Irfon Catchment Resilient Freshwater Habitats project

Stream flow and water quality modelling in the Irfon catchment:

Nutrient modelling, mitigation scenarios and natural flood management.

October 2022

Document Title: Stream flow and water quality modelling in the Irfon catchment: Nutrient modelling, mitigation scenarios and natural flood management.

Author(s): Villamizar Velez, M., Biggs, J. and Brown, C.

Date of Issue: October 2022

Version: 1

Please cite this document as: Villamizar Velez, M., Biggs, J. and Brown, C. (2022). Stream flow and water quality modelling in the Irfon catchment: Nutrient modelling, mitigation scenarios and natural flood management. Irfon Catchment Resilient Freshwater Habitats project report. University of York, York, UK, pp.33.

Team members: This project has involved the following people: Professor Jeremy Biggs, Freshwater Habitats Trust; Dr Martha Villamizar Velez, Professor Colin Brown, University of York.

The Irfon Catchment Resilient Freshwater Habitats project is funded by the Welsh Government's Sustainable Management Scheme with the support of the European Union through Welsh Ministers.

Non-Technical Summary

The Irfon catchment in mid-Wales is a Site of Special Scientific Interest and a Special Area of Conservation designated for its exceptional freshwater biodiversity, which includes one of the few remaining UK Freshwater Pearl Mussel populations. However, exposure to multiple pressures means the catchment is currently failing to meet Habitats Directive and Water Framework Directive targets. The Irfon Catchment Resilient Freshwater Habitats project aims to establish a collaborative programme to address these issues, jointly organised by local farmers, landowners, rural businesses, foresters, statutory organisations, specialist freshwater NGOs and the water industry.

This report serves as an analysis of existing data to inform the types of opportunities in the catchment that could be used to reduce nutrient loads and flood risk. Existing baseline data for the catchment are scarce, especially for sediment, nutrient and phosphorus (multiple point survey reports, but no time series). Models are constructed and used in this report to inform catchment management approaches. The following parameters have been modelled: stream flow, nutrient load and concentrations including soluble reactive phosphorus, nitrate and oxidised total nitrogen loads, and the impact of mitigation scenarios on nutrients (buffer strips and land and forest management).

Modelling indicates an average yearly total oxidised nitrogen yield of 220 tonnes and maximum concentration of up to 1.7 mg/l at Builth Wells. In addition, an average yearly soluble reactive phosphorus yield of 38 tonnes and maximum concentrations of up to 0.94 were predicted at the same location. Applying wider buffer strips on farmland could reduce loads of total oxidised nitrogen and soluble reactive phosphorus by up to 46 and 11 tonnes per annum, respectively. Similarly, maximum concentrations of total oxidised nitrogen and soluble reactive phosphorus could be reduced by up to 35 and 29%, respectively. Reductions in stocking densities and afforestation were also identified as amongst the most effective mitigation actions to reduce nutrient contamination in the river.

The catchment could benefit from flood risk reduction at Llangammarch Wells and Builth Wells through the use of natural flood management by increasing water storage in the upper parts of the catchment. Interventions such as leaky barriers and online storage ponds that have the potential to synchronise peak flows should be avoided in

parts of the catchment such as on tributaries near and downstream of Llangammarch Wells, but other NFM measures that slow flow such as floodplain reconnection, tree planting, buffer strips, offline storage ponds, riparian fencing and livestock managing could be effective in these locations.

This report makes recommendations for information and data that could help improve model predictions. A priority is proposed to be installation of permanent water quality sondes including capacity for turbidity measurements that can be related to sediment concentrations.

Contents

1. Introduction

A SWAT model was generated to simulate flow, nutrient and sediment loads and concentrations at key locations in the Irfon catchment. Predictions were also made on the quality of water in terms of nutrients (N and P) in the catchment both for the present situation and for seven land management scenarios comprising: i) removal of sewage point sources; ii) reduction of livestock levels to low intensity grassland; iii) conversion of all current arable land and intensive grassland to low input grassland; iv) a landscape based on the Dudley Stamp map layer of 1930s land use, and population equivalents; v) double the current afforestation rate; vi) afforested buffer strips installed to farmland for all watercourse out to 20 m and 50 m; vii) all soils set to have a P index value of 0.

A synchronisation analysis of tributaries was undertaken to investigate the best location for NFM in the catchment. Impact of time delay and storage on peak flow reduction as well as a cost-effectiveness analysis of NFM was included to support plans for NFM installation.

2. Methods

2.1 Stream flow and sediment modelling using SWAT

A SWAT model was set up for the Irfon catchment (290.4 km^2) up to the outlet at the outfall of the River Irfon at Builth Wells (Grid reference: SO033515) to simulate daily stream flow, sediments and nutrients. A second outlet was located 5 km upstream at the Natural Resources Wales (NRW) flow gauge station (55012) at Cilmery (Grid reference: SN995507). The catchment was delineated using an OS 5-m digital terrain model (DTM) (Ordnance Survey, 2015) (Fig. 2a). A spatial slope map was calculated using the DTM and classified into five ranges in the model (0-2%, 2-7%, 7-12%, 12-18%, >18%) (Fig. 2b). Spatial data used to defined HRUs in the model included a map of soil associations (Cranfield University, 2014) (Fig. 2c) and a modified land cover map based on the Terrestrial Phase 1 Habitat Survey map (NRW, 2022) (Fig. 2d) for the study area. The catchment was finally defined by 73 sub-basins and 7,097 HRUs.

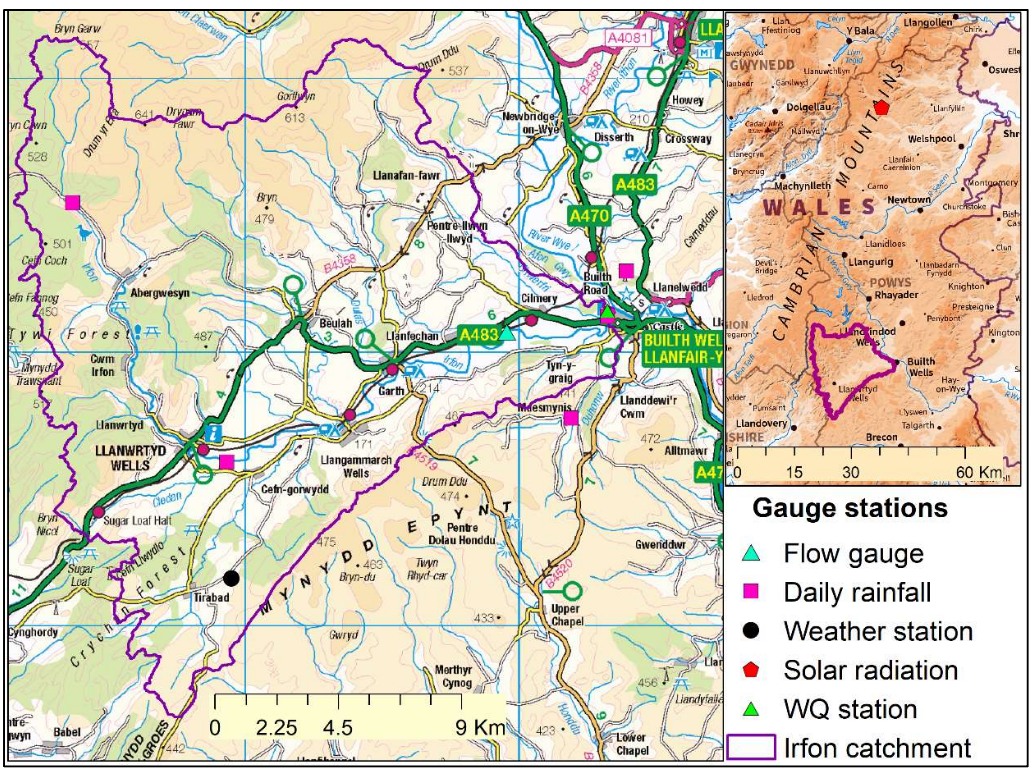


Figure 1. Location of Met Office weather and NRW gauge flow and WQ stations in the Irfon catchment.

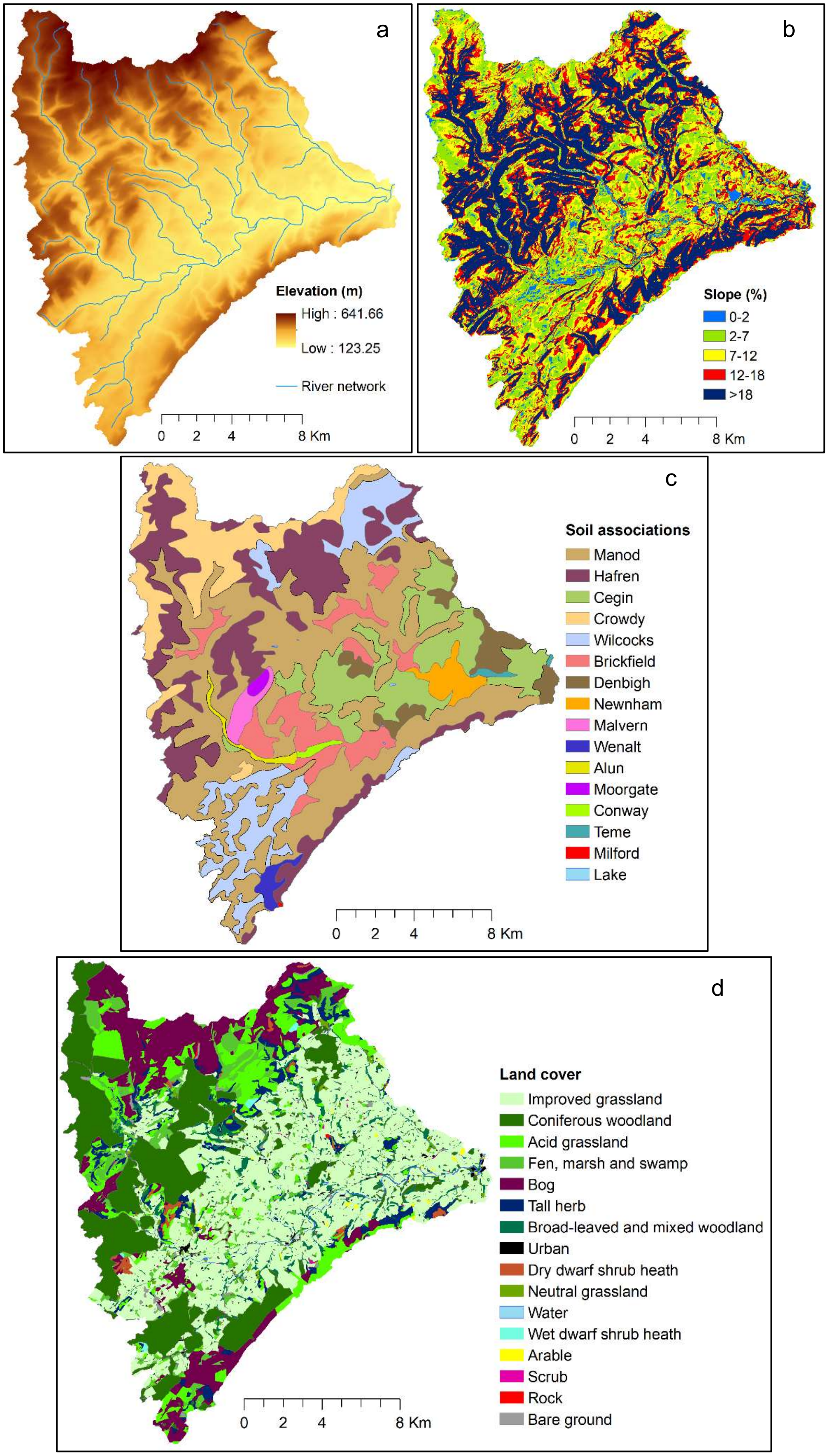


Figure 2. Irfon catchment maps of a) elevation; b) slope; c) soil associations; and d) land cover.

Slopes in the catchment are generally steep (75% of the catchment area is steeper than 7%) (Fig 2b) and altitude ranges between 123 and 642 m above sea level (Fig 2a). Soils in the Irfon catchment are mainly well drained and permeable loam soils (61% of the catchment area); soil associations include Manod, Hafren, Denbigh, Newnham, Malvern and Moor gate) (Fig 2c). Slowly permeable seasonally waterlogged soils comprise 29% of the catchment area (Wilcocks, Brickfield, and Wenalt associations). Perennially wet peat soils (Crowdy association, 9% of the catchment area) are located in the north of the catchment. Deep stoneless permeable soils affected by groundwater in flatland with risk of flooding in parts of the floodplain comprise 1% of the catchment area.

The Terrestrial Phase 1 Habitat Survey map (NRW, 2022 Fig 2d) for the study area contained 48 different land use classes. A simplified land use map with 17 classes was generated for the model (Table 1 and Fig 2d). The number of land use classes had to be simplified to reduce the number of HRUs and model run times.

Table 1. Land use classification and area (as a percentage of the catchment area) used in SWAT for the Irfon catchment.

Land use	**% of catchment**
Improved grassland	39
Coniferous woodland	21
Acid grassland	12
Fen, marsh and swamp	8.0
Bog	7.6
Tall herb	4.8
Broadleaved and mixed woodland	3.8
Buildings / urban	0.82
Dry dwarf shrub heath	0.71
Neutral grassland	0.68
Running water	0.36
Wet dwarf shrub heath	0.29
Arable	0.22
Scrub	0.14
Rock	0.073
Standing water	0.039
Bare ground	0.0080

2.2 Nutrient modelling using SWAT

Point and non-point N and P sources were added into SWAT as described below.

2.2.1 Point N and P sources

Point source information on active discharge consents for the Irfon catchment was obtained from Natural Resources Wales (NRW) (Figure 3). Information included location (UK grid reference) and discharge type (e.g. residential). No information was available from NRW on estimated annual N and P discharges from STWs. The methodology suggested by NRW to estimate P discharge data for a worst-case scenario using dry weather flow and the annual permitted concentration of total phosphorus (TP) was not possible because consent discharges in the Irfon do not specify P values. NRW also advised that no nitrate permits are currently issued. Therefore, we had to use a modified approach similar to that used by the Environment Agency in England. The EA provides estimates of annual N and P discharges based on the number of households and type of STW. We used EA annual N and P estimates for eight STWs in around the Water Friendly Farming project area in the Welland to infer a discharge value based on population/household numbers for each of the eleven STWs in the Irfon catchment (Table 2). This information was added into SWAT at the sub-basin level as an average daily N and P loadings from annual estimates.

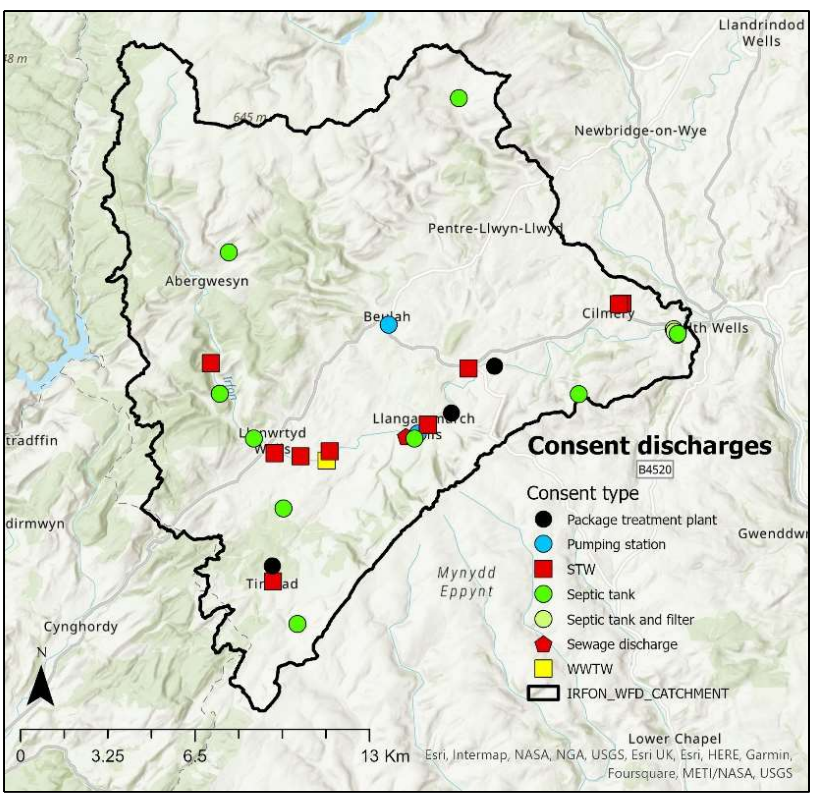


Figure 3. Location of active discharge consents in the Irfon catchment (adapted from NRW consent discharges).

Table 2. Estimated annual N and P discharges using census or number of households data for STWs in the Irfon catchment.

Consent name	Location	Population census 2011	Number of households	N (kg/y)	P (kg/y)	Model sub-basin
Cilmery STW	Cilmery	431	191	449	119	24
Garth STW	Garth	484		504	133	35
Llangammarch Wells STW	Llangammarch wells	507		528	140	48
Llanwrtyd Wells STW	Llanwrtyd wells	574		598	158	55
Tirabad STW	Tirabad		25	59	16	63

Septic tank data were added into the model at the HRU level based on the location of active residential discharges provided by NRW and assuming that each rural residential site outside of the sewage network would have a conventional septic system connected to the watercourse. We assumed that each house would have an average of 2.5 permanent residents and a surface area of drainfield of individual septic systems of 40 m^2 per permanent resident (based on typical default model values for the USA).

2.2.2 Non-point N and P sources

Non-point N and P sources such as fertiliser application and grazing were added into the model using data obtained for the catchment. National records of fertiliser usage on crops in Wales for the year 2020-21 were used to define fertiliser applications for arable land in the model, with N fertiliser mainly applied in the spring and P fertiliser in the autumn (DEFRA, 2020). An overall application rate of 95 kg N/ha and 33 kg P_2O_5/ha were used in the model for all arable land.

We used data from the national inventory and map of livestock manure loadings to agricultural land (Manures-GIS) to define manure inputs in the model from livestock in the catchment at a 10 x 10 km resolution. Livestock manure inputs from livestock sectors included dairy, beef, pigs, sheep as well as layers and broilers. Farmyard manure and direct excreta values to grassland, arable winter and spring data were used to estimate manure deposition rates as well as grazing rates. The dry weight of manure deposited daily, *MR* (in kg/ha/day) was estimated from annual Manures-GIS data for the catchment.

Grazing rates were calculated for outdoor dairy, beef and sheep. However, there was no specific information on the number and location of livestock nor grazing intensity maps for the catchment. Therefore, we combined a modified approach of the methodology reported by Leh et al. (2018) to estimate grazing rates on pasture land. Leh et al. (2018) assumed an average adult cow weight of 540 kg and an average daily intake of 2% of their body weight. The average weight used for sheep was 65 kg and a daily intake of 2.25% of their body weight (UK Agriculture and Horticulture Development Board, 2016). Daily consumption rate *CR* (kg/animal/day) was estimated by multiplying animal weight *W* (in kg/animal) by daily intake *I* (as a percentage of body mass) (Eq. 1) (Leh et al., 2018).

$$CR = W * I \qquad (1)$$

Grazing rates *GR* (in kg/ha/day) can be estimated from stocking rates *SR* (in livestock units/ha, based on the level of management intensity), *LU* (livestock unit/animal) and *CR* using equation 2 but *LU* information was not available for the Irfon catchment.

$$GR = SR \times CR \times LU \qquad (2)$$

However, *MR* can also be estimated from *M* (in kg/animal/day), SR (in livestock units/ha) and *LU* using equation 3.

$$MR = M \times SR \times LU \qquad (3)$$

We combined equations 2 and 3 to estimate *GR* in the catchment using equation 4.

$$GR = \frac{MR \times CR}{M} \qquad (4)$$

Lorimor et al. (2008) reported average estimates of daily manure weights based on animal type and weight. We calculated daily manure dry weights, *M*, of 7.7 and 0.68 kg per cow and sheep, respectively. Estimated grazing and dry manure deposition rates on pasture land were supplied to the model at the HRU level to improved pasture land. Grazing was simulated from mid-March to mid-December.

2.2.3 Other nutrient parameters in SWAT

SWAT parameters for nutrients were selected based on a combination of data reported in the literature for the UK and model approaches from the SWAT manual.

Initial soil concentrations of N and P were calculated using equations reported in the SWAT manual (Neitsch et al., 2011). Initial nitrate levels in the soil were set to vary by depth using the relationship (Eq. 5):

$$NO_{3\,conc,z} = 7.\exp\left(-\frac{z}{1000}\right) \qquad (5)$$

where $NO_{3\ conc,z}$ is the concentration of nitrate in the soil at depth z (mg/kg), and z is the depth from the soil surface (mm). Initial soil nitrate for managed land (improved pasture and arable land) was set to 100 mg/kg based on manual calibration of the model.

The concentration of humic organic nitrogen in a soil layer was calculated as follows (Eq. 6) (Neitsch et al., 2011):

$$orgN_{hu\quad,ly} = 10^4(\frac{orgC_{ly}}{14}) \qquad (6)$$

where $orgN_{hum,ly}$ is the concentration of humic organic nitrogen in the layer (mg/kg), and $orgC_{ly}$ is the amount of organic carbon in the layer (%).

The initial concentration of solution phosphorus in all soil layers was set to 5 mg/kg soil for unmanaged land under native vegetation. A concentration of 25 mg/kg soil for the topsoil layer was considered representative of cropland (Cope et al., 1981).

Organic phosphorus concentrations were assigned using the approach suggested in the model manual (Neitsch et al., 2011). The concentration of humic organic phosphorus in a soil layer was calculated assuming the N:P ratio for humic materials using equation 7.

$$orgP_{hum,ly} = 0.125 * orgN_{hum,ly} \qquad (7)$$

Hayman et al. (2001) measured average concentration of nitrate (0.35 mg N/L, ammonium (0.42 mg N/L), and total N (0.78 mg N/L) in rainfall for the UK (Environment Agency, 2005). These values were added into the model.

2.3 Modelling procedure

A simulation of daily stream flow, suspended sediments and nutrients (using SWAT revision 637) was generated for the period 2011 – 2021. The first year was used as warm up period in the model.

The SWAT calibration and uncertainty program (SWAT-CUP) (Abbaspour et al., 2007) was used for calibration of uncertain parameters using a multiple regression system with Latin hypercube sampling and with the Nash-Sutcliffe model efficiency (NSE) as objective function. Goodness-of-fit was evaluated using NSE, the coefficient of determination (r^2) and percent bias (PBIAS) against the performance criteria proposed by Moriasi et al. (2007). The model was calibrated against observed flow for the period September 2012 to August 2016, and validated using flow data for September 2016 to August 2021. Uncertain model parameters relating to nutrients were calibrated against measured data for reactive orthophosphate and nitrate from grab samples taken at the NRW water quality (WQ) monitoring station at the confluence of the River Wye and River Irfon (Grid reference: SO0331851476, Figure 1). Nutrient parameter values used in the model are shown in Table 3.

Table 3. Calibrated nutrient parameters ranges and best parameter values from SWAT-CUP for the Irfon catchment.

SWAT parameter	Definition	Calibration range	Final value
NPERCO.bsn	Nitrogen percolation coefficient.	0.01-1	0.317
CMN.bsn	Rate factor for humus mineralization of active organic nitrogen.	0.001-0.003	0.0023
RSDCO.bsn	Residue decomposition coefficient.	0.02-0.1	0.077
CDN.bsn	Denitrification exponential rate coefficient.	0-3	0.57
SDNCO.bsn	Denitrification threshold water content	0-1	0.49
HLIFE_NGW.gw	Half-life of nitrate in the shallow aquifer (days)	300-1000	895
SHALLST_N.gw	Concentration of nitrate in groundwater contribution to streamflow from subbasin (mg N/l).	0-100	60
ANION_EXCL.sol	Fraction of porosity (void space) from which anions are excluded.	0.01-1	0.79
GWSOLP.gw	Concentration of soluble phosphorus in groundwater contribution to streamflow from subbasin (mg P/l).	0.002-0.25	0.11
LAT_ORGP.gw	Organic P in baseflow (mg/l)	0-0.1	0.011
PPERCO.bsn	Phosphorus percolation coefficient.	10-17.5	11.58
PHOSKD.bsn	Phosphorus soil partitioning coefficient.	100-200	195
PSP.bsn	Phosphorus sorption coefficient.	0.01-0.7	0.61

2.4 Model limitations and uncertainty.

Observed measurements for the catchment are very scarce. Only four to seven grab samples of reactive orthophosphate, nitrate, total oxidised and total inorganic nitrogen are available per year and not all years have measured data taken at the NRW WQ monitoring station (Grid reference: SO0331851476, Figure 1). For the modelling period (2012-2021), reactive orthophosphate and nitrate measurements were available between February 2013 to September 2018 (no measurements were taken in 2016). No total phosphorus (TP) and total nitrogen (TN) measurements were available for the Irfon catchment; therefore, modelling performance of TP and TN could not be assessed. No measurements of nitrite and ammoniacal nitrogen were available so these parameters could not be included in the calibration.

There are no suspended sediment or turbidity data available for the catchment. Therefore, sediment parameters in the model were not modified and would have to be calibrated once sediment data become available. More high-resolution measured data would be needed for better use of calibration tools such as SWAT-CUP and to allow the validation of model results for nutrients and sediments.

No discharge information of nutrients from STWs was available for the Irfon catchment; hence, annual N and P discharges were estimated based on data available for England.

2.5 Mitigation scenarios

SWAT was used to assess the impact of mitigation measures targeting a reduction in diffuse pollution by nutrients.

2.5.1 Land management

Options 1-4 are intended to model a very best-case land use scenario in order to set the bounds on what is achievable under ideal, near reference, conditions.

1. Options which remove sewage point sources completely.

2. Options which reduce livestock levels to those which can be supported on low intensity grassland (i.e. largely unfertilised rough grazing land, equivalent to ‘conservation grazing’ livestock levels across the whole catchment).

3. Converting all current arable land and all existing intensive grassland to low input grassland. Land use was based on the UK CEH Land Cover map.

4. Modelling a landscape based on the Dudley Stamp map layer of 1930s land use, and population equivalents for the same era to estimate the urban pollution load.

2.5.2 Forest management

The Irfon catchment is extensively afforested and further tree planting is planned.

5. Modelling a scenario with double the current afforestation rate (assuming that all of the forest is immediately present). This was applied to non-blanket bog upland grassland which is of no nature conservation interest (conservation interest was derived from Natural Resources Wales priority habitat mapping).

Farmland field edge management options.

6. Add afforested buffer strips to all watercourses where they are not currently present; these will be with two options: a) 20 m and b) 50 m.

7. Assume that all soils have a P index value of 0 (i.e. model a value below normal agricultural practice likely to be protective of water quality, and a value reflecting typical agricultural options). A value of 9 mg/l of P was used in the model.

Predictions were made of phosphorus concentrations (soluble reactive phosphorus and TP) and loads. Predictions of nitrogen loads and concentrations were reported as total oxidised nitrogen and total nitrogen at the NRW WQ monitoring station (Figure 1).

2.6 Synchronisation analysis of tributaries

A synchronisation analysis is important to understand the impact of natural flood management (NFM) interventions on peak flow to different tributaries in order to avoid the risk of flood peaks synchronising and exacerbating flooding downstream. The Environment Agency's NFM storage calculator (Nicholson et al., 2015) was used for this analysis using design hydrographs obtained from Flood Modeller. Design hydrographs were generated using FEH catchment descriptors (CEH, 2015) for 19 catchments (Figure 11) and the revitalised flood hydrograph (ReFH) method in Flood Modeller. The EA NFM tool only allows 10 tributaries to be analysed in a single catchment, so two assessment points were defined in the catchment. The first assessment point was located upstream at Llangammarch Wells (Figure 11a) and the second point at the catchment outlet in Builth Wells (Figure 11b). A 1-in-10 year flood event was modelled with a critical storm duration of 11 hours.

2.6.1 NFM tool calibration

Manual calibration of time delays was applied to match the calculated hydrograph 'Cal-total' to the FEH whole catchment design hydrograph 'FEH whole catchment area' for the two assessment points (Figure 4 and Table 4). The synchronisation analysis was based on results for the calibrated and uncalibrated hydrographs.

Table 4 Time delay applied to each sub-basin to calibrate the EA tool.

Sub-catchment	Time delay to calibrate (h)
Upstream assessment point at Llangammarch Wells	
1	3.0
2	1.25
Downstream assessment point at Builth Wells	
11	1.75

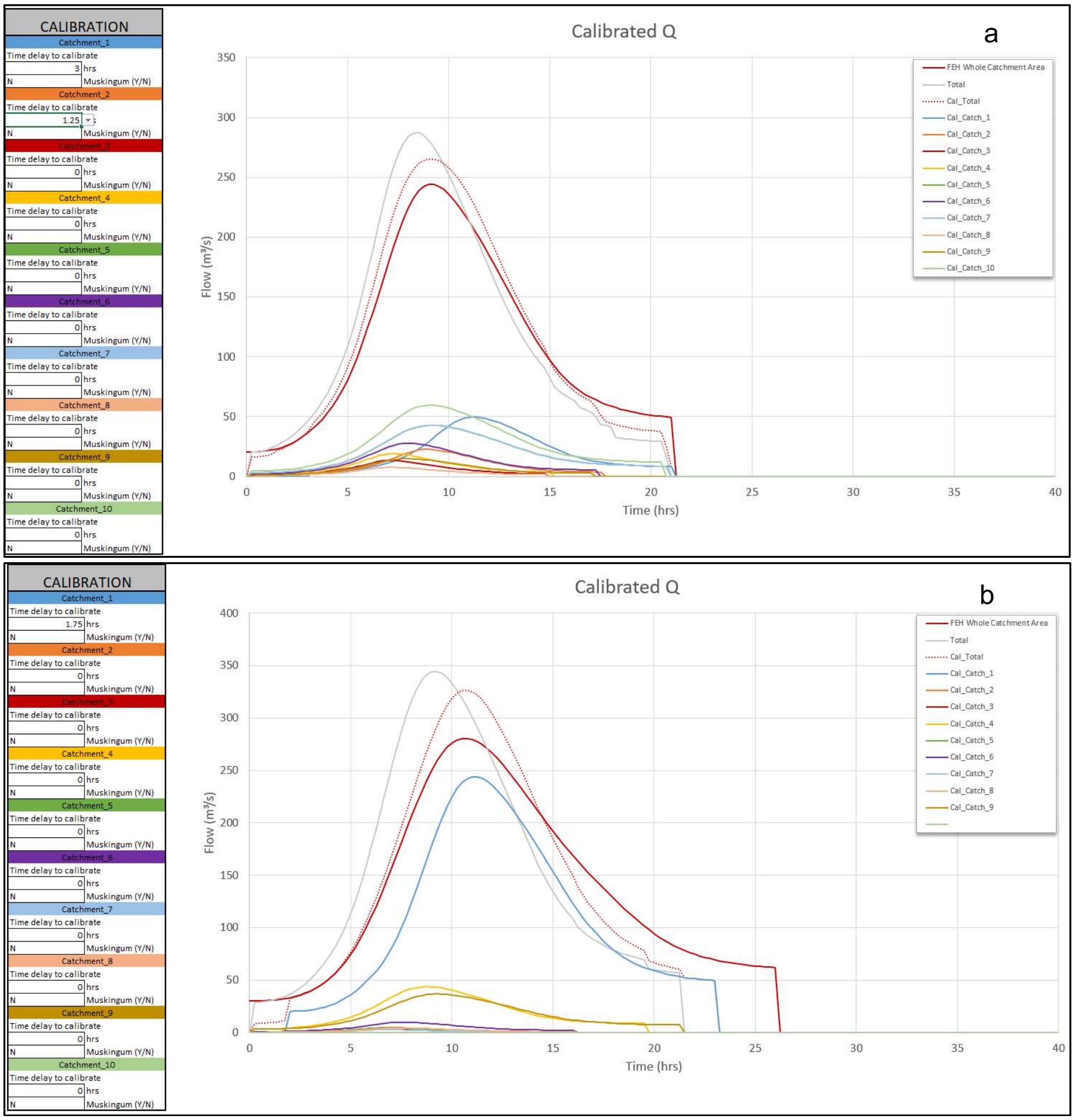


Figure 4. Calibrated hydrograph in NFM tool for the assessment points at a) Llangammarch Wells and b) Builth Wells.

2.6.2 Time-to-peak delay analysis

A preliminary analysis of which sub-basins would have the greatest impact on flood reduction by slowing the flow was carried out by varying the time-to-peak delay. The output from this analysis should be considered as a guide only. The information obtained via trial and error in this tool can then be used to inform further, more detailed analysis, within a hydraulic model (Nicholson et al., 2015). The real time-to-peak delay would have to be confirmed using a validated physically based hydrological-hydraulic model for the catchment that allows the simulation of individual NFM measures.

2.6.3 Impact of storage analysis

A storage impact analysis was carried out by applying the full planned storage value of 50,000 m^3 for each sub-basin. The first step of the impact of storage analysis is to identify the optimum threshold flow that causes the storage to fill. Then, the NFM tool predicts the impact of NFM storage at the local sub-basin and full catchment levels.

In addition, different values of storage between 50,000 and 100,000 m^3 were used to carry out a cost-effectiveness analysis measured as peak flow reduction per volume of water stored to plan the target storage to be generated in each catchment. Target storage is defined as the minimum storage required to generate a cost-effective flood management impact.

3. Results

3.1 Stream flow modelling

A comparison of the observed and simulated hydrographs for the calibration and validation periods at the NRW gauge flow station at Cilmery is shown in Figure 5. The model tends to underpredict some of the highest peak flow events by an average factor of 1.4±0.5. Goodness-of-fit statistics were good in terms of model efficiency (NSE > 0.8), a very good linear relationship between the observed and the modelled flow (R^2 > 0.9), and only a small underprediction (PBIAS = -0.6) for both the calibration and the validation period (Table 5).

Table 5. Goodness-of-fit statistics for simulated stream flow.

Simulated period	NSE	R^2	PBIAS	% of observed flow
Calibration	0.81	0.90	-5.55	94.5
Validation	0.85	0.92	-5.94	94.1

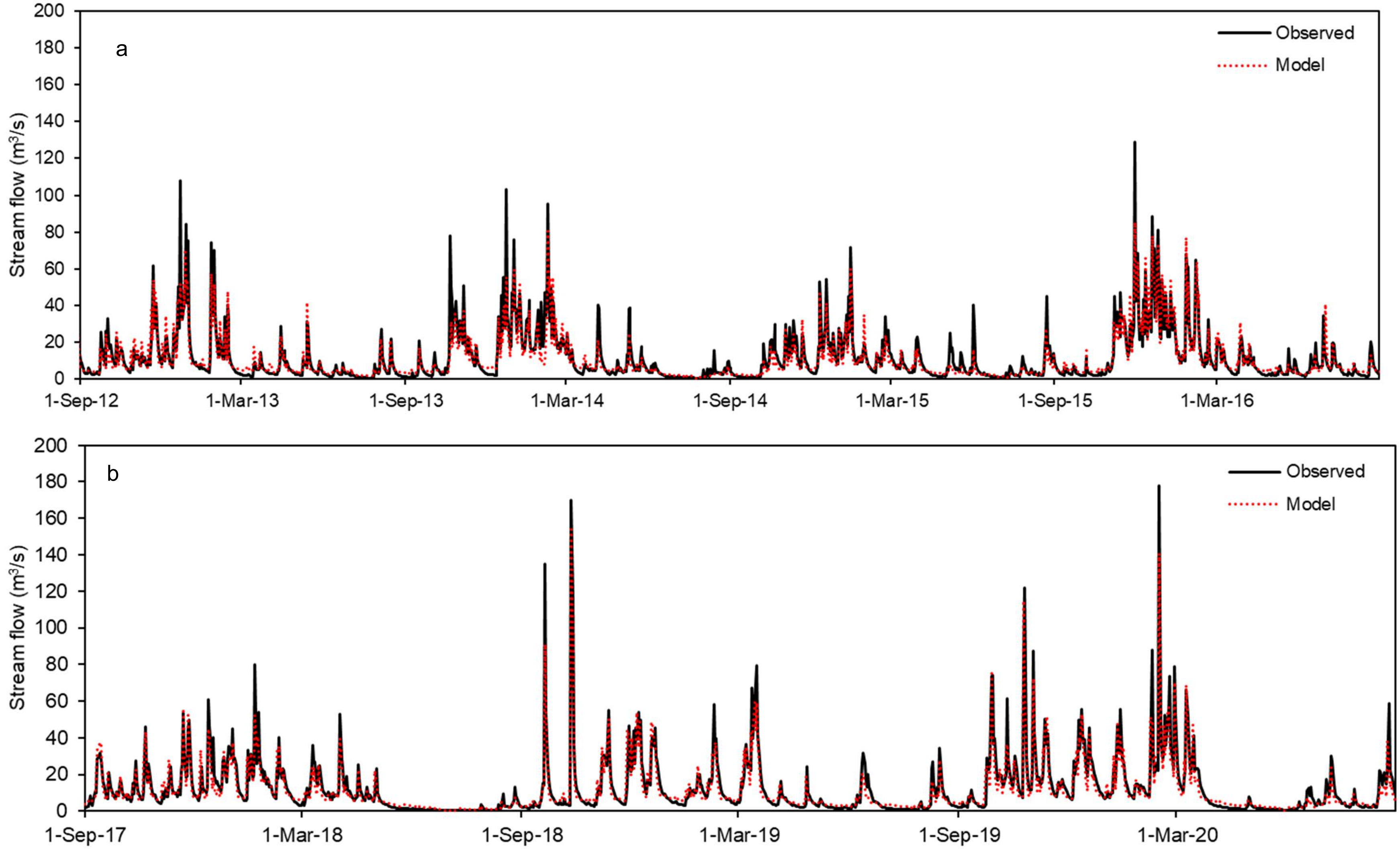


Figure 5. Comparison of the observed and simulated hydrographs for the a) calibration and b) validation period at the NRW gauge flow station at Cilmery.

3.2 Nutrient modelling

Comparisons of observed and simulated nutrient concentrations for the period with observed data available at the NRW WQ monitoring station (Figure 1) are shown in Figures 6 to 8. The model simulates concentrations of soluble reactive phosphorus (SRP), nitrate and oxidised total nitrogen within the same order of magnitude as the measured data. Average and maximum SRP concentrations were both simulated by a factor of 1.3 compared to measured concentrations. Simulated average and maximum nitrate concentrations were within factors of 1.1 and 1.2, respectively of measured data, with a slight tendency to overprediction (PBIAS = 6.18). Model simulations for the average and maximum total oxidised nitrogen were within factors of 1.3 and 1.6, respectively of the measured data; there was marked model over-prediction (PBIAS = 33), but this was still within acceptable levels according to guidance by Moriasi et al. (2007) for nutrient modelling. This result suggests some over-prediction of nitrite concentrations in the model. The average and maximum total inorganic nitrogen concentration simulated by the model was within factors of 2.0 and 2.1, respectively of measured data. These results suggest over-prediction of ammonia concentrations in the model (PBIAS = 96). No measured data for ammonia were available to include it in the calibration process. Parameters that related to the simulation of ammonia in SWAT would have to be adjusted when measured data become available.

Goodness-of-fit statistics for nutrient loads (Table 6) were good in terms of model efficiency for SRP load (NSE = 0.7) and satisfactory for nitrate and total oxidised N loads (NSE = 0.5 and 0.5, respectively), with a good linear relationship between the observed and the modelled nutrient load (R^2 = 0.8 for SRP and 0.6 for both nitrate and total oxidised N) and with very good results for PBIAS (-7, -4, -5 for SRP, nitrate and total oxidised N loads, respectively). Insufficient nutrient data were available to validate model results (only 4 data points in 2018).

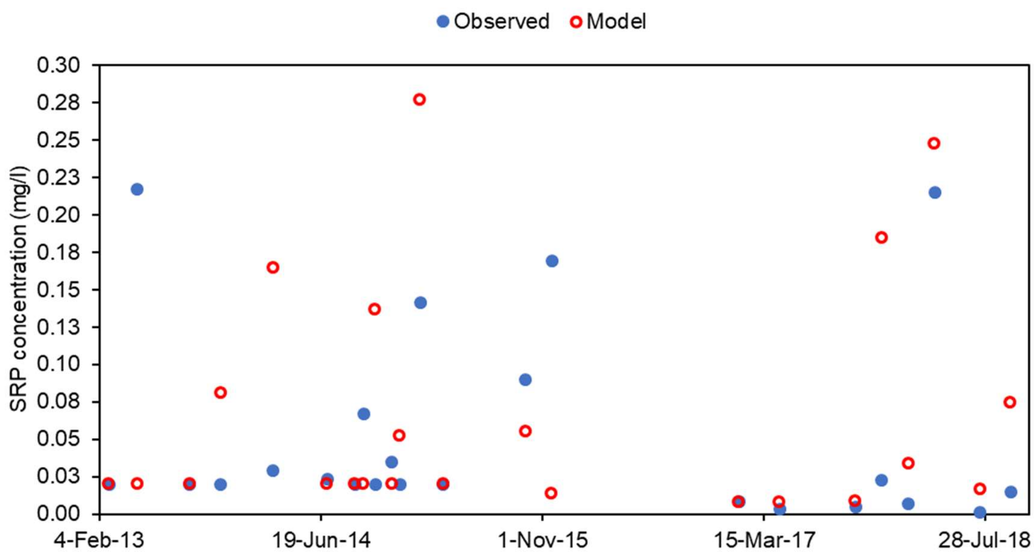


Figure 6 Comparison of observed and simulated reactive orthophosphate concentrations at the catchment outlet in Builth Wells.

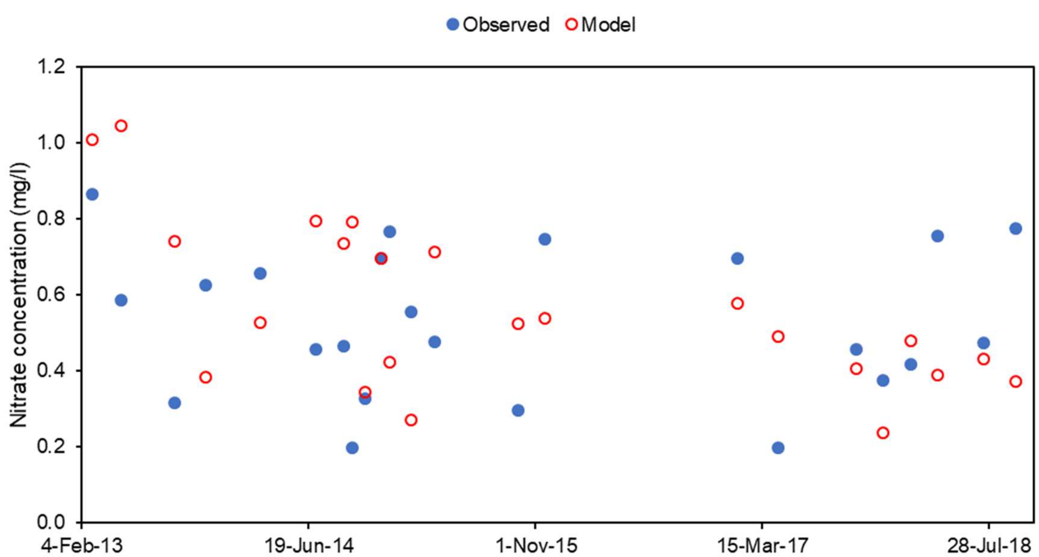


Figure 7 Comparison of observed and simulated nitrate concentrations at the catchment outlet in Builth Wells.

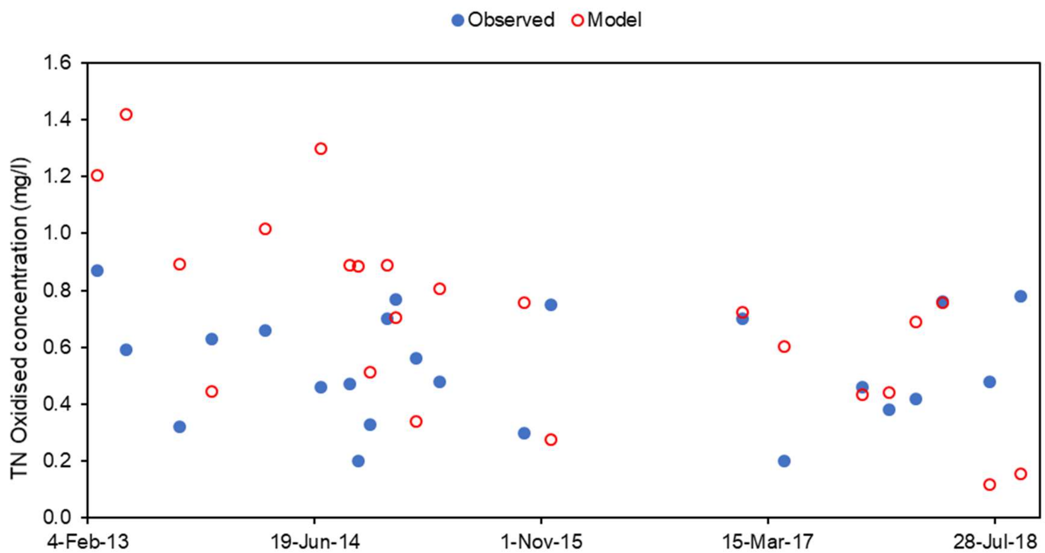


Figure 8 Comparison of observed and simulated concentrations of total oxidised N at the catchment outlet in Builth Wells.

Table 6. Goodness-of-fit statistics for simulated N and P loads.

Parameter	NSE	R^2	PBIAS
SRP load	0.67	0.77	-7.53
Nitrate load	0.54	0.56	-4.08
Total oxidised N	0.47	0.56	-4.76

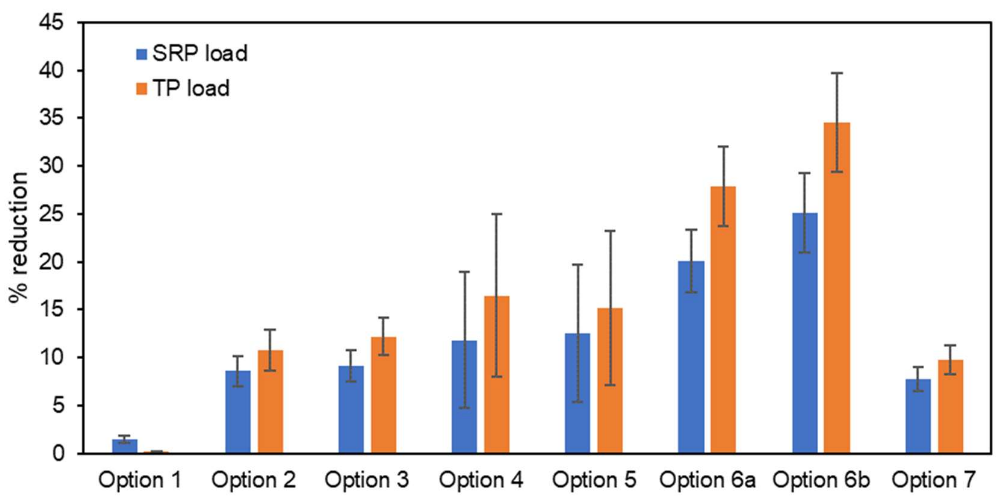
3.3 Mitigation scenarios

3.3.1 Impact on nutrient load

Model results for the impact of seven mitigation scenarios in reducing average nutrient loads are shown in Figure 9. Greater reductions were generally predicted for TP load compared to SRP load and for total oxidised N compared to TN load. The exception was for the 20-m buffers scenarios were greater reductions were predicted on TN than that for total oxidised N load.

The greatest impact on nutrient loads inputs was predicted to arise from adding 50-m afforested buffers strips on farmland located adjacent to all watercourses (Option 6b); average reductions were predicted to be between 23.3±3.0 and 34.6±5.2% (for TN and TP load, respectively). The second greatest reduction on nutrient load was generally using 20 m afforested buffers by between 16.6±0.6 and 27.8±4.1% (for total oxidised N and TP, respectively). A low livestock intensity scenario (Option 2) had the second greatest impact in reducing total oxidised N load by 16.7±6.6%. Doubling the rate of afforestation in the catchment was the mitigation scenario with the third greatest impact on SRP and TN load reductions (12.5±7.2 and 4.6±4.1%, respectively).

The smallest nutrient load reductions were predicted when removing sewage discharges completely (Option 1), resulting in a reduction of between 0.08±0.02 and 1.5±0.4% for TN and SRP load, respectively.



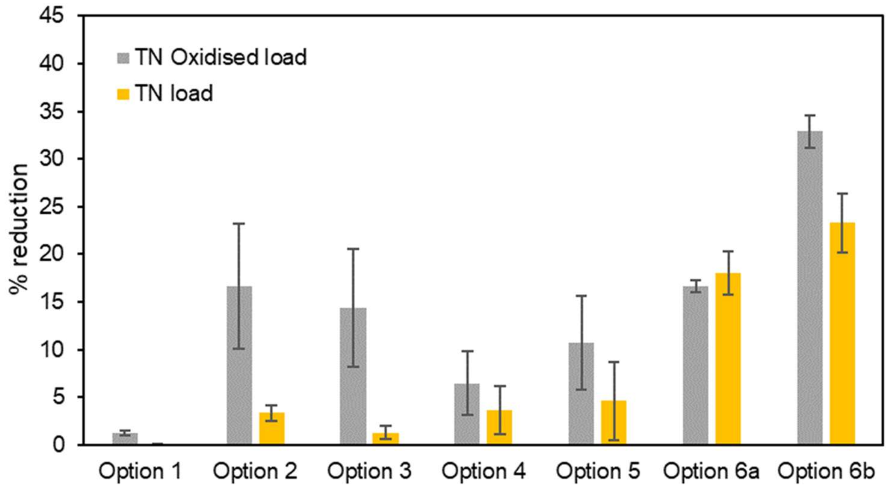


Figure 9 Simulated reduction of nutrient load from mitigation scenarios at the NRW monitoring station at the catchment outlet at Builth Wells.

3.3.2 Impact on nutrient concentrations

Model results for the impact of seven mitigation scenarios on the reduction of average maximum annual nutrient concentrations are shown in Figure 10. Greater reductions of nutrient concentrations were generally predicted for TP compared to SRP concentrations. A mixed result was obtained for N. Most mitigation scenarios had greater impact on total oxidised N compared to TN concentration. The exceptions were Options 4 and 6a where the greatest impact on N reductions was predicted for TN concentrations.

The greatest impact on nutrient concentrations were predicted when adding 50-m afforested buffers strips on farmland located adjacent to all watercourses (Option 6b); average reductions were predicted to be between 28.3±7.3 and 44.3±9.2% for TN and TP load, respectively. The second greatest reduction on nutrient concentrations was generally using 20-m afforested buffers (between 24.0±6.8 and 37.8±7.8% for total oxidised N and TP, respectively). Doubling the rate of afforestation in the catchment was the mitigation scenario with the second greatest impact in reducing total oxidised N concentration (18.4±11.0%) as well as the mitigation option with the third greatest impact on SRP and TN concentrations (23.2±7.8 and 14.3±10.5% reduction, respectively).

The smallest nutrient concentration reductions were predicted when removing sewage discharges completely (Option 1) (between 0.01±0.01 and 1.4±1.1% reduction on TN and total oxidised N concentrations, respectively; and between 0.15±0.13% and 0.20±0.10% for TP and SRP, respectively).

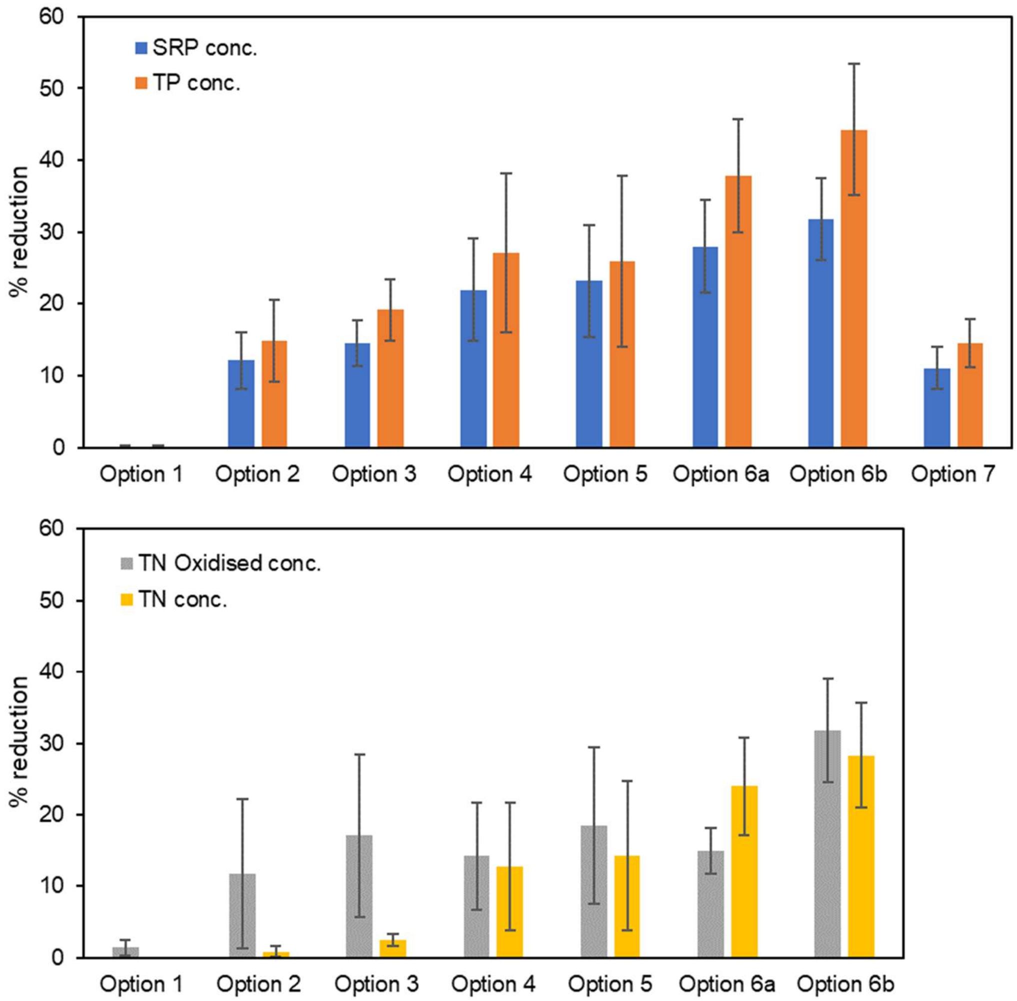


Figure 10 Simulated reduction of nutrient concentrations from mitigation scenarios at the NRW monitoring station at the catchment outlet at Builth Wells.

3.4 Synchronisation analysis

Results from the synchronisation analysis for the first assessment point at Llangammarch Wells show that NFM should not be placed on sub-basins 3 and 4 (Figure 11a) due to synchronisation of peak flow from the tributary and the main channel which increases peak flow at Llangammarch Wells by up to 0.8 and 1.2%, respectively based on a 1-hour delay (Figure 12a). Peak flow reduction from NFM is predicted when placing NFM interventions on sub-basins 1 or 5. No-effect on peak flow reduction at the assessment point in Llagammarch Wells was predicted when placing NFM on sub-basins 7 to 10. Uncertain results were obtained for sub-basins 2 and 6 due to contradictory results between uncalibrated and calibrated NFM tool. A more detailed analysis would be required to confirm whether or not these two sub-basins are suitable for NFM.

The synchronisation analysis for the second assessment point at Builth Wells show that NFM should not be placed on sub-basins 12, 13 or 15 (Figure 11b) due to synchronisation of peak flow from the tributary with the main channel which increases peak flow at Builth Wells by up to 0.9, 0.6 and 0.8%, respectively based on a 3.5-hour delay (Figure 12b). Peak flow reduction from NFM is predicted when placing NFM interventions on subbasin 11 (downstream of Llagammarch Wells). No-effect on peak flow at the assessment point in Builth Wells was predicted when placing NFM on sub-basins 17, 18 and 19. Uncertain results were obtained for sub-basins 14 and 16 due to contradictory results between uncalibrated and calibrated NFM tool. A more detailed analysis would be required to confirm whether or not these two sub-basins are suitable for NFM.

3.4.1 Time-to-peak delay analysis

Results from the synchronisation analysis show that NFM can be placed on sub-basins 1 and 5 (Figure 11a) to reduce flooding at Llagammarch Wells and on the main channel upstream of Llagammarch Wells to reduce flooding in Builth Wells (Figure 11b). The NFM tool predicts peak flow reductions at Llangammarch Wells when placing NFM on sub-basins 1 or 5 (of 8 and 9% with a 3.5-hour peak flow delay, respectively). Greater peak flow reductions are obtained at Builth Wells when placing NFM upstream of Llagammarch Wells (of 14% with a 3.5-hour peak flow delay).

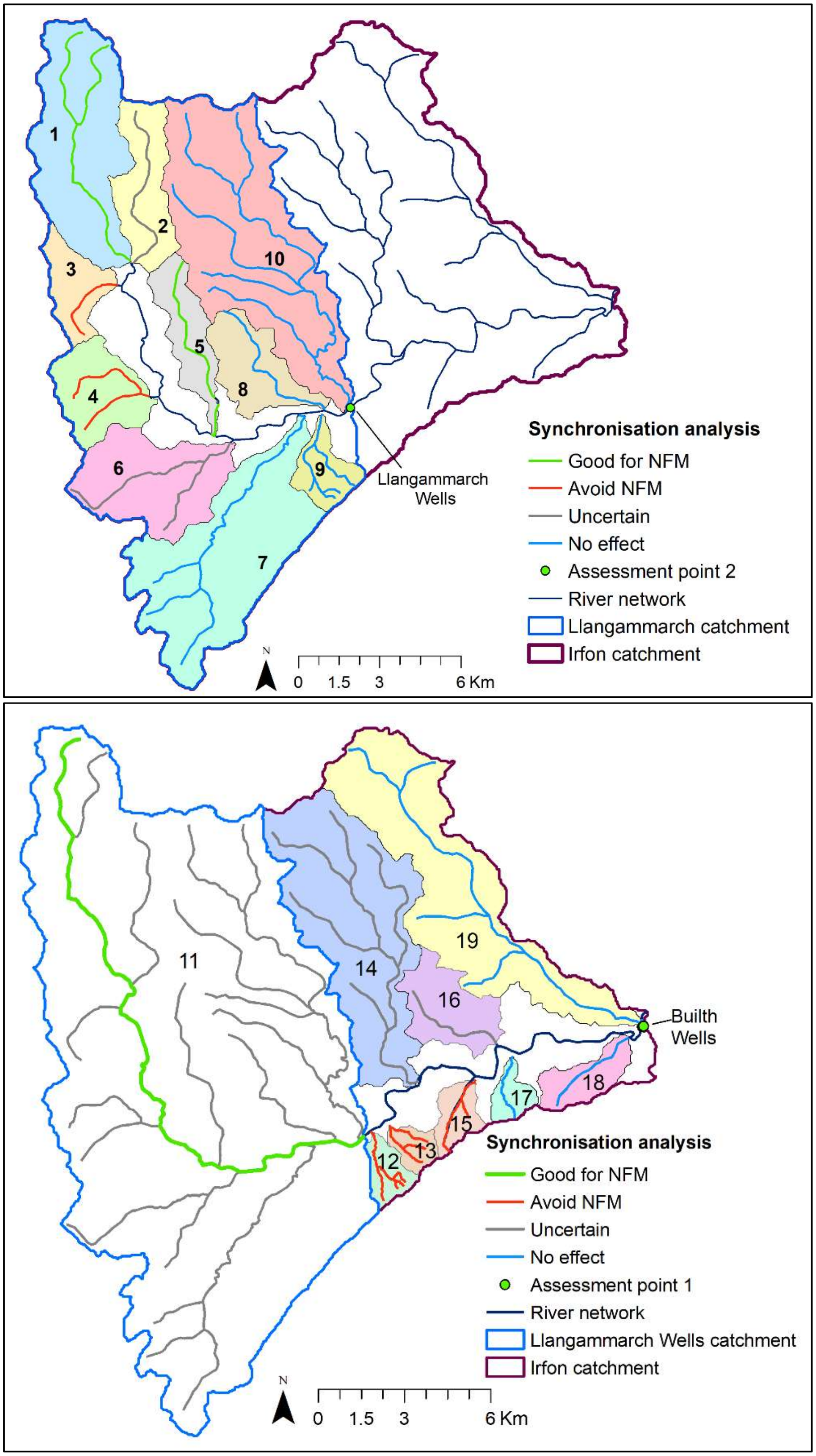
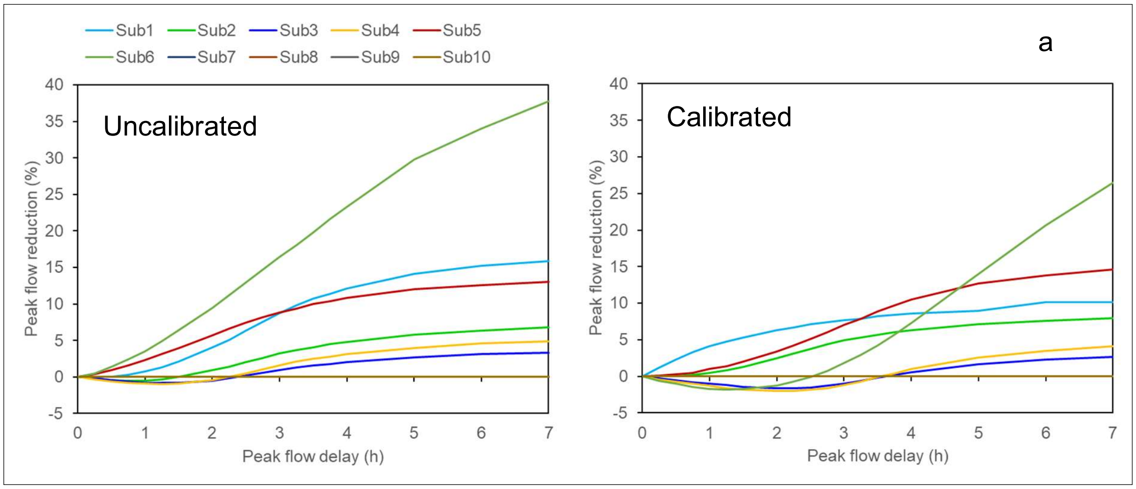


Figure 11. Map of best locations of NFM according to the synchronisation analysis with assessment points located at a) Llangammarch Wells and b) Builth Wells.



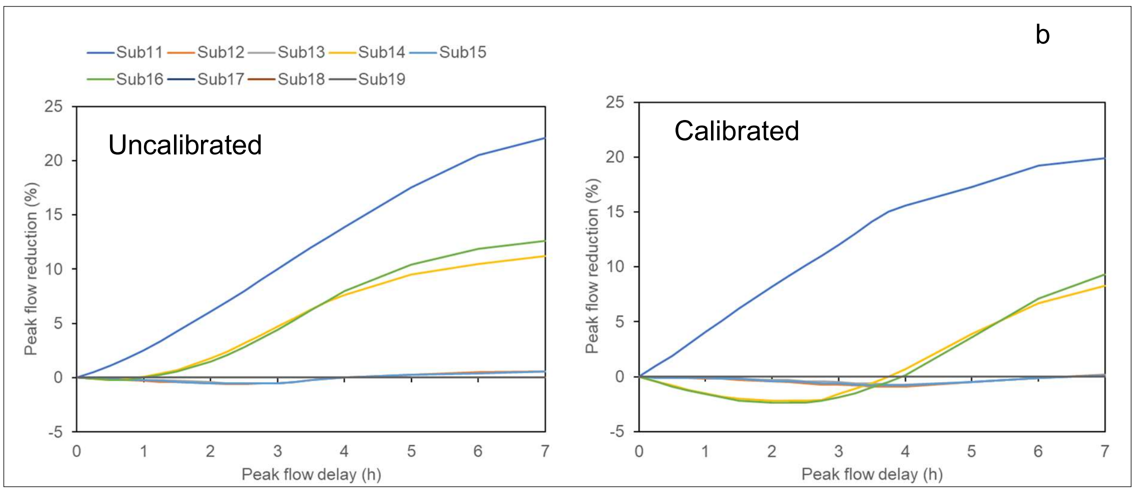


Figure 12. Predicted impact of peak flow delay due to NFM on Irfon tributaries at the assessment points a) Llangammarch Wells and b) Builth Wells obtained from calibrated and uncalibrated hydrographs in the EA NFM tool. N.B. the actual delay in peak flow that can be delivered by the totality of NFM measures is unknown at this stage. Hence, the direction of change across a range of time-to-peak delays is most important in determining the optimum location for NFM.

3.4.1 Impact of storage analysis

The impact of storage analysis shows that optimum sub-basins have similar impact when placing NFM interventions at the full catchment level (Table 7) with a 2.8% peak flow reduction for a 1 in 10 year flood event. NFM interventions placed in sub-basin 5 will have the greatest local impact (3.3% peak flow reduction for water coming out of that tributary and joining the main stream system).

Table 7. Impact of storage in each sub-basin for 50,000 m^3 storage for a 1 in 10 year flood event.

Sub-basin	Optimum threshold (m^3/s)	Local impact (at bottom of the tributary)	Full catchment impact
		Peak flow reduction (%)	
1	16.7	0	2.8[a]
5	32.9	3.3	2.8[a]
Upper catchment	223.4	0.6	2.8[b]

a: Llagammarch Wells; b: Builth Wells.

Figure 13 shows how peak flow reductions change with the volume of storage introduced. According to results from the EA NFM tool, target NFM storage values of 50,000 m^3 located on sub-basins 1, 5 and upper catchment will have the most cost-effective impact (% peak flow reduction per m^3 of water stored) at the full catchment level (Figure 14).

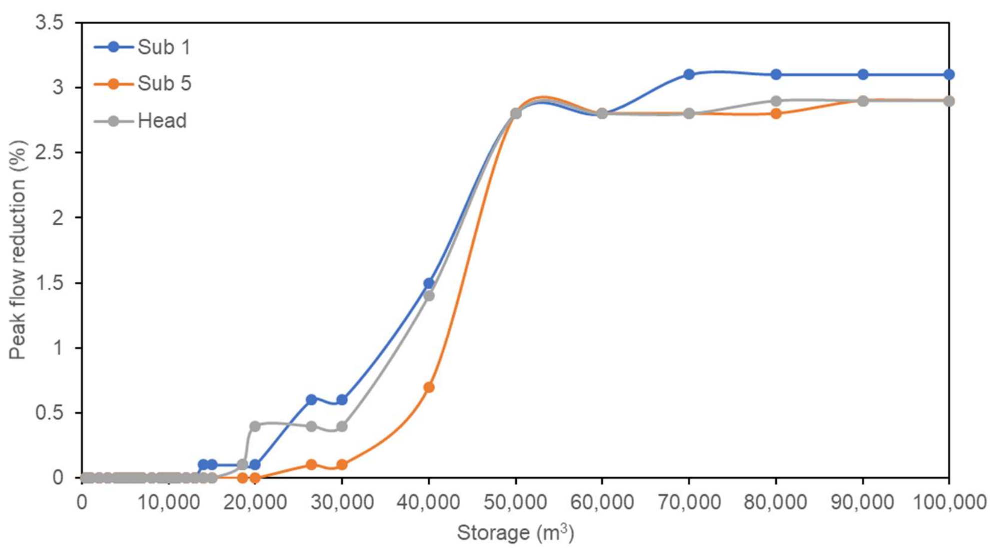


Figure 13. Predicted impact of storage from NFM on peak flow reduction for a 1-in-10 year flood event for the identified best tributaries to install NFM according to the synchronisation analysis.

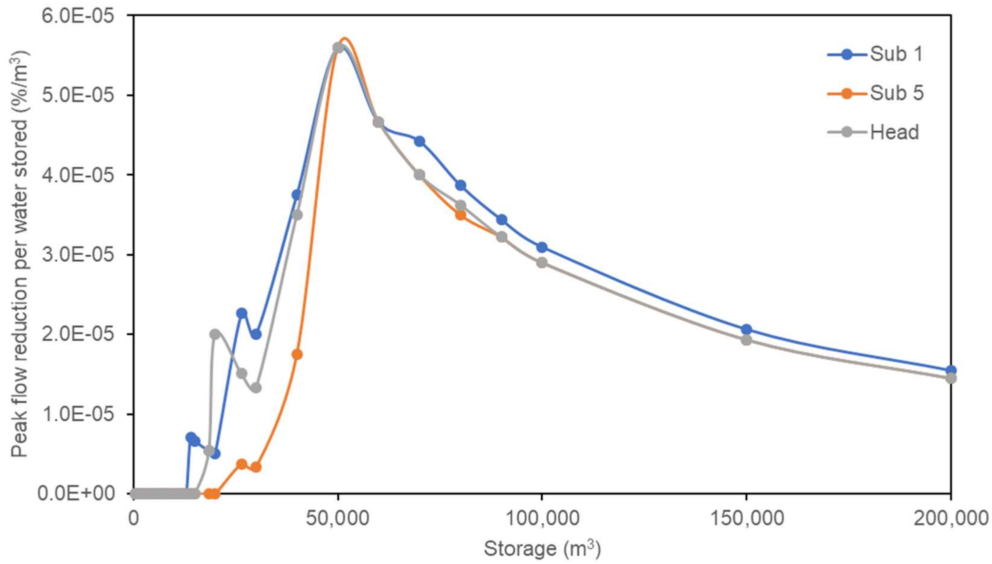


Figure 14. Cost-effectiveness analysis for target storage using a 1-in-10 year flood event for the identified best tributaries to install NFM according to the synchronisation analysis.

4. Conclusions

The model was successfully calibrated and validated to simulate stream flow in the Irfon catchment (with some under-prediction for the highest peak flow events). Despite the scarce monitoring data, the model was calibrated to simulate nutrient loads and concentrations. Sediment parameters could not be calibrated due to the lack of monitoring data. Model limitations and uncertainties include those arising from the shortage of nutrient monitoring data and lack of information on nutrient discharges from sewage treatment works. More high-resolution data would be needed to improve the performance of the nutrient model and to validate nutrient results.

The calibrated model for the Irfon was used to assess the impact of mitigation measures targeting a reduction in diffuse pollution by nutrients. Options which remove sewage point sources completely had the lowest impact on nutrient loads and concentrations. Significant reductions on N and P loads and concentrations were predicted from other mitigation options. The greatest impact on N and P loads and concentrations was predicted when adding 50-m afforested buffer strips in farmland located adjacent to all watercourses. Doubling the current afforestation rate generally delivered the second greatest impact on reducing diffuse pollution in the Irfon catchment.

5. References

Abbaspour, K.C., Vejdani, M., Haghighat, S., 2007. SWAT-CUP Calibration and Uncertainty Programs for SWAT. Modsim 2007: International Congress on Modelling and Simulation 1603-1609.

Cranfield University, 2014. The Soils Guide, Cranfield University: Available: www.landis.org.uk.

DEFRA, 2020. The British survey of fertiliser practice. Fertiliser use on farm crops for crop year 2019. Department for Environment, Food and Rural Affairs.

Environment Agency, 2005. Attenuation of nitrate in the sub-surface environment Science Report SC030155/SR2. Bristol. ISBN: 1844324265. Accessed in September 2022. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/291473/scho0605bjcs-e-e.pdf.

Hayman, G., Hasler, S., Vincent, K., Baker, S., Donovan, B., Smith, M., Davies, M., Sutton, M., Tang, Y.S., Dragosits, U., Love, L., Fowler, D., Sansom, L., Page, H., 2001. Operation and Management of the UK Acid Deposition Monitoring Networks: Data Summary for 2000. AEA Technology report for Defra reference AEAT/ENV/R/0740.

Leh, M.D.K., Sharpley, A.N., Singh, G., Matlock, M.D., 2018. Assessing the impact of the MRBI program in a data limited Arkansas watershed using the SWAT model. Agricultural Water Management 202 202-219.

Lorimor, J., Powers, W., Sutton, A., 2008. Manure Characteristics. Manure management systems series MWPS-18 Section 1, Second edition. pp. 1–24.

Moriasi, D.N., Arnold, J.G., Van Liew, M.W., Bingner, R.L., Harmel, R.D., Veith, T.L., 2007. Model evaluation guidelines for systematic quantification of accuracy in watershed simulations. Transactions of the Asabe 50(3) 885-900.

Neitsch, S., Arnold, J., Kiniry, J., Williams, J., 2011. Soil and water assessment tool: Theorical documentation version 2009. Texas Water Resources Institute, Collage Station, TWRI Report No. 406.: Texas, USA.

Nicholson, A., Owen, G., Quinn, P., O'Donnell, G., 2015. Natural Flood Management Tool for assessing impact of storage within sub-basins. Arup, Newcastle University and Environment Agency.

NRW, 2022. Terrestrial Phase 1 Habitat Survey. Natural Resources Wales. http://lle.gov.wales/catalogue/item/TerrestrialPhase1HabitatSurvey/?lang=en.

Ordnance Survey, 2015. Ordnance Survey's OS Terrain 5 DTM dataset. https://www.ordnancesurvey.co.uk/.

UK Agriculture and Horticulture Development Board, 2016. Beef and sheep BRP manual 8: Planning grazing strategies for better returns. AHDB Beef and Lamp,: Kenilworth, Warwickshire.