WATER QUALITY MODELLING

- Linking interventions to water quality is a complicated exercise that was approached using two different models: SPARROW is a statistical model that focuses on estimating annual loads in nitrate and DOC; SimplyP was used to estimate sediment, total phosphorus and soluble reactive phosphorus.
- Overall results from both models estimate very marginal water quality improvements across all parameters and catchments: load improvements were estimated to be less than 0.01% for nitrate and DOC, up to 1.8% and 0.5% for suspended sediments and total phosphorus respectively.
- Both models depend on quantifying interventions using the Farmscoper software, thereby relying on a set terminology and classification; this process is likely to have led to an underestimation of the coverage of interventions, and therefore water quality change. Interventions in the catchments might not have a direct impact on the parameters of interest, explaining in part the small change observed in the results.
- These results make the case for improved recording and mapping of interventions and also highlight the need for extended and sustained in-catchment interventions that would allow greater cumulative benefits. However, even modest reductions in P loading (in the order of Kg) will make a difference on water quality in these catchments.

Method

The objective of modelling water quality was to combine catchment interventions and their location with their known impact on water quality parameters to establish the expected changes in water quality for each catchment. The results can then be used to compare differences between catchment management scenarios of contaminant loadings calculated without and with interventions.

SPARROW

The SPARROW model[1] (Figure 1) is a statistical water quality model used to estimate the annual load of nitrate and Dissolved Organic Carbon (DOC) from point and diffuse catchment sources. Using datasets such as water quality measurements, soil type and rainfall (Table 1), the model is composed of source, transport and degradation factors that are defined using parameters selected based on expert opinion and statistical analysis. For example, the user may determine that manure inputs are important for the nitrate source factor. Not all factors are accounted for, instead the focus is on the most statistically significant variables for each water quality variable.

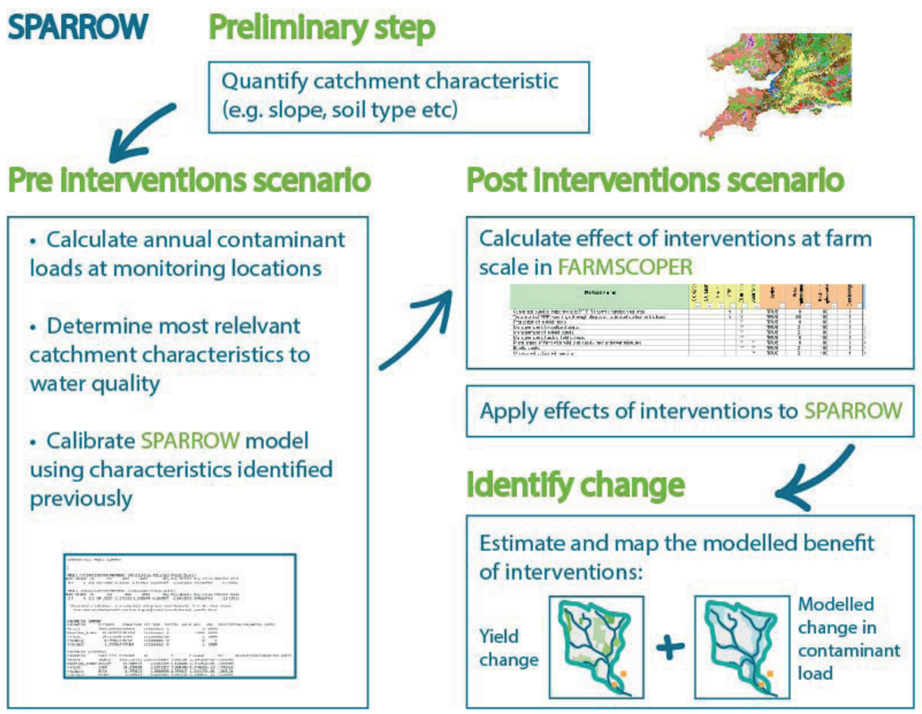


Figure 1 Schematic detailing the workflow used for modelling interventions and the impact on nitrate and Dissolved Organic Carbon using the SPARROW model.

Firstly, the change in pollutant yield was mapped (i.e. nitrate or DOC) at the spatial scale reported in Farmscoper (i.e. farm area) (Figure 1). This information was then applied to estimate the expected change after the delivery of the pollutant to the stream, i.e. contaminant load, for the reach in question and displayed through the use of a Geographical Information System (GIS) to map the potential change across catchments (Figure 2).

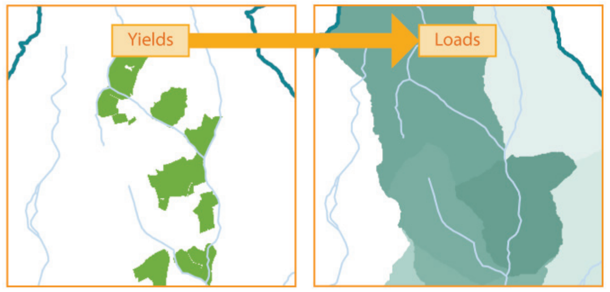


Figure 2 Example of contaminant yields (left) at the farm scale identified by the green areas, leading to calculations of corresponding changes in contaminant loads (right) for the same reach. The darker colours represent greater decrease in loadings.

Data used in the model	Source	Simply-P	Sparrow
Soil type	National Soil Resources Institute, Cranfield	✓	✓
Elevation	Centre for Environmental Data Analysis	✓	✓
Water quality measurements - Suspended sediment - Total phosphorus - Soluble reactive phosphorus - Nitrate - Dissolved organic carbon	SWW, UoE measurements, Environment Agency	✓	✓
Stream flow	National River Flow Archive, Centre for Ecology and Hydrology	✓	
Precipitation	Centre for Environmental Data Analysis	✓	✓
Temperature	Centre for Environmental Data Analysis	✓	
Evapotranspiration	Calculated using meteorological datasets from the UK MetOffice	✓	
Catchment interventions (after reclassification)	UsT Project partners	✓	✓
Land cover	Centre for Ecology and Hydrology	✓	✓
Crop types	Centre for Ecology and Hydrology	✓	
Manure input	Centre for Ecology and Hydrology		✓
Hydrological characteristics (e.g. mean flow, baseflow etc.)	Global Streamflow Characteristics Dataset		✓

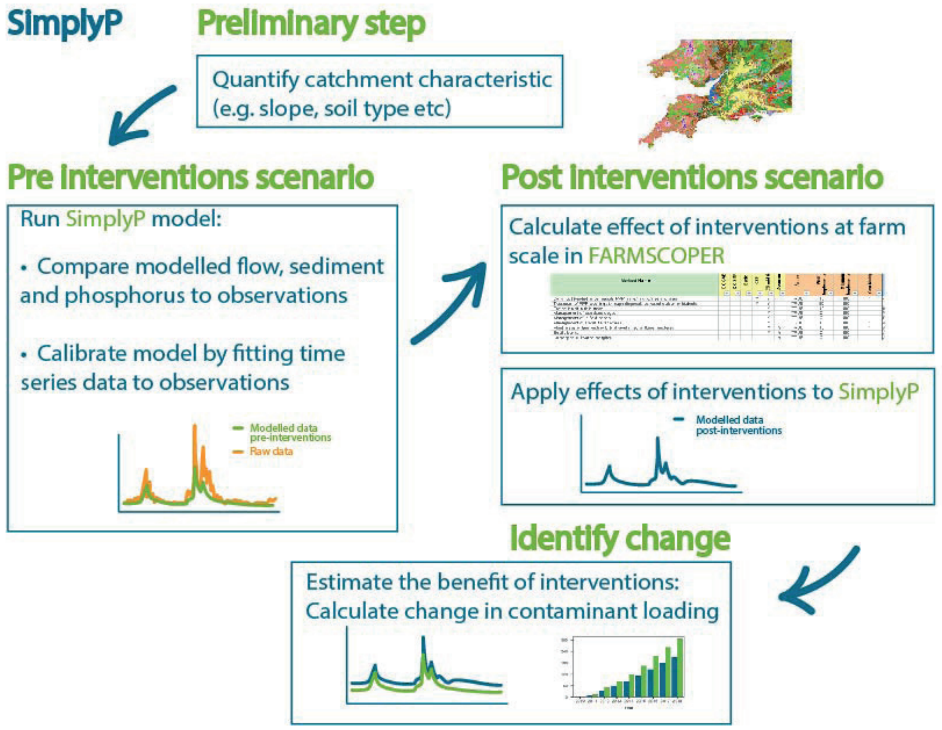
Table 1 Types and source of datasets used in the SimplyP and SPARROW models.

SimplyP

SimplyP[2] is a simple process based water quality model which can be used to estimate the concentration and load of Total Suspended Sediment (TSS), Total Phosphorus (TP) and Soluble Reactive Phosphorus (SRP). The model is separated into three separate components:

- a rainfall-runoff module, used to calculate river flow from rainfall inputs;
- a sediment module, used to relate river flow and land activity to sediment concentrations and loads;
- a Phosphorus (P) module which relates land activity, soil properties, and runoff processes to phosphorus concentrations and loads.

Figure 3 Schematic detailing the workflow used for modelling interventions impact in suspended sediment, total phosphorus and soluble reactive phosphorus using the SimplyP model.



The outputs are a time series for flow, sediment, and P for the period of interest (Figure 3). For this application, interventions were applied together at the start of a 9 year period modelled, based on hydrological and meteorological conditions, between 2010 and 2018. As some impacts are difficult to detect in the immediate years after interventions are put in place, applying the model in this way enables us to determine what sort of effect the interventions from Upstream Thinking would have in the medium term, i.e. 9 years. For example, this enables the consideration of sufficient time to pass for any significant effect to take place with regards to the mass of soil P, which might have reduced if farmers were adding less manure or slurry, but which might take some years for this reduction to manifest.

The results obtained from the modelling work will partly be influenced by the nature and characteristics of the contaminants being modelled. For example, suspended sediments largely originate from erosion during overland flow; for simplicity, the model assumes that temporal variations of suspended sediment will follow that of stream flow to a large extent. TP is a measure of both dissolved and particulate P, the latter originating from sediments and therefore largely relating to stream flow. Finally, SRP is the inorganic fraction of P, originating from the soil. Its presence in water is therefore proportional to the volume of rainfall and dissolved phosphorus in the soil store, which fluctuates over time. Greater rainfall therefore will cause a greater release of SRP from the land, and will accumulate over time. In addition, the use of actual hydrological and meteorological conditions between 2010 and 2018 means that these parameters will, to some extent, influence the variations in water quality. In addition, a detailed description of the technical caveats that may have impacted on the modelling results are presented in Appendix (p78).

A stream in the Cober catchment; photo by Emilie Grand-Clement.

General findings

The changes resulting from Upstream Thinking that each model predicts (Table 2 and Table 3) are modest for all parameters. The maximum modelled loads at catchment scale are estimated to have been less than 0.01% for nitrate and DOC, and up to 1.8% and 0.5% for SS and TP, respectively. Consequently, in some catchments, the actual estimated mass of pollutant removed is negligible compared to other catchments and studies[3]. Sediment mobilised from eroding soil or river banks could reach up to 430,000 kg in the larger Exe catchment over the modelling period, whilst no improvement is recorded in some of the Drift sub catchment. Sediment also shows the greatest change compared to TP and SRP. This is due to the fact that a large part of Phosphorus is bound to soil and sediment particles, and will therefore only be a fraction of TSS. The literature also shows that, although improvements in P loads from agricultural runoff can be observed at farm scale[4], this is rarely observed at catchment or watershed scale[5], due to the accumulation of P in soils and its release during periods of high rainfall, causing potentially long lag times for improvements[6].

Table 2 Maximum estimated change in yield and loads (%) for nitrate and Dissolved Organic Carbon in each Upstream Thinking catchment using the Sparrow model.

	Max yield change (%)		Max load change (%)	
Catchment	**DOC**	**Nitrate**	**DOC**	**Nitrate**
Argal	NA	0.0069	NA	0.00001
Drift	NA	0.062	NA	0.0001
Upper Tamar Lake	NA	0.59	NA	0.0017
Cober	0.27	0.244	0.0008	0.0005
Fowey	NA	0.22	NA	0.0009
Exe	1	0.81	0.002	0.0031

In the present case, for TP, it means an improvement of less than 1 kg over 9 years in Argal and Upper Tamar Lake, whereas it could be over a tonne in the Lower Exe in the same time frame. This highlights that, although both catchments have about 30% total engagement, this may not directly translate into the establishment of interventions tackling this particular problem. Modelling work on the Axe catchment (outside of UsT intervention area) showed that a reasonable scenario of 25% of intervention uptake in the catchment would only be cost effective if the cumulated P offset was over 200 kg of P. Although this is based on a catchment with different characteristics (e.g. land use, water quality, stream connectivity etc.), it highlights the issue of P improvement that is both costly and uncertain.

			Mean annual improvement (%)			Total load improvement over 9 year		
Catchment	**Sub catchment**	**Catchment area (km2)**	**Suspended Sediment**	**Total P**	**Soluble Reactive P**	**Suspended Sediment (T)**	**Total P (kg)**	**Soluble Reactive P (kg)**
Argal	Argal stream	3	0.010	0.006	0.004	0.01	0.1	0.02
Drift	Newlyn River	12	10^{-5}	0.252	0.285	0.0001	38.9	27.0
	Sancreed brook	5	1.752	0.542	0.295	7.4	38.9	12.1
Upper Tamar Lake	NA	8	0.004	0.009	0.013	0.1	1.4	0.7
Cober	NA	26	0.424	0.296	0.140	9.7	23.2	3.3
Fowey	NA	168	0.295	0.207	0.139	29.6	99.8	26.0
Exe	Allers	434	0.299	0.272	0.192	338.2	1236.3	210.6
	Pynes	624	0.252	0.234	0.176	430.0	1631.0	307.8

Table 3 Mean annual improvement (%) over a 9 year period for each catchment for Suspended Sediment, Total Phosphorus and Soluble Reactive Phosphorus, and corresponding load improvement; note that Suspended Sediment is expressed in T and Total P and Soluble Reactive P in kg.

Some of the reasons for these small changes forecasted by the modelling exercise and the differences between catchments are discussed below and illustrated in Figure 4.

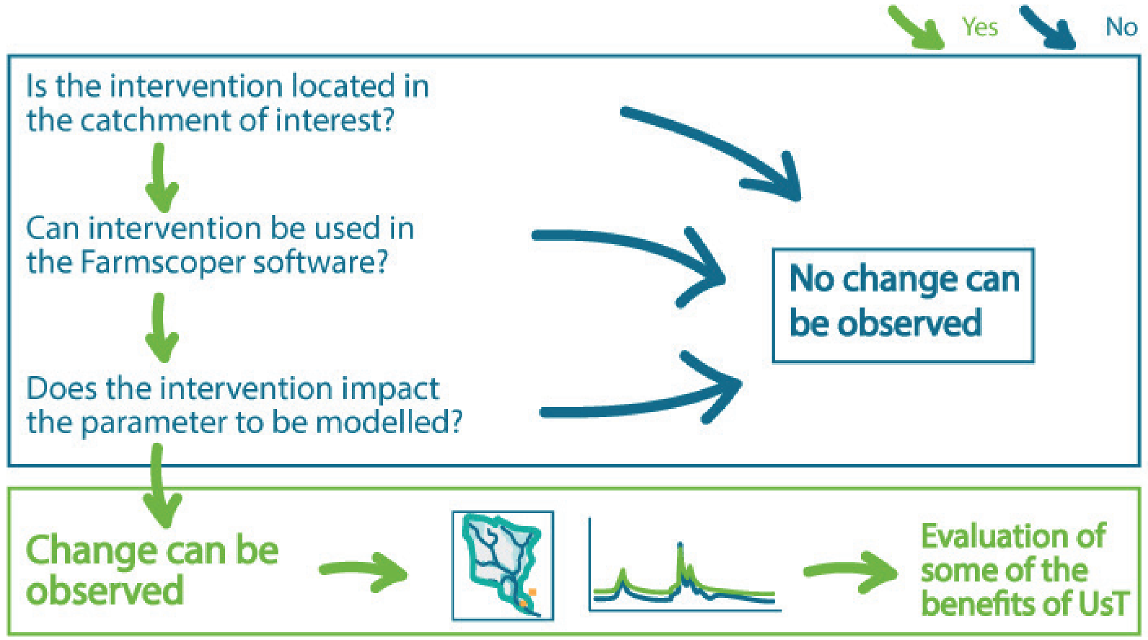


Figure 4 Challenges associated with the modelling exercise and range of factors that may lead to an underestimation of the benefits of in-catchment interventions on water quality from Upstream Thinking interventions.

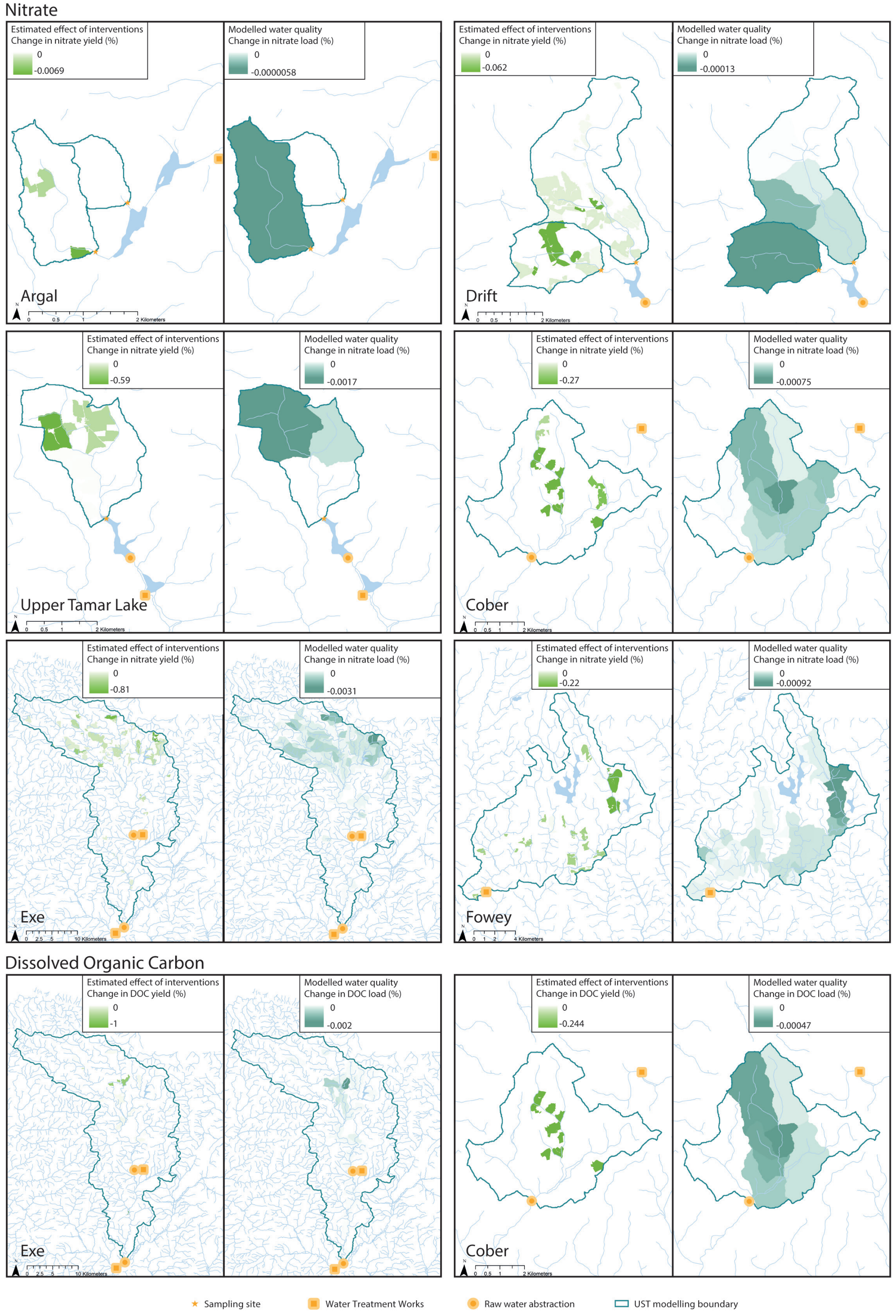


Figure 5 Estimated impact of mapped interventions on nitrate and DISSOLVED ORGANIC CARBON yields and resulting loads in water courses in the Upstream Thinking catchments using the SimplyP model.


Maize farming in the Lower Exe; photo by DWT.

Types of interventions and quantification in Farmscoper

This work has focused on estimating the impact of the Upstream Thinking interventions on water quality, rather than that of all catchment management measures. Other interventions carried out via other funding streams, such as the Countryside Stewardship (CS) scheme, were therefore not considered, leading to an underestimation of the activity in the catchment. Additionally, the intervention data went through a reclassification step using the Farmscoper software. This has been a necessary step for the use of both models. However, as Farmscoper relies on a specific nomenclature of interventions, not all activities carried out in the catchment could be categorised and captured by this process. Similarly, some interventions used had biodiversity benefits with a secondary focus on water quality, and were therefore not included in the modelling work.

Overall, these caveats are likely to have led to an underestimation of the extent of catchment management work, translating, in turn, into a likely underestimation of yields and loads modelled.

For example, interventions in the Cober and Argal catchments largely related to habitat improvements. It is difficult to quantify the impact on water quality of interventions which focus on habitat improvement and therefore they do not appear in Farmscoper. As a result benefits of these types of interventions cannot be estimated by this type of modelling. For example, this has resulted in an estimated maximum nitrate load improvement of 0.0005% in the Cober. Similarly, in the Argal catchment, the small number of interventions quantified in farmscoper have led to a modelled 0.01%, 0.006% and 0.004% for TSS, TP and SRP respectively (Table 3).

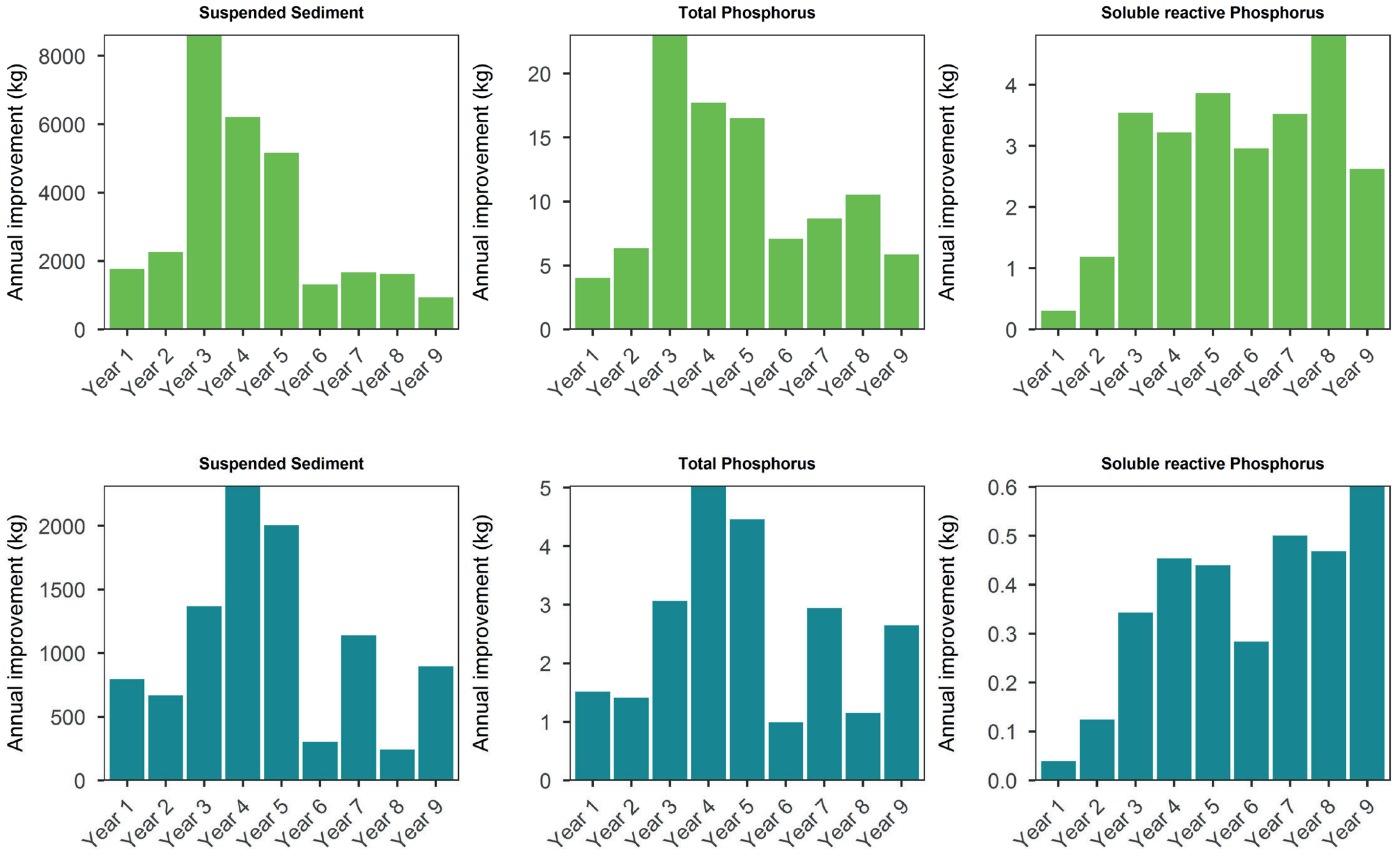


Figure 6 Annual improvement in contaminant loading per year (kg) for suspended sediment, Total Phosphorus and Soluble Reactive Phosphorus in the River Fowey (top) and the River Cober (bottom).

Impact of interventions on parameter to be quantified at catchment scale

Our modelling work has particularly focused on parameters found to be generally affected by diffuse pollution from agriculture and that could be modelled, i.e. nitrate, phosphorus, sediment and DOC. On the other hand, the work carried out by project partners in catchments has focused on farm improvements, with the general aim that these interventions will improve water quality and biodiversity. Pesticides were also a focus for project partners, having been identified as problematic by the EA, however they could not be modelled. Whilst there is evidence of the impact of each intervention on a number of water quality parameters, the type of interventions implemented on a farm, to address specific problems, might not address the parameters of interest at catchment scale and/or that were modelled, and therefore resulted in low modelled change.

For example, interventions in the Lower Exe catchments have largely focused on pesticides, with less emphasis on nutrients and sediment yield. In the Argal catchment, the small yield change in nitrate is likely to be the result of two interventions, namely, to re-site gateways away from high risk areas, and to minimise the volume of dirty water, both likely to reduce nitrate (Figure 5).

On the other end of the scale, in the Fowey, most of the interventions occurring in the catchment tend to reduce nutrients[8] (Figure 5). The most significant interventions were to fence off rivers from livestock, which prevents livestock from directly inputting nutrient to the stream via excretion. This led to higher mean loading change of 0.2% for TP and 0.1% for SRP. In Upper Tamar Lake, interventions also had a generally positive impact on nitrate (Figure 5), with interventions that focused on loosening compacted soil, and thus increasing nitrate leaching through the soil, having the greatest effect. However, there were only two relevant interventions for SS and phosphorus in the catchment, namely the loosening of compacted soil, and the improvement of storage of manure and slurry. This has resulted in some of the lowest change observed across the region (Table 3).

Difference between catchments

Using the percentage change to calculate loads (i.e. cumulated mass of contaminant carried out by river flow) showed the same differences between catchments. Unsurprisingly, small catchments (i.e. Argal and Upper Tamar Lake) that have low percentage change were found to show low cumulated improvement (Table 3). Conversely, large catchments show a greater cumulated load, mostly due to the size of the river or stream considered, and flow used in the calculations. This largely explains why the Exe shows a modelled decrease of up to 430 tonnes for TSS, over 1 tonne for TP and 300 kg for SRP. Figure 6 illustrates some of the inter-annual variability in the model output for the River Fowey and the River Cober. As the modelling was based on flow and meteorological conditions between 2010 and 2018, this is reflected in changes in loads per year.

The Argal catchment; photo by Emilie Grand-Clement.

Overall, these results make the case for improved recording and mapping of interventions and also highlight the need for extended and sustained in-catchment interventions that would allow greater cumulative benefits. However, even modest reductions in nutrient loadings will make a difference on water quality in these catchments.

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