool kit for ecological targeting of agricultural diffuse pollution mitigation measures
- Economic work would be beyond scope due to scale of Case Study but to be discussed with Defra for priorities across Case Studies

Workplan:

<u>Baseline scenarios</u>

These are from (where possible) pre-existing model runs for the River Thames from Hannington Weir (SU5040013800) to Runneymede (TQ1703971391). The base line period is 2010 to 2012. Models for the baseline exist for SAGIS and for QUESTOR. The branched version of the INCA-P model will be setup by April 2015.

All three models will be run for the baseline: INCA-P and will deliver estimates for P species. SAGIS will provide estimates for N and P species. QUESTOR will provide estimates for N and P species plus chlorophyll-a (algae). The differences between the model results s will tell us about uncertainties created by the structure of the model selected for the simulation.

Uncertainty model runs with the baseline
The QUESTOR river model will be run with driving data from the SAGIS and INCA-P models. The QUESTOR outputs for N, P and algae from these runs will be compared with the baseline runs to assess the difference made by using different driving data.

INCA-P and SAGIS will provide flow and concentration data to replace the observed data used by QUESTOR. INCA-P data will be daily data (flow and P), SAGIS will provide monthly average data (flow, N and P). The current observed data is available weekly.

Comparison of N, P and algae concentrations generated by the baseline, and two scenarios will be compared.

Mitigation Methods for reducing algal growth.
There will be at least 4 approached tested

1. Increased river shading provided by growing tree on the river bank (shade scenario): QUESTOR only
2. Flow augmentation to reduce residence times in summer low flows (flow scenario): QUESTOR and INCA-P.
3. Land use change at a gross level in parts of the catchment. The details of the nature of the change and the extent and locations are yet to be decided. This will be done using INCA-P and the data will driver QUESTOR (land use Scenario, there could be more than one of these).
4. Changes in farm practice. A national case study is looking at baskets of farm practices to reduce N and P loss from catchments. The percentage change in loss rates is calculated by Farmscoper. The values for the Thames basin will be extracted and applied to the SAGIS loads. The resulting SAGIS outputs will be used to drive the QUESTOR model (farm practice scenario).
5. The effect of imposing stricter discharge consents for SRP on sewage works that are less than 10,000PE in size. A suitable consent level will be agreed (P point scenario).
6. The effect of imposing stricter discharge consents for NO_3 on all sewage works. A suitable consent level will be agreed (N point scenario).

The effects of the mitigation options will be assessed in terms of the changes in distributions of N,P and algae at at least three locations along the River Thames: Upstream, Middle (below Oxford) and that Runneymede. Foe algae we will also compare days above a threshold that would be deemed unacceptable. We will compare the changes in these metrics for the mitigation measures with the differences in the baseline runs and the differences caused by the different driving data.

The possibility of putting tools on the data/model platform server to allow this comparison (or any combinations of comparisons will be investigated.

Actions required:

- Andy Wade will implement the branched version of INCA-P for the agreed temporal and spatial scale end of March 2015).
- Richard Williams will provide the current QUESTOR reach structure so that this can tie in with the INCA-P branch structure (30th January 2015).
- Richard Williams will provide the list of locations where QUESTOR requires input of water quality. These are in general the upstream model point and at all tributaries entering down to Runnymede (30th January 2015).
- Peter Daldorph to provide appropriate SRP and NO_3 consent levels for the point source scenarios (mid February 2015).
- Andy Wade to suggest gross land use change that might be appropriate for the land use scenario based on outputs from the EU FP7 REFRESH project (March 2015).
- Peter Daldorph to get N and P percent reductions for the Thames catchment from suitable mitigation options using Farmscoper runs in Case Study 2 (March 2015).

Milestones:

- Scope out Case Study (Feb 2015)
- Develop model documentation for the Platform (March 2015)
- Establish the common spatial and temporal extent for the parallel applications of QUESTOR, INA and SAGIS. Also how to transfer output data from SAGIS to INCA and QUESTOR and from INCA to QUESTOR Agree on mitigation options and how they will be enacted in SAGIS and INCA. Agree on metrics to assess results of mitigation measures. Agree time frame, catchment extent, input data and mitigation measures to be included as scenarios. (Apr 2015)
- Start conditioning and ingestion of data and models with documentation into Platform including model input and outputs (June 2015)
- Completion of first model application outputs and testing with Community Forum (Nov 2015)
- Start conditioning and ingestion of external data and models into Platform (June 2016)
- Iteration to identify benefits of model coupling (Nov 2016)
- Final report (Mar 2017)

Link to Enduser Questions:

Future pressures and extrapolation of impacts

- Potential effects of future trends such population growth, climate change; land use change, food security and nutrient supply need to be better quantified.

Uncertainty, confidence and communication

- How does using different input datasets affect the model outputs and hence the evidence base upon which to base action?
- What is the uncertainty associated with modelling the different effectiveness of measures?

Effectiveness of measures / mechanisms

- What is the combined impact of multiple pressures, biological response, and the effectiveness of measures?