PHOSPHORUS SOURCE APPORTIONMENT SUMMARY: UPDATING THE SAGIS RIVER DEE MODEL

SAGIS Non-Technical Calibration Report for the River Dee

15TH DECEMBER 2022

Dŵr Cymru Welsh Water

Cyfoeth Naturiol Cymru Natural Resources Wales

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DOCUMENT AUDIT

AUDITOR	ORGANISATION	DATE
CP, LK, NH	Binnies on behalf of Natural Resources Wales	9/12/2022

CONTENTS

FIGURES

1. MODELLING THE RIVER DEE SAC

The purpose of this note is to provide an overview of the computer modelling approach being used to develop plans for wastewater investments to help ensure the River Dee achieves water quality objectives for phosphorus.

The River Dee is designated as a Special Area of Conservation (SAC) under the Conservation of Habitats and Species Regulations 2017, as amended (referred to as the 'Habitats Regulations'). In January 2021, Natural Resources Wales (NRW) published a report on the compliance assessment for tightened phosphorus targets showing that c.33% of waterbodies in the River Dee SAC fail to achieve the targets, with one of nine waterbodies in the SAC not assessed. In November 2022 NRW published a review of water quality targets which led one water body (Ceiriog - confluence Dee to Teirw) being downgraded from pass to fail. As a result c.44% of water bodies in the SAC fail to achieve the targets.

In response, NRW and Dŵr Cymru Welsh Water (DCWW) have implemented a programme of water quality modelling to develop an improved understanding of the sources of phosphorus within the catchment, and to explore approaches for improving water quality.

Note that whereas the term 'phosphorus' is used in this document, the form of phosphorus that has been modelled is known as 'orthophosphate', the form measured and compared with environmental targets. This may be understood to represent the most bioavailable form of phosphorus.

This note focuses on the River Dee SAC in Wales and England (border shown by the red boundary in Figure 1). Figure 1 also shows the SAC and WFD regulated waterbodies.

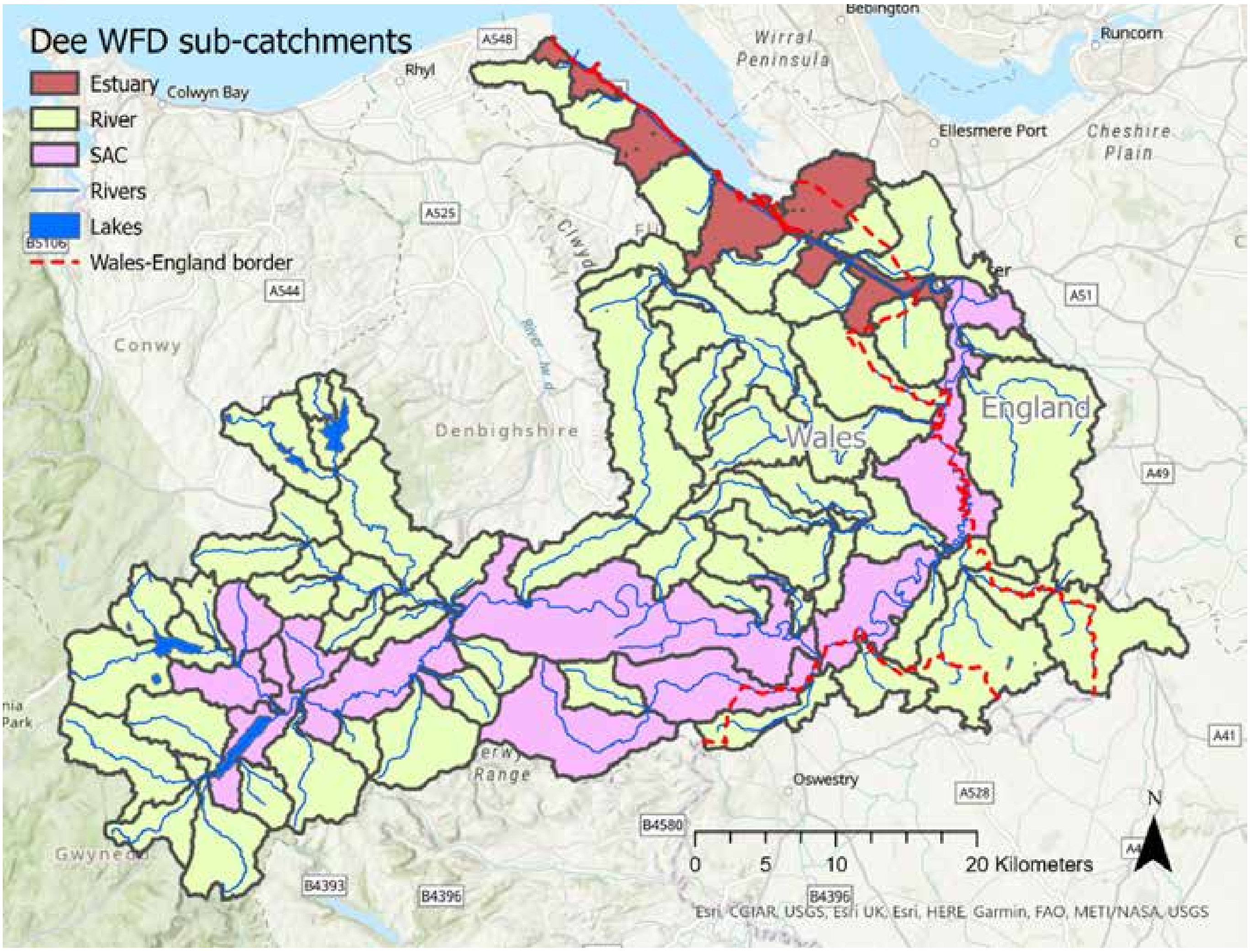

Figure 1 - Map showing the River Dee (England-Wales border shown by the red boundary)

2. WATER QUALITY MODELLING

Water quality modelling has been used for many years in wastewater planning to assess the effectiveness of controls on point sources of pollution and to help identify those interventions that are likely to be most effective in reality. Modelling helps to provide confidence that measures will deliver the envisaged environmental outcomes.

Computer models, however, provide only a simplified representation of complex natural systems and consequently, their limitations must be considered as part of the process of developing plans of action. Indeed, modelling is most useful when deployed as part of a 'weight of evidence' approach where it is used in combination with information from other sources, including local knowledge and input from other subject matter experts. Key stages in the modelling process include:

- Models are updated and calibrated so that they provide a reasonable representation of recent catchment conditions.
- Important limitations and uncertainties are identified and characterised.
- Water quality improvement scenarios are simulated following regulatory guidance to identify the most effective combinations of measures.

NRW uses water quality models to define new discharge quality permits for DCWW's wastewater point source discharge assets and where necessary to target further monitoring and investigations. Permit conditions for water company assets are subsequently formalised and implemented through normal investment planning and delivery processes.

3. SOURCE APPORTIONMENT GRAPHICAL INFORMATION SYSTEM (SAGIS)

The Source Apportionment Graphical Information System (SAGIS) has been used to create the virtual representation of the River Dee. SAGIS is derived from earlier modelling approaches (SIMCAT and RQP) that have been in use in the UK for several decades which have underpinned the investment made by the UK Water Industry in measures to improve water quality. Together with SIMCAT, SAGIS (also known as SAGIS-SIMCAT) is the standard tool used by regulators and the water industry to identify assets where controls on effluent quality are required. The SAGIS build version used in this study was 1.0.8112.21765. The version of SIMCAT was 15.7.

MODEL DATA

There are two main types of data contained within SAGIS model databases - measurement and sector data (further information is provided in Appendix A):

- **Measurement data** - river flow (for the period 2016 to 2019) and quality (phosphorus) measurements as well as sewage treatment works discharge flow and quality (for the data period 2016 to 2019). A four-year period for river flow was used because period statistics are less likely to be impacted by unusual conditions within a single year. The complex hydrology of the Dee catchment, driven by the Dee Regulation Scheme, was considered with regard to the flows in the model. A four-year period for river quality was used due to concerns over anomalous measurements in 2014 and 2015. Where measured effluent quality data was not available a default value of 5mg/L was applied. For treatment works with descriptive permits, discharge flow was estimated as the population served multiplied by 165 litres per person per day. For other sites discharge flow was based on either measured data or the permitted discharge flow.
- **Sector data** - for inputs from sources other than sewage treatment works.
  - Estimates of diffuse inputs are included in the model by sector as an annual load input by waterbody. Contributions from urban, industry, septic tanks and rural land use have been estimated. Within the modelling process waterbody loads are distributed across the river reaches in the originating waterbody.
  - Storm Overflows (CSOs) - SAGIS includes representation of inputs from intermittent discharges such as CSOs and storm tanks.

MODEL CALIBRATION

SAGIS calibration is a process through which the level of agreement between observed and simulated values is optimised. Within the calibration process, the parameters controlling the sector input loads (the total input load) and variability (the variability associated with the total input load) are adjusted along with the determinand decay rate (a parameter representing a combination of effects, including in-river losses due to uptake of nutrients like phosphorus into the environment, deposition to sediment, and chemical transformation).

MODEL CONFIDENCE

Following the calibration process, the level of agreement between measured and simulated values is assessed. The level of agreement helps to identify locations or regions where modelled values diverge from measured values, and therefore where the model may be inappropriate to support decision making (or at least to identify where there may be uncertainty associated with the outcomes of actions that are supported by model outputs).[1]

For the River Dee SAC, the level of agreement between measured and simulated concentrations was evaluated at the monitoring locations in England and Wales, with the results indicating:

- In England, model performance was assessed at 12 locations. Nine of the sampling locations were situated outside of the Dee SAC and were therefore of peripheral importance for this study. River quality at one location (outside the SAC) was considered unsuitable for characterising model performance due to the lower number of samples (Moderate). There was a Good level of agreement between observed and simulated values at eight locations (of which three locations are within the SAC). The remaining three locations were classed as Poor.
- In Wales, model performance was assessed at 55 locations, with a Good level of agreement at 41 locations (11 within the SAC). One location (located outside the SAC) was classed as Moderate due to the low number of samples (less than 12, but more than 8 samples) so was considered unsuitable for characterising model performance. The remaining 13 locations were classed as Poor with none of them being found in SAC waterbodies.

MODEL AUDIT

To provide assurance that the model is robust and can be used as the basis for wastewater planning, NRW commissioned a quality assurance of the SAGIS-SIMCAT modelling of phosphorus in the river. The aims of the QA were to ensure the models have been built and calibrated in line with agreed guidance; check that the correct water quality targets have been applied at the correct locations, and that the spatial location of model features is correct; identify any discrepancies between the models and guidance and help prioritise any required changes; ensure the outputs from the models have been correctly represented tools to be used for wastewater planning purposes.

In summary, the QA identified a number of corrections to be made which are planned for completion in early 2023. However the model is otherwise in line with agreed guidance and fit for the purpose of informing wastewater planning decisions. A number of other lower priority recommendations for model development will be taken forward for review later in the year.

4. MODEL RESULTS

At the assessment location (quantified at water quality monitoring station 689), the model shows that, under current conditions, approximately 108kg of phosphorus is discharged from the River Dee catchment on a daily basis. Effluent from sewage treatment works accounts for 34% of the average daily load (kg/d) with rural land use contributing 48%, storm overflows contributing 11% and a further 7% from other sources including septic tanks and urban run-off.

The model shows that under current conditions effluent accounts for 34% of the average phosphorus concentration (mg/l). The concentration and load apportionment can differ because inputs from different sources tend to occur under differing river flow conditions but in this instance, the load and concentration apportionment for sewage treatment works is the same. For example, inputs from treatment works occur continuously (i.e. under high and low flow conditions) whereas inputs from diffuse sources tend to occur under higher river flow conditions where there is a higher level of dilution available in the receiving water. This means that, on balance, a kilogram of phosphorus discharged from a treatment works will have a relatively greater impact on the in-river concentration than the equivalent input from diffuse sources.

The modelling also takes account of decay effects which, in this context, represents a combination of influences, including in-river losses due to uptake into the environment, deposition to sediment, and chemical transformation. Consequently, the loads at the furthest downstream point are not necessarily equivalent to the total input loads.

The modelled load apportionment information is presented in Figure 2 which shows load apportionment at the water quality monitoring location 689 (also shown in Figure 2) which is situated in the downstream waterbody in the River Dee catchment (GB111067057080B) and serves as a convenient reporting location. Note that apportionment will differ at different locations within the catchment.

SAGIS also provides an estimate of the phosphorus contribution from the storm overflows in the catchment. These were estimated at approximately 11% of the catchment load (at monitoring location 689). This information is shown in Figure 2.

The availability of water quality monitoring data and sewage treatment works performance data, means that SAGIS modelling provides a robust framework for use in decision-making for wastewater investment planning. In general, estimates of loadings from diffuse sources from other sectors, within SAGIS, have a greater degree of uncertainty.

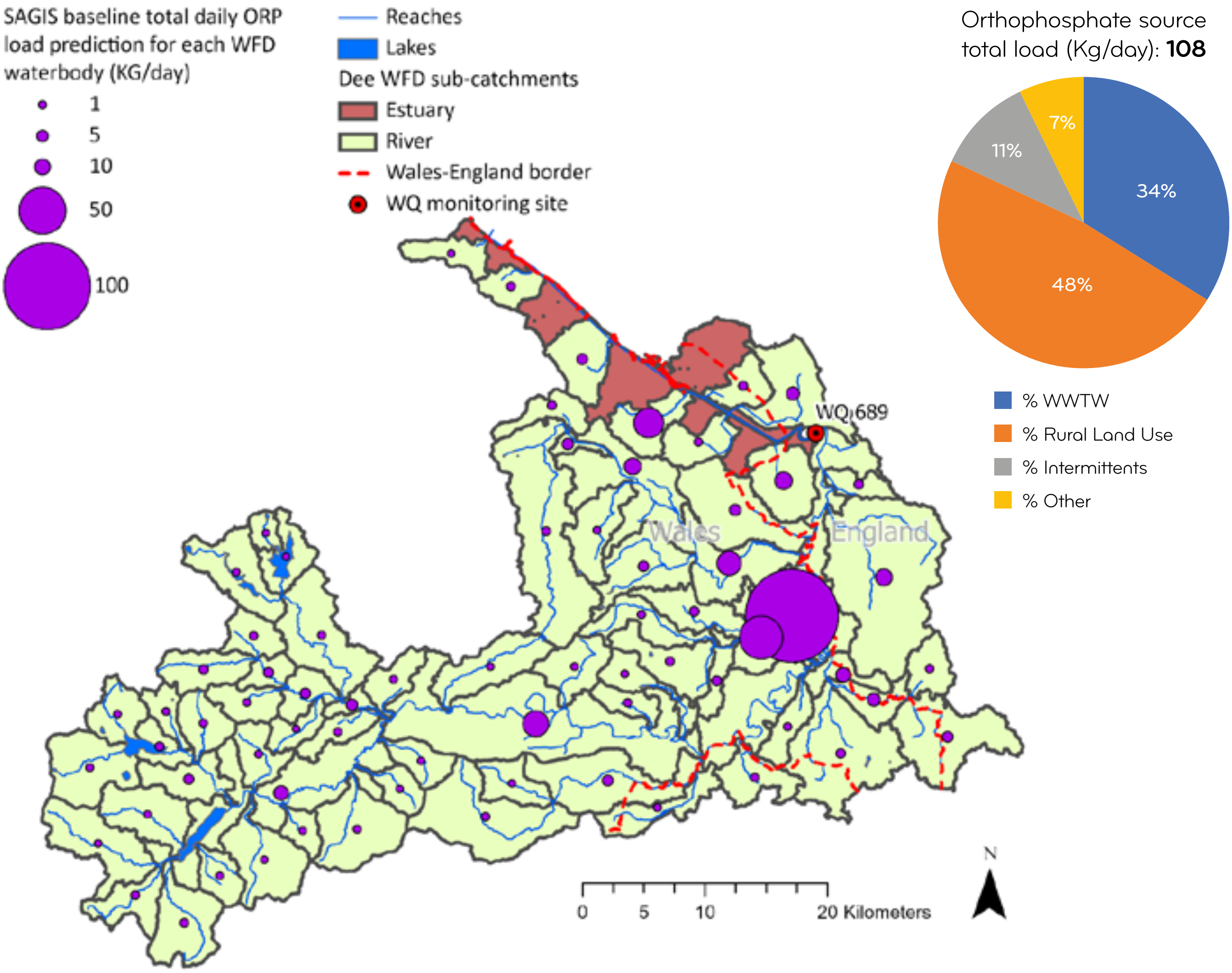

Figure 2 - Phosphorus apportionment by source at the furthest downstream point on the River Dee.
Note that the 'Other' category is comprised of estimated contribution from diffuse sources of urban, industry and septic tanks.

5.SCENARIO MODELLING

The SAGIS model has been calibrated and will be used shortly to test the theoretical impact of changes in effluent quality at a range of catchment sewage treatment works (i.e. 'what if' scenarios). Scenarios are intended to inform on the scale of the challenge of bringing the river into compliance with the targets and the level of investment that may be required.

APPENDIX A

MODEL DATA

There are two main types of data contained within SAGIS model databases, namely, measurement data and sector data. Measurement data are derived from routine monitoring activities, and include river quality information obtained by NRW, river flow information reported at national river flow gauges, as well as effluent discharge flow and quality data. Models are calibrated to the measurement data so that models are expected to recreate (virtually) conditions that span the period of time over which the measurement data was obtained. The model for the River Dee SAC has been developed using phosphorus data covering the period 2016 to 2019.[2] There are two important points relating to how the river quality data are processed prior to inclusion in the model:

- Data obtained as part of reactive pollution monitoring were excluded from the summary statistics to ensure the model data are not unduly distorted by infrequent or random events.
- Data was checked for outliers which had the potential to distort summary statistics, but no samples were found which had a statistically significant impact on the results.

The sector data contained within the model databases represent estimates of inputs from sources other than sewage treatment works, primarily diffuse sources. Estimates of diffuse inputs are included in the model by sector as an annual load input, by waterbody.[3] Within the modelling process these waterbody loads are distributed across the river reaches within the originating waterbody. An occasional consequence is that within the modelling process inputs from certain sectors may be distributed to river reaches in which they are not expected to occur although this tends to primarily affect river reaches situated in headwater locations.

Agricultural input estimates are based on data from the Phosphorus and Sediment Yield CHaracterisation In Catchment model (PSYCHIC; Davison et al., 2008; Stromqvist et al., 2008), which provides an estimate of phosphorus 'losses' to waterbodies at a 1km^2 grid scale, but which have been aggregated to a waterbody scale for use within SAGIS.[4] Modelled transfer pathways include release of soil phosphorus, detachment of sediment and associated particulate phosphorus, incidental losses from manure and fertiliser applications, losses from hard standings and the transport of all the above to watercourses in underdrainage (where present) and via surface pathways. The model is sensitive to a number of crop and animal husbandry decisions, as well as to environmental factors such as soil type and field slope angle. The PSYCHIC model utilises the mean climate drainage model (MCDM, Anthony, 2003) to calculate the evapotranspiration, soil moisture deficit and soil drainage. The presence of artificial drainage systems the relative importance of different sub-surface drainage pathways are based on the Hydrology of Soil Types (HOST; Boorman et al., 1993) classification. PSYCHIC has been applied across the UK in support of government policy (e.g. Anthony et al., 2005; Gooday et al., 2015) and has also been applied to a number of European catchments (Silgram et al., 2008).

The current phosphorus data within SAGIS for England and Wales is from the PSYCHIC model (Davison et al., 2008) based agricultural census data for 2010.

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Davison, P.S., Withers, P.J.A., Lord, E.I., Betson, M.J. and Stromqvist, J., (2008) PSYCHIC – a process-based model of phosphorus and sediment transfers within agricultural catchments. Part 1. Model description and parameterisation. Journal of Hydrology, 350(3-4), 290-302.

1. In the model for the upper River Dee SAC the following criteria have been used to characterise model certainty/confidence:
   - Good. Where the difference of <0.005 mg/L between observed and simulated values,
   - Moderate. Where there is a difference of >0.005 mg/L between observed and simulated values but the difference is not statistically significant (or the number of samples is <12)
   - Poor. Where there is a difference of >0.005 mg/L between observed and simulated values and the difference is statistically significant.
2. Implies that future conditions will be representative of conditions within the snapshot period. Models are updated and recalibrated on a periodic basis.
3. This is the scale at which diffuse sector inputs can be quantified with reasonable confidence.
4. The substantial uncertainty associated with estimates for individual 1 km2 grids is well accepted.