Mapping the potential for payments for ecosystem services schemes to improve water quality in agricultural catchments: a multi-criteria approach based on the supply and demand concept

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Abstract

Payment for Ecosystem Services (PES) schemes are one option in a suite of policy tools for improving water surface water and groundwater quality. In these schemes, downstream water users who are impacted by agricultural diffuse pollution incentivise upstream farmers to adopt better practices. However, this type of scheme will not be successful in all situations, in part, due to a lack of potential for agriculture to supply improved water quality and/or a lack in demand from downstream users for good water quality. As such, this study aims to present a flexible approach to mapping the potential for PES schemes to improve water quality in agricultural catchments. The approach is based on multi-criteria analysis, with supply and demand as key criteria. It uses expert judgement or current guidance on PES to select supply and demand sub-criteria, expert judgement to weight criteria through pairwise comparisons and readily available, national datasets to indicate criteria. Once indicator data are normalized, it combines them in a weighted sums analysis and presents results spatially at the national scale, all within a geographical information system. The approach can easily be applied to the country or region of interest by using locally relevant criteria, expert judgement and data. For example, when applied to the situation for river waterbodies in England, supply sub-criteria were the contribution of agriculture to loads of the major pollutants (nitrogen, phosphorus and sediments) and the demand sub-criteria were the different downstream water users present (water companies and, tourist and local recreational users) in each catchment. Expert judgement assigned equal weight to supply and demand criteria and the highest weights to sediments and water companies for sub-criteria, respectively. Readily available, national scale datasets were used to indicate these criteria. When indicator data were combined in a weighted sums analysis, it was possible to identify areas of high potential for PES, which would hopefully motivate more detailed research at the individual catchment level into the constraints in linking supply and demand. Three case-study schemes were also examined to show how some of these constraints are being identified and overcome. As such, the approach presented is the first tier in a two-tier framework for establishing PES schemes to improve water quality in agricultural catchments.

1. Introduction

Diffuse pollution from agriculture remains a major problem in Europe, contributing to poor water quality in aquatic ecosystems with associated impacts on related goods and services, on human health and on economic activities (Le Moal et al., 2019). Despite this, the costs of these impacts are not internalised in the purchase price of food (Bell et al., 2018). Instead, governments seek to reduce the impact of diffuse agricultural pollution on water quality through policy initiatives that aim to improve the sustainability of farming practices and change land use. These publicly funded initiatives include regulation, such as the Nitrates Directive (OJEC, 1991) and advisory schemes, such as Catchment Sensitive Farming in the UK. They also include incentive schemes such as the Basic Payment Scheme and the Republic of Ireland's Green, Low-Carbon, Agri-Environment scheme both funded under the EU Common Agricultural Policy. In incentive schemes, government bodies pay farmers for taking up practices that are expected to improve water quality. However, there are several issues including funding limits, low uptake by farmers in certain areas, poor spatial targeting of best practices and low levels of compliance monitoring. As such, schemes don't always lead to improved water quality and reduced costs, or achieve policy objectives (Collins et al., 2021; Collins and Anthony, 2008; Kay et al., 2012; Pulley and Collins, 2021), such as 'good' ecological status (GES) as set by the European Union Water Framework Directive (WFD) (OJEC, 2000).

With poor water quality continuing to cause impacts and costs, downstream users who are impacted by diffuse pollution from agriculture are increasingly looking to implement catchment management, through what are often referred to as 'Payment for Ecosystem Services' (PES) schemes. This is evidenced by a year-on-year increase in the number of PES schemes in Europe, coupled with increasing private sector investment in catchment management (Bennett et al., 2017). These schemes usually exist because the expected cost of catchment management is lower than the costs of impacts caused by poor water quality, and are usually set up by downstream users themselves, or by an 'intermediary' organisation who facilitates the scheme (Cook et al., 2017). In these schemes, downstream water users (buyers) voluntarily incentivise upstream farmers (sellers) to adopt best practices, featuring options for land management and/or land use change. As well as providing additional funds for wider catchment management, these schemes tend to have higher levels of farmer enrolment, measures tend to be more locally specific with better spatial targeting, and there are higher levels of compliance and ecosystem service monitoring than in government incentive schemes (Wunder et al., 2018, 2008). Despite these potential benefits, PES is still a relatively underdeveloped component of catchment management and diffuse agricultural pollution policy in most EU member states, and more specifically in the UK (Cook et al., 2017). However, interest in PES is growing due to recent opportunities to reform both EU and UK agri-environmental policy (Bateman and Balmford, 2018; Bieroza et al., 2021).

Despite the possible benefits of PES, the success of this approach to improving water quality will be variable, with the approach more likely to succeed in some catchments than in others, partly due to supply and demand factors (Table 1). For instance, where the potential for agriculture to supply water quality improvements, above those required by law, is coupled with a high demand for the better water quality, then there is likely to be a high potential for PES schemes - i.e. there needs to be a good balance of 'buyers' and 'sellers' of good water quality (Rogers et al., 2015; Smith et al., 2013). However, the potential for agriculture to improve water quality will be lower when other sources of nutrients, such as sewage treatment, are present, which could also make the desired effects of an agriculture focused scheme difficult to achieve and quantify (Bol et al., 2018; Pohle et al., 2017). However, in those areas PES could aim to maintain a low contribution of pollutant inputs from agriculture. Furthermore, it is more difficult and costly to solve water quality problems caused by some pollutants than others, as some are subject to transformation and lag times as they move through catchments (Melland et al., 2018). Demand for good water quality may come from a range of downstream users who vary in their willingness-to-pay and/or their technical capabilities for establishing a scheme (Glenk et al., 2011; Hampson et al., 2017). In some areas where there are multiple individual downstream users, the use of 'intermediary organisations' may be necessary to facilitate a scheme (Cook et al., 2017), and there are also higher transaction costs associated with multiple buyers, which could lower gains from any exchange (Jack et al. 2008, Goldman-Benner et al. 2012). Since all of these supply and demand factors will vary in presence and/or severity from one catchment to another so will the overall potential for PES schemes to improve water quality.

[Insert Table 1]

Being able to link supply and demand, or buyers and sellers, is critical in establishing a successful scheme, and there are many technical, legal and economic constraints (Table 1) that need to be overcome in the scheme design if the potential for PES is to be realised (Engel et al., 2008; Goldman-Benner et al., 2012; Jack et al., 2008; Smith et al., 2013). In agricultural catchments these might include technical challenges such as targeting of payments at 'critical source areas' of the catchment that contribute the majority of pollutant loads (Le Moal et al., 2019); legal constraints such as those that discourage or prevent tenant farmers from enrolling on schemes (Harrison-Mayfield et al., 1998; Maye et al., 2009); and economic constraints such as the balance between the costs of impacts, the actual budget available for catchment management, and the estimated costs of improving water quality through catchment management (Engel et al., 2008; Glenk et al., 2011).

Mapping the spatial variation in the potential for PES to improve water quality could motivate PES establishment, advise on the type of schemes that might be most suitable and potentially inform policy at the strategic level. Although, there is currently no approach or framework to do this in Europe, studies with similar aims but concerned with the effects of deforestation on sediment loads in equatorial regions have successfully combined readily available, national scale indicator data in a multi-criteria analysis (MCA) (Locatelli et al., 2014; Wendland et al., 2010). Multi-criteria analysis lends itself well to these strategic level studies as it allows the key aspects or 'criteria' of a problem, such as supply and demand factors, to be organised in a hierarchical manner (Balasubramaniam and Voulvoulis, 2005). A MCA can also incorporate expert judgement to weight criteria in relation to their importance in a transparent way, which would be particularly important for criteria involving different pollutants and downstream users. It also has advantages of being able to handle the mixed data sets, the types of which might be available at national scale, to indicate those key criteria. Weighted data indicating the key criteria can then be parsimoniously combined and mapped (Arora, 2012; Fealy et al., 2010).

An MCA approach should be achievable for integrating and mapping supply of and demand for good water quality in Europe, since there are national scale data sets available to indicate them. However, the very specific nature of the constraints in linking supply and demand, and subsequent issues with data availability, means that these would be better researched at the individual catchment level for the time being. Such an exercise could therefore not be expected to inform all aspects of scheme design. Instead, it would form part of a two-tier type approach to establishing PES, where this exercise motivates further research into PES at the individual catchment level, advises on the types of schemes that are most suitable and informs policy. The former research would allow the constraints in linking supply and demand to be identified and the finer designs of a scheme to be detailed.

This study aims to present a flexible approach to mapping the potential and type of PES to improve water quality in agricultural catchments. The approach presented is based on MCA, with the potential for agriculture to increase the supply of good water quality and the demand from downstream water users for water quality improvements as key criteria. It uses expert judgement or current guidance on PES to select supply and demand sub-criteria, expert judgement to weight criteria through pairwise comparisons and readily available, national datasets to indicate criteria. Once indicator data are normalized, it combines them in a weighted sums analysis and presents results spatially at the national scale, all within a geographical information system (GIS). This approach is applied to the situation in England to show how it can be easily tailored to the country or region of interest, and where there are a number of established PES schemes against which to validate the approach. Three case-study schemes were also examined in greater detail to show how the constraints in linking supply and demand are being identified and overcome.

2. Material and methods

2.1. Criteria and indicators

Current UK guidance on PES, which is based the PES literature and on experiences with a number of pilot schemes (Defra, 2016; Smith et al., 2013), was used to define a number of key criteria and sub-criteria important in establishing a successful scheme. Critically, this advice states that 'PES schemes are most likely to emerge where specific land management actions have the potential to increase the supply of a particular ecosystem service (in this case water quality), and there is a clear demand for the service in question'. Sub-criteria for supply and demand included the key agricultural pollutants (N, P and sediments for surface waters and N for groundwaters) and sources of demand (for drinking water and recreation), respectively, as identified in the guidance and pilots (Figure 1). These supply and demand criteria, and sub-criteria were considered for rivers and groundwaters separately, since they involved contrasting pollutants, stakeholders and management in the pilot schemes.

[Insert Figure 1]

Indicator data for these criteria were selected based on availability at national scale, and on suitability for indicating water quality demand as outlined by Wolff et al. (2015). In addition to being outlined below, further details on the sources, formats, resampling and normalisation of these datasets are presented in Supplementary Table S1. Indicator data are also mapped in Supplemental Figures S1, S2, S3 and S4. All data were resampled to WFD inland river water body (n = 3753) and groundwater body (n = 271) catchment scale, as was the approximate scale at which PES schemes were established. This and all other data processing and analysis, and mapping were carried out within a GIS using ArcGIS Pro (version 2.5) and QGIS software (Version 3.14.1).

The relationship between percentage contribution of agriculture to pollutant loads, actual loads in kg/ha, chemical and ecological change, and impacts on different downstream users is extremely complex and is probably better researched at the individual catchment level. For the purposes of this study, the percentage contribution that agriculture makes to pollutant loads used is a simple metric that provides information about when other sources, such as sewage treatment, are present, which could make water quality improvement difficult to achieve and quantify (Bol et al., 2018; Pohle et al., 2017). It would also allow for suggestions about scheme type to be made, i.e. whether to lower the contribution or maintain low contributions. For river waterbodies, data on N, P and sediments were taken directly from Zhang et al. (2014). Whereas data for groundwater, data were calculated from modelled N loads leaching to groundwater from agricultural land by the NEAP-N national scale leaching model (Anthony et al., 1996) and from all other sources by the Lerner model (Lerner, 2000) (see Supplemental Table S1). All three models use a range of catchment characteristics and management to model loads from agriculture and all other sources.

To indicate demand for drinking water and the presence of water companies in river waterbodies, where abstractions can occur downstream, i.e. outside of the catchment, the contributing areas upstream of all Environment Agency licensed abstraction points were delineated. This layer was then used to sum the maximum permitted abstractions (ML) downstream of and within each river water body catchment. For groundwaters, which are more hydrological independent, maximum permitted abstractions (ML) for drinking water within each waterbody catchment were summed. Summing abstraction was done on the premise that water companies are more likely to establish PES when large abstractions are at risk. Demand for recreational use by tourists and local populations were indicated separately, as previous studies have shown recreational users within the water body catchment to have higher willingness-to-pay for good water quality, than users from outside the catchment (Hampson et al., 2017). Indicator data were percentage of tourists visits for outdoor recreation and population by water body catchment, with both raw datasets being obtained from the National Office of Statistics. When these indicators are high, demand for good water quality for outdoor recreation are also expected to be high (Wolff et al., 2015).

Indicator data for N, P and sediments, and water use, tourist use and local use were not significantly correlated ($p > 0.05$) to suggest biases, such as double accounting for criteria. However, data were on differing scales with differing distributions. Each dataset was therefore normalised to a 0-1 scale, either by min-max scaling or by rank normalisation when data contained many zeros and/or extreme values.

2.2. Determining weights

Indicator data were weighted by asking thirteen PES experts from universities, water companies, government organisations and non-government organisations to conduct pairwise comparisons of criteria and sub-criteria as outlined in Analytical Hierarchy Process (Saaty 1980, Saaty and Vargas 1991). For instance, they were asked to compare whether it is easier or harder to improve river water quality through PES for N, P or sediments. The three potential comparisons (N vs. P, N vs. sediments and P vs. sediments) were presented to the experts in a table, each comparison with a 9 through 1 to 1/9 scale, with 9 being extremely easier, 1 being equal difficulty and 1/9 being extremely harder. The scores assigned by the experts were entered into one half of an N, P and sediment matrix, and in the other half, the corresponding reciprocal values were calculated and entered. The matrix was then normalised by dividing each value in the matrix by the sum of values in the corresponding column. The mean of the values in each row of the normalised matrix is then taken as the weight, and the sum of these is always equal 1 (Saaty, 1980; Saaty and Vargas, 1991). Where comparisons of three or more criteria are made, this approach allows for the calculation of a ‘consistency ratio’ with values close to zero indicating the highest consistency between comparisons. Ratio’s above 0.1 indicate inconsistencies amongst comparisons (Saaty, 1980; Saaty and Vargas, 1991).

Experts weighted supply and demand criteria equally in both rivers and groundwaters, quoting that there needs to be a good balance of ‘buyers’ and ‘sellers’ for a scheme to be successful, which validates current guidance (Smith et al., 2013) with more recent experiences with PES (Figure 1). For rivers, sub-criteria under supply were weighted in the order: N<P<sediments. Experts commented that this reflected the transformations and lag times associated with N and, to a lesser extent P transfer, when compared with sediment, which would make improving water quality more challenging and costly. They also felt that best practices for sediment are more likely to be effective than for N and P. One expert placed P more highly than N and sediments, commenting that because P is an ecological quality parameter for WFD it may therefore receive added government attention. This slightly increased the consistency ratio to 0.06 compared to values of 0.01 and 0.02 for surface water and ground water supply, respectively. Sub-criteria under demand were weighted highest for drinking water abstraction but similarly for tourist and local use for outdoor recreation in both surface water and groundwater catchments (Figure 1). They felt that good water quality are generally underappreciated by the general public, and that as multiple buyers are involved, transaction costs would be high and an intermediary organisation would be

required to facilitate a scheme. They felt that impacts of poor water quality on water companies are usually due to the chemical aspects, rather than the ecological aspects that impact recreational users, which are more difficult and take longer to solve. Furthermore, they felt that where abstraction for drinking water is high, water companies are actively looking to reduce the cost of raw water treatment through catchment management and have the funds and technical skills to establish a successful scheme. In terms of hydrological setting, experts felt that the slow movement of pollutants through groundwater makes it more difficult to identify the sources of pollution and would delay any water quality improvement due to PES compared to in river catchments.

2.3. Combining indicators

Indicators were then combined using a weighted sums analysis (Figure 1), which keeps data on approximately continuous scales, thereby helping to maintain model resolution (Arora, 2012; Balasubramaniam and Voulvoulis, 2005); an important quality when dealing with such large numbers of catchments. Data for supply sub-criteria were then multiplied by their respective weights depending on whether data was for groundwater or river water bodies and then summed, then the same process was carried out for demand sub-criteria (Figure 1). Totals for supply and demand criteria were then multiplied by their respective weights and then the two were summed. Optionally, the new totals can be multiplied by weights for hydrological setting. The resulting values indicated the overall potential for PES to improve water quality (Figure 1). Results were are divided into quintiles of supply, demand and potential scores, for river and groundwaters separately. The first, second, third, fourth and fifth quintiles, indicate: low, medium-low, medium, medium-high and high, supply, demand or potential, respectively.

While some catchments will have both high supply potential and high demand for improved water quality and lend themselves to a classic PES scheme, other catchments may lack supply, demand or both. Identifying these catchments would allow suggestions about alternative types of scheme for private sector investment in catchment management. This was based on supply and demand scores for individual catchments and whether they were above or below the overall median, and this was carried out for rivers and groundwaters separately. These PES and alternative scheme types are defined in Figure 2, and some example schemes are outlined in Table 2.

[Insert Figure 2]

2.4. Validation

In the absence of water quality data, the approach was validated by testing the scientific hypothesis that catchments where PES are currently established or being established would contain a higher proportion of waterbodies scoring high potential or identified as PES restoration types than would be present in the overall population of waterbodies. This was tested on the premise that PES schemes are most likely to emerge where agriculture has the potential to increase the supply of water quality, and there is a clear demand for improved water quality (Smith et al., 2013). Thirteen existing schemes, containing 105 individual waterbodies were used in this validation (Figure 3). Schemes included those in the rivers Fowey, Western Rother, Wicksters Brook, Tamar, Wolf, Lyd, Sussex Ouse, Evenlode, middle Severn and Gara, and in groundwaters Frome and Piddle, Upper Hampshire Avon and Chichester Chalk. The proportions of waterbodies in these catchments scoring high potential were tested against the same proportion in the wider population using a two-sample Z-test of proportions, which was repeated for PES restoration scheme types.

2.5. Technical, legal and financial constraints in linking supply and demand

Three case-study schemes in the south of England were examined in greater detail to show how the constraints in linking supply and demand are being identified and overcome. All three schemes are case-studies in the EU Interreg VA funded Channel Payments for Ecosystem Services Project led by the University of Chichester. The project aims to establish PES schemes to improve water quality in the north of France and south of England (for more information see: https://www.cpes-interreg.eu/en/). The three case-studies used here were the river Western Rother in West Sussex, South Downs groundwater in West Sussex and the Salcombe-Kingsbridge estuary in Devon (Figure 3). They differ in hydrological setting as the river Western Rother and South Downs groundwater both have ground and surface water hydrological components, whereas, being located away from principal aquifers, the Salcombe-Kingsbridge estuary is surface water dominated (Figure 3). The catchments also differ in supply and demand factors, and in the technical, legal and economic constraints in linking them, and hence also have different scheme designs (Table 2).

[Insert Figure 3]

[Insert Table 2]

3. Results and discussion

3.1. Potential of PES for improving water quality

The approach presented here is based on MCA and uses current guidance to select criteria, expert judgement to weight criteria and readily available, national datasets to indicate those criteria. Once indicators are normalized, it combines them in a weighted sums analysis and presents results spatially at the national scale, all within a GIS. The analysis is flexible and can easily be built upon to include additional supply criteria, such as pesticides, bacteria, metals or dissolved organic carbon, and/or additional demand criteria such as conservation and angling groups. It can therefore also be easily applied to the country or region of interest by using locally relevant criteria, expert judgement weight those criteria and data to indicate them. For example, when applied to the situation for river waterbodies in England, current guidance suggested that the potential for agriculture to improve the supply of good water quality (for nitrogen, phosphorus and sediments) and the demand for improved water quality from key downstream users (water companies and, tourist and local recreational users) should be key criteria for deciding potential. Readily available data was used to indicate these and expert judgement, using pairwise comparisons, assigned equal weight to supply and demand criteria, and the highest weights to sediments and water companies for sub-criteria. When combined in a weighted sums analysis, it was possible to identify areas with high potential for PES, and these results are presented in Figures 4 and 5. For rivers, high potential areas include the north and west of the country, where the varied topography suits surface water collection and storage for drinking purposes. Whereas for groundwaters, these areas were in the south-east of the country, where principal bedrock aquifers are present and a greater water company reliance on them as drinking water sources (EA 2012). However, as with MCA in general the results are highly influenced by the selection of criteria and sub-criteria (Balasubramaniam and Voulvoulis, 2005), and it is possible that results would follow a different spatial pattern when other pollutants or types of downstream users are included. An alternative way of selecting comprehensive criteria and sub criteria would be to draw on expert judgement, and this has been used with great success in other MCA analyses (Bampa et al., 2019).

[Insert Figure 4]

[Insert Figure 5]

The main difference between this approach and the ones presented in similar studies is the focus here on private sector investment in catchment management through small-scale PES schemes. Because of this focus, it has been essential to weight criteria, especially for demand, as different downstream users vary greatly in their willingness-to-pay upstream farmers and in their abilities to set up a scheme. This is compared to previous approaches that are mainly concerned with identifying areas for government investment in catchment management through national scale schemes, where weighting may not have been so necessary (e.g. Locatelli et al., 2014; Wendland et al., 2010). When applied to the situation in the UK, the approach was able to utilise a comparably higher quality of data than what has been used in previous studies (e.g. Burkhard et al., 2012; Vrebos et al., 2015). This is due the catchment-science specific and high-resolution of data recently available in this country. Supply indicators involved detailed modelling of pollutant loads to rivers and groundwaters for all waterbody catchments (Zhang et al., 2014). Indicating demand involved combining abstraction volumes with areas upstream of abstraction points, which allowed demand from users downstream of the waterbody catchments themselves to be included. As with many supply and demand mapping studies, other aspects were constrained by data availability (Wolff et al., 2015), and this would likely be the case especially when the approach is applied to more data sparse areas or countries (Pohle et al., 2021; Vrebos et al., 2015).

For example, this study indicates demand from tourists for recreation using the percentage of tourist visits for outdoor recreation purposes. This does not directly indicate use of the waterbodies for recreation, because outdoor recreation doesn't always involve water. While the willingness-to-pay of local and tourist recreational users for improved water quality has been accurately estimated for individual waterbodies (Glenk et al., 2011; Hampson et al., 2017), an exercise to extrapolate those results to the national scale would very valuable for future mapping studies.

If the approach is to be considered at all accurate then catchments where PES are currently established or being established would contain a higher proportion of waterbodies scoring high potential than would be present in the overall population of waterbodies. This was indeed the case, with 65 % of waterbodies within the catchments where PES are currently being established scoring high potential, compared to 20 % in the overall population (significantly different to $p < 0.0001$). These proportions were not expected to reach 100 %, since not all factors were included in the analysis and because PES is often targeted at problematic waterbodies within the wider catchment area of the scheme and these were not always known. Water quality improvement data from the schemes would also further strengthen this validation when it becomes available.

This validation exercise also shows how PES schemes are already starting to emerge in a small proportion of high potential waterbodies, and this mapping study could further motivate that proliferation. Even though the target pollutants and scale of these schemes will not always be aligned with the WFD, a water quality improvement at any level should be a welcome contribution to achieving GES. The current agricultural policy reforms happening in Europe must ensure adaptation of policy to accommodate this new wave of catchment management.

3.2. Type of schemes to improve water quality

The approach was also validated based on the scientific hypothesis that catchments where PES are currently established or being established would contain a higher proportion of waterbodies identified as PES restoration types than would be present in the overall population of waterbodies. A proportion

76 % of waterbodies within catchments where PES schemes are being or have been established were identified as being PES restoration types, compared to 25 % in the overall population (significantly different to $p < 0.0001$).

The situation where water companies are incentivising upstream farmers to adopt better practices because they are being impacted by diffuse pollution, or 'PES restoration' type schemes, are the most common types of scheme found in England. However, there are alternative options for private sector investment in catchment management for when supply potential, demand or both are lacking. To suggest alternative types, the mapping approach further classifies catchments as being best suited to either 'PES protection', 'community restoration' or 'community protection' type schemes. This is based on whether their scores for demand are above or below the overall median, and this was carried out for rivers and groundwaters separately (figures 4&5).

The PES protection type schemes would be best suited to catchments with high water company demand but low potential for agriculture to improve the supply of good water quality. Such area include the Thames Basin upstream of London, where sources other than agriculture are more important for water quality (Figures 4 & 5). These schemes are important as they provide protection when external forces such as agricultural intensification bought about by the abolition of EU milk quotas (Groeneveld et al., 2016), or climate change (Ockenden et al., 2017) threaten to increase agricultural diffuse pollution. As such, water companies may establish these schemes for risk management since they aim to eliminate future impacts and associated costs of water treatment. Catchments with high supply but low demand scores, where community restoration schemes are more suited, are mainly located around the fringes of the country (Figures 4 & 5). These schemes would likely require an 'intermediary' organisation to effectively facilitate payments from multiple individuals and businesses to farmers (Cook et al., 2017; Engel et al., 2008). These intermediaries may play a number of roles including: introducing downstream users and farmers and building rapport between them; establishing water quality baselines; identifying best practices that will improve water quality; assisting in determining prices, accessing grants, structuring agreements and agreeing a mutually acceptable payment regime; performing activities related to implementation (including monitoring, certification, verification, etc); and overall scheme administration (Cook et al., 2017; Smith et al., 2013). These activities cannot be conducted without cost and one example of how policy might be adapted to accommodate PES, is to channel more government funding towards the facilitation of these community type schemes by regulatory bodies or environmental charities. If the budget available for incentivising practice and/or land use change is not sufficient to improve water quality, intermediaries may also seek additional private sector funds from outside the catchment, for example, from companies looking to offset their carbon emissions. In catchments with low supply and demand, externally funded protective schemes may look similar, except with the aim to ensure the inputs of pollutants from agriculture kept low.

3.3. Technical, legal and financial constraints in linking supply and demand

This mapping approach allowed for some basic supply and demand barriers to be identified in advance (See Supplemental Table S2), and these barriers were confirmed by more detailed research within each catchment (Table 2). However, it could not be expected to identify the catchment specific constraints in linking supply and demand. Instead, the downstream users or intermediary organisations establishing a scheme would carry out extensive research to understand their catchments and design the scheme in detail. In the case-study schemes, this research involved gathering existing data, monitoring, modelling, field experiments, cost benefit analysis, stakeholder analysis and mapping, and stakeholder engagement. Amongst others, these constraints included technical challenges such as targeting of payments at 'critical source areas' of the catchment that contribute the majority of pollutant loads; legal constraints such as those that discourage or prevent tenant farmers from enrolling on schemes; and economic constraints such as the balance between the costs that impacts are creating, the actual budget available for catchment management, and the estimated costs of improving water quality by catchment management (Table 2).

In the South Downs groundwater scheme, combined monitoring and modelling by the water company identified a gradual increasing trend in nitrate concentrations at their groundwater boreholes as water moves slowly through the chalk matrix (~1 m yr^{-1}). This trend is overlain by a series of spikes, which they proved through tracer experiments, to be due to rapid transfer of N through fissures in the chalk in response to rainfall events (Stuart et al., 2016). The water company identified all fields overlying these fissures and plan to incentivise arable reversion to low input grassland on them to address the N spikes, whilst also incentivising widespread adoption of cover crops in attempt to halt any increase in the longer-term trend.

Farmers on short term tenancy agreements, or farmers whose landlords determines any interaction with agri-environment schemes may be less likely to enrol on these types of schemes (Harrison-Mayfield et al., 1998; Maye et al., 2009). This has been the case particularly in the Western Rother catchment, where, despite over 50 years of research into erosion and management, the issue remains unresolved (Boardman, 2016; Boardman et al., 2009; Farres et al., 1990). To encourage adoption of practices, the water company operating in this catchment are working with farmers to co-design a scheme to ensure practices are financially attractive and compatible with the farming systems present. They are also working with land-owners to have those practices written into farm tenancy agreements.

Understanding the costs that water quality impacts are creating relative to the costs of incentivising enough practices to improve water quality, can be key to designing a successful PES scheme. For instance, in the South Downs groundwater scheme it was important for the water company's catchment management team to demonstrate this to be able to secure internal funding for PES. Through their modelling work, they demonstrated that incentivising farmers in a PES scheme would cost ~£3.3M to achieve the desired affect by 2075. This is compared to the ~£8M cost of setting up and running a nitrate removal plant over the same timescale, giving a net benefit of ~£4.7M, a clear case for PES restoration.

Such a quantitative assessment is not always necessary. In the Salcombe-Kingsbridge estuary scheme, it was quite clear to the Westcountry Rivers Trust (WRT), the intermediary organisation establishing a community restoration type scheme, that funds generated within the catchment would not be sufficient to improve water quality. The types of multiple individual or small business 'buyers' that are present here are generally supportive of the concept of catchment management, however, previous schemes have found them difficult to engage (Rogers et al. 2015). The WRT have established a trust fund, to which local businesses and individuals can contribute, which will reduce the costs associated with multiple transactions (Jack et al. 2008, Goldman-Benner et al. 2012). To further boost funds, they are also looking to attract external buyers who wish to offset their carbon emissions by investing in practices that involve tree planting and/or other practices that result in increased soil organic carbon. They will distribute the funds to farmers in exchange for practice or land use change either through one-to-one visits with a WRT advisor to negotiate grant funding or through a reverse auction system. In the auction system, farmers bid for funds and the bids likely to deliver the greatest impacts on water quality are funded, making any actions more cost-effective (Valcu-Lisman et al., 2017). The WRT are also involved in several of the other schemes mentioned in section *2.4*, such as those in the river Tamar catchment.

These are just a few of the design considerations made in the case-study schemes in-order to link supply and demand, and realise PES potential. They also made many of the frequently cited design considerations such as, how the scheme will provide additional protection or restoration for water quality above what is already present, and how the payments will be conditional on implementation of practices (Engel et al., 2008; Wunder et al., 2018). The Channel Payments for Ecosystem Services project will bring together experiences from these schemes and from three other schemes in northern France, to provide up-to-date guidance, specific to catchment management, for designing PES in this second tier.

4. Conclusion

This study presents an approach to mapping the potential for PES to improve water quality in agricultural catchments. The approach is based on MCA, with the potential for agriculture to increase the supply of good water quality and the demand from downstream water users for water quality improvements included as key criteria. The approach involves the following steps:

1. Select supply and demand sub-criteria using expert judgement or current guidance on PES

2. Weight criteria using expert judgement through pairwise comparisons
3. Indicate criteria with readily available, national datasets
4. Normalise indicators using appropriate techniques
5. Combine indicators in a weighted sums analysis
6. Present results at the national scale

Whilst following these steps the approach can easily be applied to the country or region of interest by using locally relevant criteria, expert judgement and data. When applied to the situation in England, it was possible to identify areas of high potential, which would hopefully motivate more detailed research at the individual catchment level into the constraints in linking supply and demand. This study also allows for some basic barriers to PES to be identified and suggestions for alternative types of schemes to be made. Furthermore, by simultaneously assessing the current state of PES in England, it was possible to make some initial policy recommendations. Specifically, this was that policy must be adapted to accommodate this new wave of catchment management, and one way this might happen is for some government funding to be channelled towards the facilitation of community type schemes.

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