CREW CENTRE OF EXPERTISE FOR WATERS

Reviewing best practice in the delivery of good drinking water quality using a prevention-led approach

CENTRE OF EXPERTISE FOR WATERS

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EXECUTIVE SUMMARY

ABBREVIATIONS

Art. 7 (or A7)	Article 7 of the Water Framework Directive
DOC	Dissolved Organic Carbon
DOM	Dissolved Organic Matter
DOMQUA	Drinking Water Treatment Adaptation to increasing levels of DOM and changing DOM quality under climate change.
DWD	Drinking Water Directive
DWPA	Drinking Water Protection Areas
EU	European Union
N	Nitrate
P	Phosphorus
SAVE	Saving the Archipelago Sea by applying gypsum to agricultural fields
SCaMP	Sustainable Catchment Management Programme
SWW	South West Water
TOC	Total Organic Carbon
WFD	Water Framework Directive (2000/60/EC)
WRT	Westcountry Rivers Trust
UST	Upstream Thinking
UK	United Kingdom

Executive Summary

Aims and objectives

The aim of this project was to collate evidence related to prevention-led approaches within catchments, that was of relevance to Scotland and the benefits that they could bring to safeguarding drinking water supplies. This project sought views, nationally and from other EU (and international) countries, on how or what they have learnt from implementing a prevention-led approach. A Steering Group, comprising colleagues from Scottish Government, Scottish Water, DWQR and SEPA guided our focus on two key pressures on Scottish drinking water supplies: a) organics (e.g. Dissolved Organic Carbon) and b) Taste and odour issues. The objectives of the project were to:

1. Produce a long list of potential case studies which address either of the two key pressures;
2. Select a shortlist of case studies, to take forwards for detailed analysis and steering group review;
3. Host a workshop focussed on organics, to explore new evidence from selected short listed cases relevant to Scottish drinking water supplies;
4. Highlight key evidence that are applicable to the Scottish context from selected cases studies.

Research undertaken

A long listing exercise of potential cases which fitted the project criteria was conducted, providing 18 cases. A short-listing process took place to select four cases, which were presented and discussed during the workshop. A detailed case study template, with 15 questions, was produced for each of the workshop case studies: covering what had been done, and what had been learnt. The workshop was focused on best practice approaches to manage DOC and colour issues; two of the selected cases also had approaches to address taste and odour issues. The detailed information given to delegates ahead of the workshop allowed them to focus fully on and discuss the knowledge generated from these cases, lessons learnt, outlook and challenges.

Key findings and recommendations

- The four shortlisted workshop case studies generated a large amount of empirical evidence. The two English case studies (SCAMP and UST) suggest that measures such as peatland restoration are beginning to reduce pressures due to DOC loads but their effectiveness is uncertain. As a result, longer term datasets are needed to fully assess the cost-benefits.

- Catchment hydrological processes' are complicated, and it may take decades to improve drinking water supply pressures through restoration activities such as ditch blocking and vegetation restoration. After restoration, some short-term increases in DOC levels may occur resulting in negative consequences. Nevertheless, the case study water utilities believe, long-term, that decreases will occur. Both South West Water and United Utilities are committed to a prevention led approach in the long term and see the potential benefits of a prevention-led approach from the early monitoring evidence.

- However, the Scandinavian case study DOMQUA is more sceptical about potential benefits as most of the observed rise in DOC concentrations over the past decades can be attributed to climatic factors.

- When other ecosystem services are costed measures become more cost effective (as seen in the SCAMP case study).

- Partnership working is key to the delivery of a prevention-led approach. As this can help with gaining buy-in for land and water management measures with landowners and farmers and leveraging extra funds.

- Fundamentally, funding is required to enable these changes in land and water management measures and to monitor their effectiveness in a scientifically robust way.

- The issue of ensuring that land managers do what they are paid to do was also raised.

- We found a limited number of prevention-led cases in Europe. The two most relevant cases, to the Scottish context, were from England (SCaMP and UST) and have the most relevant and extensive datasets and transferable knowledge.

- There is a continued need to better share knowledge gained from prevention-led approaches to avoid the duplication of effort. This could be done through a knowledge and data exchange network.

1 Introduction

The introduction of the Water Framework Directive 2000/60/EC (WFD) aimed to facilitate a shift from many fragmented water management policies to a holistic approach, integrating all parts of the wider environment system [1, 2]. It promotes increased awareness of catchment processes, and challenges reliance on a 'treatment-led approach' for the supply of potable water compliant with the European Drinking Water Directive (DWD) [3]. WFD Article 7 promotes a 'prevention-led approach' to DWD compliance, based on preventing pollution at source, with the objective to reduce investment in drinking water treatment works to deal with contaminants of concern. This presents a significant challenge for preventing diffuse pollution for numerous parameters, including for example, colour, TOC, and turbidity, which are providing pressures on drinking water supplies in several catchments in Scotland, despite current treatment.

Within Article 7, member states are required to implement measures in Drinking Water Protection Areas (DWPAs) with the aim of avoiding deterioration in water quality due to anthropogenic sources of pollution and reducing the level of water treatment required over time to meet drinking water standards (Article 7.3) [4]. However, the way in which safeguard zones are defined, and the measures placed within them can vary between Member States. Also, it is thought that a shift from a 'treatment-led' approach to a combination of 'prevention-led' and 'treatment-led' approaches will require collective action and shared mutual understanding between several stakeholder groups (e.g. Environmental regulators, Water supply companies, landowners, conservation groups etc). However, evidence to support this transition, available from long term prevention-led management studies, is limited and therefore sharing of knowledge between case studies is essential. To this end, there is a need to work with stakeholders from across the EU to explore and identify best practices in delivering good drinking water quality using a prevention-led approach.

The aim of this project was to collate evidence related to prevention-led approaches within catchments, that was of relevance to Scotland and the benefits that they could bring to safeguarding drinking water supplies. This project sought views nationally and from other EU (and international) countries on how they have implemented a prevention-led approach. A Steering Group, comprising colleagues from Scottish Government, Scottish Water, DWQR and SEPA guided our focus on two key pressures on drinking water: a) Organics (e.g. Dissolved Organic Carbon) and b) Taste and odour issues, from both diffuse and point sources. These pressures were identified by the steering group and therefore taken forward by the project.

The main objectives of the project were to (refer to Figure 1):

1. Produce a long list of potential case studies which address either of the two key pressures;
2. Select a shortlist of case studies, to take forwards for detailed analysis and steering group review;
3. Host a workshop focussed on organics, to explore new evidence from selected short-listed cases relevant to Scottish drinking water supplies;
4. Highlight key evidence that are applicable to the Scottish context from selected cases studies.

2 Project processes and methods

We undertook a long listing exercise to find case studies which were implementing a prevention-led approach to safeguarding drinking water (and other ecosystem services). This was then narrowed down to a potential short list for consideration in the next stages of the project (Section 3) through discussions with the steering group (Figure 1). Criteria for selecting case studies included those which had:
1) Available findings or have an ambition to report on findings;
2) Similar land use/climate/policy to Scotland;
3) Active points of contact.

These criteria were co-constructed with the steering group to select cases which were of relevance to Scotland. Figure 1 highlights the steps undertaken in the project (a detailed overview of the methodology can be found in Appendix A; however, a summary of the methodology is presented here).

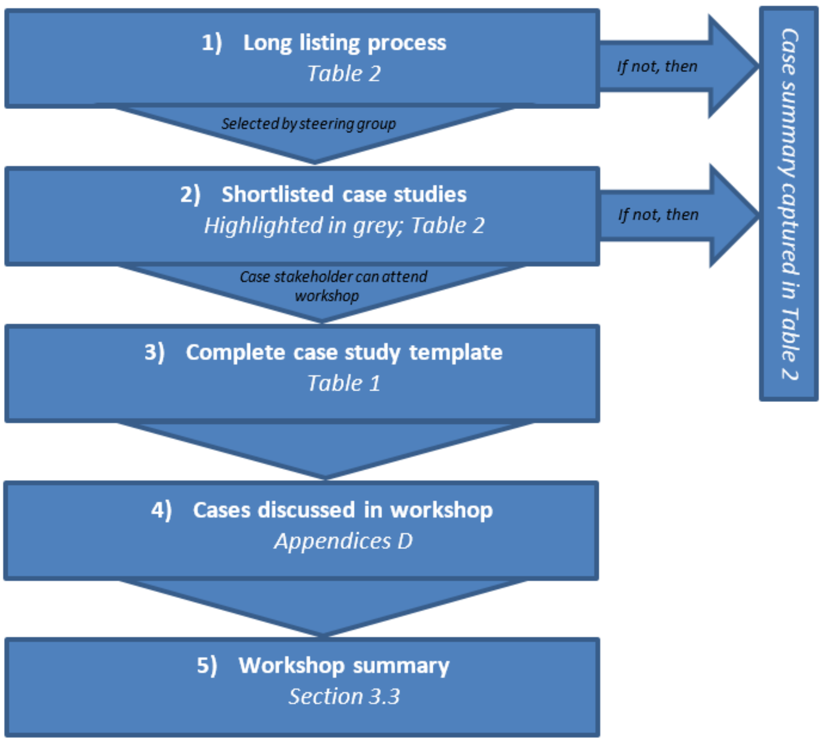

Figure 1; Flow chart of project methodology

The first step in this project (Figure 1, step 1) was to collate a long list of potential case studies that are addressing the pressures of interest (DOC and taste/odour). This was carried out using two linked approaches: Firstly, we identified case studies through known contacts and existing networks and secondly, we identified case studies through literature and web searches. The long listing of cases was captured in a database which contained information such as the project name, country, number of sites, work done, key finding, project website and contact organisation. We shared and discussed the long list with the project steering group to shortlist cases for further investigation. The steering group were looking for cases which could bring new knowledge on delivery of a prevention-led approach (e.g. new management methods, evidence, governance structures) that would be relevant to the Scottish context. It was decided on the information presented, that 4-6 shortlisted UK and EU cases (Figure 1; step 2), would be explored in further detail and through a one-day workshop event (see Section 2.2.). Based on the cases presented and to keep the workshop focused, only cases of relevance to DOC and colour management were selected (however, most of the selected cases also explored nutrient management to address algal issues within their catchments).

The short-listed cases were explored in detail, a key point of contact was confirmed (Figure 1; step 2), asked for further information on their case study and invited to a workshop where the case would be discussed in detail. If a case study point of contact could attend the workshop, they were then asked to complete a detailed case study template (Figure 1; Step 3). A template (Table 1) was developed, with input from the steering group, to provide a consistent approach for extracting relevant information from the shortlisted selected cases. The key question areas the template explored were:

a) What new evidence is available?
b) What has and what hasn't worked?
c) What are the gaps in our knowledge?

This template (Table 1) was then initially completed for the chosen case studies by the project team, and then sent to the relevant case study contact for review and to add further detail. After another iteration of the case template, a final document was created and was used as the basis for a one-day workshop event.

We then designed a one-day participatory workshop focussed on advancing our knowledge of evidence for protecting drinking water supplies in Scotland from DOC. The objectives of the workshop were to present and discuss what new evidence was available; what hasn't worked (and why), and; what were the main gaps in knowledge. Four cases were presented at the workshop; a list of the workshop participants is provided in Appendix B. In total there were 15 participants. The workshop was structured around a series of activities (see Appendix C), that aimed to set out the Scottish context and the need for the project, followed by a presentation from each of the cases and a plenary discussion. This was followed by small group discussions, where the participants rotated between each case and further discussion in pairs to summarise key evidence and gaps from a Scottish perspective. The workshop was planned and facilitated by an experienced facilitator, and notes were collected by five colleagues and summarised with agreement from the participants.

3. Case studies and findings

3.1. Cases of relevance to prevention-led approach/best practices; long listing

We targeted our searches to countries which have a similar land use, climate and policy setting as Scotland (i.e. northern EU member states). As DOC was raised by the steering group as a key pressure, evidence from countries with large areas of peatlands was explored. Generally, these were Northern European countries such as Finland, Sweden, Ireland and Estonia as they have approximately 29.5%, 15.6%, 16.5% and 21.7% relative area cover of peat soils (0-30cm) [5]. Case studies from within the UK were also collected. Most countries across the EU have issues related to nutrients in watercourses and lakes, however, those which had taste and odour issues were specifically chosen. At this point international examples were also selected with a few relevant examples found in New Zealand and China. Several relevant drinking water-related mailing lists/groups were contacted by email. The email gave an overview of the project and the issues being addressed. It then asked for interested groups to reply if they had a relevant case and wished to participate in the study further. If a positive reply was received with information that addressed the project priority issues, this was included in the summary table (Table 2).

Table 2 highlights the outcomes of the long listing exercise. In total 18 cases were identified for discussion with the steering group. The table highlights the project name, contact organisation, the issue (must include either DOC or nutrients affecting taste and odour of drinking water), whether it is a single or multiple site study, the country and the project website. It also gives an overview of the work done within the project and key project information or findings.

Table 1; Detailed case study template

Question	Reasoning from December Steering Group meeting
Where carried out?	
Status e.g. ongoing	
Contact	
Pressures addressed?	Multiple pressures may be addressed
Type of prevention-led best practice e.g. catchment management, point sources	The focus of the study is about prevention-led, therefore catchment management is just one of the measures. Project will include point sources.
What was driving these initiatives/ measures?	What are other countries doing and what is driving these measures? Is it Article 7 or other social aspects? Information about measure success and on how they delivered this (individual or collective).
What has been done?	Beneficial to understand from other case studies: what is going to be used and how?
Is there information about the success of the measure?	What are other countries doing and what is working? Important questions include: what is driving these initiatives/measures (is it Article 7 or other social aspect) therefore information about measure success.
Is there information on how they delivered the measures?	Information on how they delivered this (individual or collective)
Is there any cost information?	If costs are available, then it would be good to include but it was discussed this may be challenging to extract that information. People may not know what the costs will be. Cost benefit can be very difficult.
How relevant is this to best practices in Scotland?	Trying to learn how other EU countries are implementing A7, and how relevant these best practices are to Scotland.
Background	

Table 2; Long listing exercise collating national and international examples of prevention-led approach. Lines in italics are sub-cases within the wider project initiative (so for example there could be a large EU funded project with six cases in each individual country)

Code	Project	One case site or multiple	Locations	Issues: Does it cover Organics/ Nutrients?	Work done	WEBSITE	Key findings (from website literature)	Contact Organisation
1	Source to Tap (N. Ireland/ Ireland – cross border)	Multiple (in one region); Erne and Derg Catchments.	N. Ireland	Nitrate (and herbicides/ pesticides)	Just starting, mainly learning and outreach to deliver catchment management. This will be achieved by: 1) learning and outreach programme to inform and empower the public about their role in protecting clean freshwater environment; 2) piloting best-practice forestry and peatland management measures; 3) delivering an Agricultural Land Incentive Scheme focused on changing land management practices for the protection of water	Source to tap	• Commenced in 2017 and will run to 2021; • Project will run an Education programme on domestic water management practices, peatland restoration, pesticide management; • Project will construct settlement ponds/sediment traps of different sizes and filtering of the runoff from the forestry operation sites; • Restoration of 135ha of previously afforested peat bog areas adjacent to watercourses on Forest Service.	NI Water
2	Garron Plateau	One	N. Ireland	Organics	The Garron Plateau is the largest intact bog in N. Ireland and it supplies drinking water to 14,000 homes (via Dungonnell Reservoir). Erosion has led to discoloration in the water and increased processing costs at the treatment works. Widespread blanket bog restoration. As part of SCAMP NI (working in partnership with RSPB and NIEA) a large area of the site has been restored (2000ha).	Garron Plateau	•Initial results suggest that spikes in TOC and colour are less pronounced and fewer outliers occur; •Turbidity data is less conclusive.	NI Water
3	Upstream Thinking	Multiple in one region (SW England)	England	Organics and nutrients	A comprehensive catchment management programme extending across 10 drinking water abstraction catchments and covering 75% of SWW's abstractions. Upstream Thinking aims to protect tap water quality at the source by working together with farmers and landowners to improve agriculture, restore wetlands and reduce pollution. The project has two areas of work; lowland farms and upland peatland. The project is a collaborative partnership with a sustainable approach aimed at considering how we think about water in the landscape. For example, the Exmoor Mires Project has blocked drainage channels using local materials to rewet the area. As of 2015, 5000 acres were restored with over 14,000 ditches blocked.	Upstream thinking	• Exmoor Mires Project: noted a decrease in concentration of DOC of up to 30% [6] at local sites; •Grand-Clement et al. (2014) highlighted no significant change in DOC concentrations six months after restoration (using a restored and control stretch of drains); •Water quality: In Exmoor, DOC, colour, humic to fulvic acid ratios and pH monitored at eight locations. Researchers have noted an overall reduction in the total carbon yield from the restored sites of up to 50% since restoration [7]; •750 farm plans resulting in actively improved management and investment in the catchment (in the current UST2 period);	South West Water
4	SCaMP	Multiple in one region	England	Organics and nutrients	SCaMP 1&2: widespread catchment management. Work included peatland restoration, afforestation and livestock reduction over 27,000 ha of land. ~13,000 ha of bare peat has been re-vegetated and 320 km of moorland drains have been blocked. Since 2015 SCaMP focuses on land regardless of ownership and aims to implement activities identified under the Environment Agency's Safeguard Zone Action Plans (under Article 7.3 of the WFD). The aim is to address pollution at source to (i) reduce deterioration and (ii) prevent or delay the need for additional water treatment by restoring natural processes. A catchment management approach is being used to tackle a range of water quality issues from colour, pesticides and algae in surface water to nitrates and solvents in groundwater.	SCaMP	•Since 2015, 31 water safeguard zones have been created; •Long term (10 years+) monitoring shows that some degraded peatland sites are on a trajectory towards recovery which should in time reduce or stabilise the increase in DOC release to drinking water supplies; •Advice-led approaches are more successful for reducing a source contaminant such as pesticides, and the advice is most effective when coupled with wider advice for the farm business, e.g. nutrient management planning.	United Utilities

5	AAC France	Multiple (across France)	France	Nutrients, pesticides	Lots of examples of case studies across France; A great number of case studies from France, includes 306 case studies for protection of groundwater, 23 for protection of surface water and 9 for karst regions against nitrate pollution.	ACC (in French) & (in English; for wider European links)	•Best practice examples from across France; •Knowledge exchange hub to share experiences; •2011-2013 review of measures for mitigating groundwater pollution from nitrates and pesticides (Vernoux and Surdyk 2014) found that the effectiveness of measures to prevent nitrate pollution varies on a site-specific basis. Ongoing long-term actions are more effective; •It was not possible to evaluate the effectiveness of agri-environmental measures to ameliorate pesticide pollution.	Oieau, France
6	*ACC case example (see case 5)*	*One site*	*England*	*Nitrates*	*Till Fell Sandstone groundwater body, 25 farmers, water serving 25,000*	*(ACC in English; for wider cases)*	*• This case engaged with 15 farmers and have established good working relationship. Landowner communication is critical.*	*Via Oieau, France*
7	*ACC case example (see case 5)*	*One site*	*Belgium*	*Pesticides, nitrates*	*Protection of groundwater resources. A sandy area with short travel times from surface towards drinking water wells. Serves 175000 and is managed by 20-30 farmers.*	*(ACC in English; for wider cases)*	*•Case only just started.*	*Via Oieau, France*
8	DOMQUA	multiple	Norway, Finland, Sweden	TOC	Trend analysis of TOC in lakes from 1980s to present, in relation to acid deposition, climate and land-use.	DOMQUA	•Lakes with longer residence time remove a higher % of incoming DOC; •Explaining variables of DOC conc. are site-specific but mainly due to climate (rainfall) and atmospheric deposition (de Wit et al. 2016); •TOC concentrations in Finnish freshwaters are generally high due to flat topography and high peatland proportion in catchment but there is no good method to decrease TOC transport from the catchment (Kortelainen, pers. comm). The organic carbon is in a dissolved form, coagulation is effective in a lab, but too expensive in the field. Helsinki Region Environmental services authority HSY uses iron sulfate to coagulate DOC from drinking water source. The Gypsum case study by Petri Ekholm demonstrates the possibility to decrease DOC load from fields.	SYKE Finland, NIVA Norway
9	Water Protect (Ireland)	Ireland case study presented here but other countries involved.	Ireland	Nitrate and pesticides	Water Protect project: assessing the efficacy of mitigation measures to protect water resources in a rural agricultural environment. It aims to create an integrated multi-actor participatory framework that includes instruments that enable monitoring, financing and implementation of effective catchment management practices and measures (to protect water sources). This case is one of seven cases across Europe.	WP – Ireland	•Just commencing; •Suite of interventions to mitigate N and pesticides will be tested at the field scale; •Socio-economic aspects of cost-effective measures will be identified to inform uptake of measures; •The research will investigate the occurrence of MCPA in groundwater through the sampling of private water wells in both study areas On a field scale, the study will then focus on MCPA and its behaviour and fate post application for rush control treatment in a poorly draining impermeable grassland field; •Installed "Chemcatcher" passive samplers at catchment outlets to monitor three acid herbicides (MCPA, 2,4-D and mecoprop). These samplers provide a time weighted average of the pesticides which overcome the issues around one-off grab sampling.	Teagasc, Ireland

10	*Water Project (Italian case; see case 9)*		*Italy*	*Pesticides and nutrients*	*Water Protect project: assessing the efficacy of mitigation measures*	*WP - Italy*	*Val Tidone,*	*Unicat, Italy*
11	*Water Protect (Polish case; see case 9)*		*Poland*	*Pesticides and nutrients*	*Water Protect project: assessing the efficacy of mitigation measures*	*WP - Poland*	*Gowenieca River,*	*PIG, Poland*
12	Governance of WFD	Five case study countries explored; Netherlands focus	EU	Nutrients and pesticides	New project collating case studies. Focus on regional cooperative arrangement between stakeholders, prioritizing/ differentiation of approaches and mix of policy instruments to address diffuse pollution from agricultural practices. Project looks at mode of governance regarding the implementation of the WFD in five-member states (Denmark, Germany, Austria, Belgium and Ireland) with a view to draw lessons for the Netherlands.	WFD governance	•Ongoing project with two phases; •First phase explores how WFD was implemented in case study catchments to produce a long list of policy issues for the Netherlands; •Second step is an in-depth analysis of some core issues.	Radboud University
13	NOMiNOR	multiple	Scandinavia	Organics	NOMiNOR: Natural Organic Matter (NOM) in Nordic drinking waters project. Project focuses more on treatment processes rather than prevention-led approach. The objective of the project was to look at NOM control and removal in water treatment.	NOMiNOR (in English)	•Focus was on treatment rather than prevention-led approach.	UiO, Norway
14	Wessex Water Catchment Partnership	Multiple regions (England)	UK (England)	Mixed, nutrients	Catchment Partnerships; a partnership approach to help protect and restore the water environment in the Bristol Avon, Hampshire Avon, Somerset and under Dorset, Poole Harbour and the Stour regions.	Catchment partnerships	•Partnership working approach as part of the Catchment Based Approach initiative.	Wessex Water, UK
15	Hydrology LIFE project	Multiple sites	Finland (focus case)	DOC	Hydrology LIFE project looks to restore peatlands in 103 Finnish Natura 2000 areas. Project assess multiple benefits Inc. DOC management, however, there is a strong habitat focus. One such case is the Haapasuo Bog. It was drained in the 1960s and restoration began in the 1990s (habitat improvements were the driver). Ditches were blocked using four different types of measure.	Hydrology LIFE	•Just starting out project runs from 2017 to 2023; •In previous research Haapalehto et al (2014) studied a mix of restored, pristine and drained peatland sites at 38 locations; •They found restoration has the potential to reduce leaching of nutrients and DOC in the long term, but practitioners should be prepared for potential temporary increases of leaching of N and P for at least 5 years after restoration of boreal sphagnum peatlands.	Metsahallitus, Parks and Wildlife Finland.
16	Su et al., 2017 paper	China; one area	China	Algal blooms	Miyan Reservoir had long term issues with odour production (2-methlyisoborneol; 2-MIB) associated with deep living Phanktothrix sp.	Link	•They used remotely sensed surface water elevation and an algorithm to manage a reduction in high-risk areas by raising water level above as set height. They used Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) Global Digital Elevation Model Version 2 (GDEM V2);	Wider International
17	SAVE (Saving the Archipelago Sea by applying gypsum to agricultural fields)	One catchment; Savijoki river basin in Lieto, southwestern Finland	Finland	Phosphorus, eutrophication, DOC	The pilot area covers an area of 82 km². The field percentage of the area is 43%, and 43% of the fields were amended with gypsum, that is, a total of 18% of the catchment was treated with gypsum to reduce phosphorus pollution and therefore eutrophication	SAVE	•Application of gypsum to 1550 hectares of agricultural land as part of cultivation practices as a means for protecting waters; •Gypsum has the potential to significantly lower the phosphorus loading originating from agriculture; •In addition to phosphorus, gypsum markedly reduces the losses of DOC from agricultural fields. The effects begin immediately after the dissolution of gypsum and last for several years.	SYKE Finland
18	PMP (Phosphorus Mitigation Project)	Multiple sites	New Zealand	Phosphorus	This project was initiated by farmers and aims to validate the performance of detainment bunds as a mitigation strategy addressing storm water runoff from farm pastures. These low earth bunds are constructed on ephemeral stream paths.	PMP	•PhD research project (Brian Levine) investigating the variables that affect bund treatment performance; •Initial findings (from Brian Levine, 2018) showed the ponding treatment decreased loads of suspended sediments, total phosphorous, dissolved reactive P, total nitrogen, nitrate and ammonia by 90%, 83%, 76%, 76%, 83% and 78% respectively; •Further research is still being conducted with more sampling	Massey University

Long list of cases and shortlisting process

The long list (Table 3) contained six case study examples which were addressing nutrients, in particular N and P (and in some cases pesticides), four cases which were focused on DOC management and three cases which addressed both nutrients and DOC. However, approximately half of the nutrient focused studies were more focused on pesticide management (e.g. case 9) or were on catchments which were very different to the Scottish context (e.g. Karst aquifers) (e.g. case 5). All the DOC cases were relevant to the Scottish context; however, some were more focused on the technical aspects of DOC removal (e.g. case 13). Many of the cases have active examples of a prevention-led approach, however, there were a few case examples which were in early days of project timeline and had limited conclusive findings (e.g. cases 1, 9, 15 and 18 – although project 15 had some background study information). All the DOC management cases were based in the UK and Scandinavia. In many UK examples, water companies were the lead partners in the delivery of measures. Nevertheless, in cases that had another leading pressure (e.g. restoration of habitats for wildlife), water quality was also measured. Many cases are trying to educate key stakeholders e.g. farmers. This involves, for example, delivering courses on pesticide/fertiliser management and visiting schools and communities (e.g. cases 1, 3, 4, 9 and 14). Nearly all cases used a partnership approach to deliver their prevention-led approaches. Table 2 identifies one contact organisation, but in all cases, there were more partners involved in the projects (i.e. a partnership approach, see website links).

There were very few long-term projects (to our knowledge and based on literature published in English) which had either concluded or had long term findings. Many projects were either just starting or in progress. This is most likely a result of Article 7 being relatively new, and the long-term timespans needed to determine the effectiveness of a prevention-led approach.

The long list was presented to the steering group and five DOC studies were shortlisted (two of which contained nutrient management approaches to help improve taste and odour issues (Table 3; highlighted grey)). These cases were Upstream Thinking, SCaMP, DOMQUA, Hydrology LIFE and SAVE. Case 15 (Hydrology LIFE) was selected for inclusion in the workshop, however, a representative was unable to attend. Therefore, it was decided to extract key findings for the summary table (Table 2). Also, this project has recently commenced. Upstream Thinking was selected as it was a long-term study that is more appropriate to the Scottish context. DOMQUA was of interest as it was investigating DOC in three Scandinavian countries - a key parameter that is applicable in the Scottish context. SCaMP was shortlisted as it is a long-term study, now moving into a third phase and is applicable to the Scottish context. Whilst the other cases were of interest to the project, they were not taken forward. Reasons for not selecting these cases ranged from little evidence, early days of the project, geologies/settings not applicable to Scotland or policies which were not aligned to Scotland.
The steering group identified one nutrient case study for further investigation (Case 9 – water project). However, further investigation found this study has just commenced and therefore had limited findings. Also, the project was focused on nutrients rather than DOC, therefore was not included for discussion during the workshop. A further update was received on the project at the end of this study and was included in Table 2.

3.2. Synopsis of detailed cases

A detailed case study template was completed for the four shortlisted case studies. The full completed cases can be found in Appendix D. Two of the UK cases delivered a catchment-based approach through partnership working and had in depth knowledge from many years of experience. One case (DOMQUA) investigated DOC trends and their causes in Fennoscandinavia (de Wit et al. 2016). Whilst the SAVE project was initially implemented to reduce P loads into the Archipelago Sea in Finland, it was also found to reduce DOC levels. A summary of key findings is given below as a series of points.

SCaMP

- Through the delivery of the SCaMP, United Utilities is recognised within the UK water industry as being at the forefront of catchment management which aims at securing multiple benefits at a landscape scale;

Figure 2: Map of cases from Table 1 and their home country. Purple number represents a case looking at taste and odour issues and brown is a case focused on DOC management (note; some cases look at both and therefore have been separated). Numbers refer to how many cases are present in that country from Table 1.

- The initiative began in 2005 and is currently in its third phase. SCaMP has put in place plans to restore a vast area of the ~56,000 ha of landscape United Utilities owns in the North West of England;

- Work included:
  - o Peatland restoration, afforestation and livestock reduction over 27,000 ha of land. More specifically, approximately **320 km of grips have been blocked, 470 ha of eroded peat has been treated** with new vegetation or heather brash;
  - o There has been a reduction in stocking densities and moorland burning;
  - o However, through SCaMP 3 (which is the third phase of the project) the area of interest is increasing significantly. Since 2015, **water safeguard zones have been created** through a collaboration between United Utilities and the EA as a basis for long term catchment management, 31 zones have been created.

- United Utilities pay particular reference to Article 7 of the WFD in their safeguard zone documentation [8] and have worked with the EA to deliver action plans (Article 7.3) which form part of the River Basin Management Plan. It is hoped this initiative will improve the key pressures. However, in the event there is no improvement in water quality then the EA may seek to designate these areas as Water Protection Zones and enforce mitigation measures.

- United Utilities **work with many partner organisations and SCaMP is founded on a partnership approach**. For example, a partnership with the RSPB supported United Utilities 's farm tenants to apply for agri-environment payments;

- Long term (10 years+) monitoring shows that some degraded peatland sites are **on a trajectory towards recovery, which should in time reduce or stabilise the increase in DOC** release to drinking water supplies. The research suggest **colour production and delivery to streamflow appears to be generally stable** within the long-term dataset (with a couple of exception sites) [9]. However, **year on year there are changes in the trend** depending on local factors;

- In 2018 it was reported that the **raw water colour trajectories were stabilising** in most catchments, with only a few increasing trends remaining [10]. In Longdendale, the trend of increasing colour was rapidly increasing before restoration. After restoration this trend has slowed down, but colour is still an issue therefore some investment may still be needed at the treatment works;

- Cost benefit analyses were conducted by United Utilities across six catchments and treatment works [11]. The results show that pressures such as **pesticides and algae have a quick payback time, however, nitrate and colour take much longer**. This is due to Nitrate being present in groundwater systems which are slow to respond, and the long time required for a blanket peatbog to restore fully. Therefore, United Utilities are committed to the long-term plan.

Upstream Thinking

- Upstream thinking (UST) is a comprehensive catchment management programme extending across 10 drinking water abstraction catchments in SW England. The project was initiated in 2006, but came into full force in 2010, and is currently in its second phase;

- The project is **aware of Article 7** and it is a key driver of their work [12]. UST believe that catchment-based (prevention-led) approaches are more sustainable than investing in end of pipe solutions;

- **Water treatment costs and taste issues were the main starting driver** for taking a catchment-based approach;

- The projects have included monitoring outcomes since inception; in many cases, they have at **least five years of monitored restoration data**. The project is addressing a range of ecosystem services, which are important to the delivery partners, water customers and the Regulators from improving drinking water quality to enhancing bio-diversity. SWW's main pressures were from increased DOC concentrations (and colour issues), agricultural diffuse pollution and taste issues from algal blooms in reservoirs;

- The project has a vast array of catchment improvements. As of 2015:
  - o **5000 acres of the Exmoor Mires were restored with over 14,000 peatland ditches blocked;**
  - o In the lowland programme across the 10 catchments the focus was on drawing up **management plans with farmers** and land managers to protect waterways whilst helping to keep farms profitable [6];

- The total budget for UST 1 (the first phase of the project) was £9m and £10.5m for UST 2;

- Key wider evidence findings highlights include, **a third less water now leaves a restored site** on Exmoor during heavy rainfall, compared to three years ago [6]. The same local site has noted a **decrease in concentration of DOC of up to 30%** [6]. However, Grand-Clement et al. (2014) found **no significant change in DOC concentrations six months after restoration** (using a restored and control stretch of drains). Angus et al. (2017) noted an overall reduction in the **total carbon yield from the restored sites of up to 50% since restoration** [7]. Initial results from the Exmoor restoration also suggest that **restoring Sphagnum moss cover may deliver improved drinking water quality** [13]. Restoration has generally caused a decrease in overall DOC load downstream, owing to the lower peak river flows [13, 14];

- With respect to diffuse pollution management, by using controlled-release fertilisers, one farmer in the Otter Valley halved the amount of fertiliser applied to first-cut silage from 108 to 49kg/N/ha [6];

- The monitoring of these restoration sites is ongoing, so further findings will arise from this project over time.

- The project has noted some challenges. In Exmoor, the use of bales, commonly used elsewhere to block drainage channels was found to be problematic. Dartmoor peatland r**estoration was expensive due to remoteness of sites**, need for UXO (unexploded ordnance) surveys and requirements for high spec diggers and intensive site management. Much work has gone on into simplifying and automating site survey and block location prioritisation with researchers at the University of Exeter;

- **Partnership working has been key to the success** of this project. It has improved relationship between landowners, farmers, public and project partners. The project delivery partners have been key to this (e.g. WRT) with a 'honest broker' approach.

DOMQUA

- Lakes and rivers are the source of drinking water for most people in Norway, Sweden and Finland. Presently, climate change is posing a threat to the quality of these drinking water sources;

- In recent years, concentrations of dissolved organic matter (DOM) in lakes and rivers have increased and associated with this surface waters have become browner. This poses a major challenge to drinking water providers, as removal of DOM is a key step in drinking water treatment;

- The main aim of the DOMQUA project was to predict future DOM concentrations and colour of raw water sources under climate change, and to assess how to adapt drinking water facilities in the Nordic countries to meet these future conditions (de Wit et al. 2016). The scientific participants in DOMQUA have strong expertise in understanding and modelling of DOM in catchments, lakes and rivers, and in studying effects of climate change and treatment technology on quality of drinking water sources and treated drinking water. Also, social scientists were involved to make a socioeconomic analysis of adaptation in collaboration with natural scientists and stakeholders;

- In this academic project, no land or water management measures were implemented, however trends in DOC and potential causes driving these trends were investigated;

- The % cover of lakes in catchments has been shown to be negatively related to C, N and P load exports to the Baltic Sea [15, 16]. Further, in numerous studies strong negative correlation between catchment lake % area and TOC has been shown [17]. Lakes remove a higher % of incoming DOC, when lake water residence time is higher. In this case this was not managed, the variation in water residence time was an effect of climate variability;

- As a hypothesis, while it is not certain if the same principle in terms of water residence time applies to water residence times in catchment soils, but if so, it would be beneficial for DOC removal to increase water residence time in the landscape and thereby allow for more processing of DOC (Kortelainen pers. Comm.);

- Explaining variables are site-specific and observed changes are mainly due to a combination of climate and atmospheric deposition. No relationship between DOC increases and land-use related factors or specific catchment characteristics was found. A lot of the browning in Scandinavian catchments is usually explained by regional phenomena like sulphur deposition and rainfall patterns, and these cannot be easily managed by water utilities or land managers. This is likely to be the case for the UK as well;

- Scandinavian drinking water catchments are often protected – as in having as little management as possible, and hardly any settlements and agriculture. In some cases, this is not possible, especially in densely populated areas. Management in such catchments is not aimed at reducing DOC, but rather at reducing point sources of pollution to reduce the risk of parasites and other health hazards such as algal toxins;

- **TOC concentrations in Finnish freshwaters are generally high due to flat topography and high peatland proportion in the catchments but there is no good method to decrease TOC transport from the catchments (Kortelainen, pers. comm);**

- The organic carbon is in a dissolved form, coagulation is effective in a laboratory setting, but too expensive to be implemented in the field. Helsinki Region Environmental Services Authority HSY uses iron sulfate to coagulate DOC from drinking water source.

SAVE

- The pilot area of S. Finland covers an area of 82 km². **Application of gypsum to 1550 hectares of agricultural land** as part of cultivation practices as a means for protecting waters. A hydrologically uniform area was treated with gypsum, and the effects on the water quality of river Savijoki and the nutrient state in the fields are monitored;

- Phosphorus loading and erosion were expected to reduce significantly, clearing the water in the river Savijoki, thus making the river more attractive for recreational use. **Gypsum application to fields was more cost-efficient at reducing P loading than any other water protection method** currently in use;

- The recruitment of farmers to the gypsum experiment began in February 2016. The farmers living in the target area, a total of **107 people, were first contacted** with a letter;

- Adding gypsum ($CaSO_4 \cdot 2H_2O$) enables phosphorus to remain in the soil. It increases the ionic strength of soil solution, creating larger aggregates of soil particles and, thus the phosphorus release to run-off is decreased. Phosphorus remains available for plants, but erosion will be reduced and the soil structure will improve;

- **Gypsum reduces the run-off of both dissolved and particulate phosphorus, along with organic carbon run-off**

- The effects begin immediately after the dissolution of gypsum and last for several years [18]. This case study was carried out on clay soil fields which are suitable for the gypsum treatment procedure. On the other hand, there are no lakes in the pilot area, which could suffer from release of sulfate from gypsum, or acid sulfate soils, on which gypsum treatment is unlikely to work, and might increase the losses of exchangeable aluminium;

- The potential ecological effects of sulfate on riverine biota has been extensively tested in the SAVE project. The laboratory and in situ ecotoxicological studies, involving the effects on fish, mussels and mosses, showed no harmful impacts at the concentration level anticipated to occur after gypsum amendment of agricultural fields;

- In addition to phosphorus, **gypsum markedly reduces the losses of DOC from agricultural fields. The magnitude of the reduction is currently being investigated.**

3.3. Focused DOC workshop results and analysis

On the 27th September 2018 we held a one-day workshop focussed on advancing our knowledge of evidence for protecting drinking water supplies in Scotland from DOC and colour. The workshop included representatives from the international case-studies selected by the steering group, as well as the steering group members and the project team (15 delegates in total). After an introduction to the day and information on the Scottish context the workshop was broken into three sections;

1) A short overview presentation and discussion of the four cases (Appendix D) [Key cases; Key messages]
2) Discussion on key evidence and gap analysis from a Scottish perspective
3) Overall summary discussion on day [General points]

3.3.1. Key cases; key messages (Summary of best practices and delivery)

Each case study gave a short 10-minute presentation. The presentation pulled out the key findings from the case study template documents (Appendix D). Each case study representative was asked to cover the following topics as a summary (detail on these points are in Appendix D).

1) Background/what was done
2) Types of intervention installed
3) How this was done
4) Cost estimates/information
5) New evidence and success

SCAMP

Presentation key points further developing the case study template:

- Need to understand **spatial and temporal dynamics of how habitats function** and respond to changes in management [related comment to multiple benefits];

- Need to work with **partnerships** to secure funding for management actions. Taking an ecosystem approach to changes in management [highlighting good partnership working is key to delivery].

Key points from the small group discussions on the case study:

- Different types of evidence **including visual changes** in habitats and improvements in drinking water (i.e. the role of qualitative data alongside quantitative data). Amongst water utilities and regulators there are **different perspectives on the relative importance of these;**

- Some locations/habitats are easier to manage e.g. Forest of Bowland compared to others e.g. industrial areas as they may be in a better starting condition;

- In an English context, are land managers doing what they say they will do in stewardship schemes? United Utilities **do not have a mechanism to enforce compliance** (in the Scottish priority catchments this is less of an issue);

- United Utilities would like to see more of their findings/ evidence communicated in the form of peer-reviewed scientific papers to enable greater acceptance and uptake of the new knowledge;

- When the project started, in 2005, they did not know the problems they would face today (e.g. hydrophilic DOC);

- Difficulties in modelling future changes in drinking water due to changes in management and climate;

- Partnerships with RSPB and river trusts has been vital; managing these relationships can be challenging.

Upstream Thinking

Presentation key points further developing the case study template:

- Clear evidence from Exmoor that **ditch blocking results in raised water table** and sphagnum regrowth. Changes in DOC (less coloured and harder to treat hydrophilic) occurred/were observed after peatland restoration. **Partnerships are key as delivery** is contracted out with a range of organisations e.g. river trusts. **Consistent monitoring programmes** run by researchers are important to produce **evidence of impacts. Mechanisms to enable long term agreements/partnerships with farmers are also key.**

Key points from the small group discussions on the case study:

- Strong evidence on **positive hydrological effects of restoration; these include reductions in peak flows and less DOC delivery during those peak flows**.

- New understanding on changes in DOC through robust monitoring by researchers. Strengths of this monitoring include the **length of monitoring and control sites (BACI design).**

- There are still a range of uncertainties that include understanding long-term changes in DOC, impact of wider environmental change.

- Challenges associated with land owners being wary of management advice, especially if it goes against their previous understanding and objectives e.g. draining land for agricultural improvements.

- Early, and limited, evidence enabled further investment despite uncertainties in improvements in drinking water. Importance of partnerships, though scientific evidence of this has not been a focus.

- **Working with a range of stakeholders is difficult,** as some can feel excluded resulting in negative attitudes.

DOMQUA

Presentation key points further developing the case study template:

- This was primarily about long term monitoring of water quality in a Finnish lake that is a drinking water source: with good overall condition but increasing DOC concentrations (Forsius et al. 2017). They have **concerns over changes in seasonal variation in DOC levels** and the quality of the DOC. Observed changes are linked to climate and atmospheric inputs.

Key points from the small group discussions on the case study:

- This case was about long-term monitoring, not implementation of measures, so no examples of 'what works best'. Though this reinforced the message (perspective from natural science researchers) that **long term monitoring is vital** to understand these bio-physical and biogeochemical process.

- The overall message was that the observed trends in increasing DOC concentrations could largely be attributed to climatic and deposition effects, and that no effective land management mitigation measures could mitigate these effects in Scandinavian countries.

- Questions about most effective size of catchments for management alongside **how to integrate laboratory-based studies with field and catchment-based monitoring** were raised. Further questions were raised about how long you need to monitor DOC related processes to understand trends.

- The need to **share information across countries** was stressed to **avoid duplication of effort**.

SAVE

Presentation key points further developing the case study template:

- Finland has water eutrophication problems, so needs to reduce P losses to water bodies;
- This case was about testing application of gypsum to agricultural fields (clay soils); Large landscape scale application (working with famers) and monitoring. Provided evidence of a reduction in DOC alongside P, and that it is cost effective;
- Need to be aware of the purity (low levels of cadmium and uranium, and small enough particles to dissolve) of the gypsum for safety issues;
- Good process understanding of the biogeochemistry of when gypsum is added to soils.

Key points from the small group discussions on the case study:

- Understanding the relevance to Scottish context as the method would need to be tested on organic soils. This would require laboratory studies using Scottish soils to examine the effects on DOM quality. It may be physically difficult to apply gypsum in upland catchments, where there are reservoirs with DOC pressures but may be attractive for P management in lowland catchments from a cost-effectiveness point of view.
- Gypsum could change the quality of DOM and make it more difficult to treat (make it more hydrophilic). Questions were asked (by Scottish Water and DWQR) if this had been tested in drinking water areas; in Finland most drinking water is from groundwater. Scottish Water maybe interested from a cost-effective perspective.

3.3.2. Key themes related to evidence and delivery

The focus of the afternoon session was to explore the key evidence further and to carry out a gap analysis. The following themes and issues emerged/were discussed.

Targeting: What management change or interventions do you target and why? Do you target improvements at a specific catchment process e.g. runoff generation (or ecosystem service) or at a habitat (SCAMP example of rewetting of bogs through drain-blocking reduced wildfire risk)? This choice is linked to the funding available.

Catchments are complicated: Natural and semi-natural habitats are complicated in terms of their overall biophysical functioning. When we change management there are often multiple interacting impacts (some planned improvements and other potentially negative impacts). Difficult to know what future issues/risks drinking water may face as projects progress. Increased variability in climate e.g. 2018 drought may complicate the interpretation of the evidence from the UK case studies. Need to understand changes in the DOC fractions/physio-chemistry as hydrophilic fraction may become more predominant following ditch blocking and is harder to remove by treatment. Need to understand the system from catchment to tap, as potential for risks during transportation of water e.g. once treated and being transported in aqueducts.

Evidence – types, use, sharing, transferability, timescales and emerging areas: A wide range of evidence types/attributes e.g. natural science monitoring, social science understanding about social processes including governance was presented. Understanding short- and longer-term trends and seasonality is important. There is increasing use of remotely sensed imagery to support understanding catchment functioning and to target changes in management. Use of this imagery needs to be linked with managing where and when contractors carry out management actions. Challenge of providing controls/counterfactuals of change to support evidence of improvements due to changes in management. One participant was involved in an international study looking across trends in DOC and the causes, evidence suggests that peatland percentage is the most important predictor for DOC, temperature and forestry extent are also important.

Partnership approach: Partnerships are often needed especially if multiple individuals or organisations own the land and are involved in its management. They work best when they provide positive outcomes for all involved. There is a need for national and international (e.g. International Union for Conservation of Nature) partnerships to enable greater sharing of evidence and gaps in our knowledge. Funding is needed to establish and maintain these partnerships.

Funding: Fundamentally finance is required to enable these changes in management and to monitor their effectiveness. Ensuring that land managers do what they are paid to do is essential.

Other issues:

1) Though DOC is primarily viewed as an upland pressure, it can also be a pressure in lowland agricultural catchments, particularly in low-lying areas such as lowland fens;

Figure 3: Photo of Workshop event; Sept 2018

2) Debate about approach to targeting management, is there evidence that if you restore the ecosystem then the rest of the desired functioning will follow?;

3) The main management intervention that has been studied in the English case studies is ditch blocking; our understanding of the positive and negative impacts of this are fairly well understood and can be applied (and already are in peatland restoration work) in Scotland. There is a need to keep thinking about other management interventions and be realistic about what we can influence through land and water management;

4) A long-standing challenge is that water utilities often do not own the land that they need to manage for improvements in drinking water supplies.

3.3.3. General points and findings

There was wide recognition of the importance of long-term data. However, it was identified these long-term trends are influenced by climate change and reduced acid rain deposition (thereby shifting the baseline). With this there is a need to understand the effect on before/after type studies with controls. Evidence is bound up in the context of the human-environment context, and this makes it difficult to extract advice for a Scottish context from these cases. Though we did not carry out any formal evaluation of the workshop, comments during the workshop were supportive of the time spent to help share understanding. The need to increase sharing of data in relation to how prevention-led management can result in improvements and potentially negative impacts on (and negatively impact) drinking water was highlighted several times.

4. Summary

4.1. Best practice measures for a prevention-led approach

Three workshop case studies looked at best practice prevention-led approaches and delivery of measures to reduce DOC levels within catchment (SCaMP, UST and SAVE). SCaMP and UST also implemented measures to address taste and odour issues (alongside nutrient and pesticide concerns) within drinking water catchments. A range of different approaches have been used in these cases and some measures have been monitored and assessed. A summary of the key messages from five best practice approaches in these cases are summarised as follow (for further detail and references see Appendix D):

Table 3; Summary of findings for upland drain (grip) blocking

Pressure: DOC and colour	
Approach: Upland drain (grip) blocking	
Cases: UST and ScaMP	
Extent of measure in shortlisted cases	• Approx. 320 km of upland drains have been blocked in NW England (as of 2015); • 14,000 peatland ditches blocked (as of 2015) in SW England.
Key message through monitoring and evidence (both qualitative and quantitative). For further references please refer to Appendix D (case study document) [+] positive finding, [-] negative finding or challenge in approach, [0] neutral finding/no change, [#] point for consideration	ScaMP findings • [+] Long term (10 years+) indicates degraded peatland sites are on a trajectory towards recovery; • [+] At most sites, colour production and delivery to streamflow appears to be generally stable within the long-term dataset [9]; • [+] Raw water colour trajectories were stabilising in most catchment (as of 2018) [10]; • [+] Longdendale, the increasing rate/trend of colour in water has now slowed down after restoration; [-] but colour is still an issue; • [#] The timeframes in order to see the benefits for drinking water quality are long (e.g. >60-year payback period for colour)[11]. UST findings • [+] A third less water now leaves a restored site in the Exmoor moorland during heavy rainfall and has seen a decrease in concentration of DOC of up to 30% [6]; • [0] Research also highlighted no significant change in DOC concentrations six months after restoration [19]; • [+] Overall reduction in the total carbon yield from the restored sites of up to 50% since restoration [7]; • [+] Restoration has generally caused a decrease in overall DOC load downstream owing to the lower peak flows [13, 14]; • [-] Dartmoor peatland restoration very expensive due to remoteness of sites, need for UXO (unexploded ordnance) surveys and requirements for high spec diggers and intensive site management; • [-] In Exmoor, the use of bales, commonly used elsewhere to block drainage channels was found to be problematic. [+] Leaky dam or wood/peat combination dams were used instead and found to be better at diverting flow and last longer [20]. [#] Need to understand changes in the DOC fractions/physio-chemistry e.g. [-] as hydrophilic fraction may become more predominant following ditch blocking and is harder to remove by treatment.
Costs	• In SW England, costs varied from less than £1 per metre of ditch blocked (using peat dams and an excavator) to £16.50 per metre with wooden dams: o This roughly works out at a cost of £490 ha and represents a third of the median restoration costs of other sites (probably owing to the shallow nature of the Exmoor peatlands [as deeper peatland sites have more expensive working costs]) [12]; • SWW has invested £3.2m into peatland restoration over the period of 2010-2015. Therefore, a total £4.5 million (2010 to 2020) in envisaged to restore 3,000 ha of peatland, with 1,400 ha achieved by December 2016 [7].

Table 4; Summary of findings for vegetation and other improvements on degraded peatlands

Issue: DOC and colour	
Approach: Vegetation and other improvements on degraded peatlands	
Cases: UST and ScaMP	
Measures and approaches	• 5,000 acres of the Exmoor Mires were restored in SW England (which included upland drain blocking); • 60 ha of damaged peatland were restored on Dartmoor in SW England; • 470 ha of eroded peat has been treated with new vegetation or heather brash in NW England; • Reduction in stocking densities and moorland burning in NW England; • Hard grazing exclusion is crucial to enable plants and trees to flourish.
Key message through monitoring and evidence (both qualitative and quantitative). For further references please refer to Appendix D (case study document) [+] positive finding, [-] negative finding or challenge in approach, [0] neutral finding/no change, [#] point for consideration	**Please refer as well to Upland drain restoration as some of these results are interlinked** UST • [+] Initial results from the Exmoor restoration also suggest that restoring Sphagnum moss cover may deliver improved drinking water quality [13]. ScaMP • [+] At a selection of sites, once degraded peatland is on a trajectory towards recovery; • [+] The moorland restoration has been a success in terms of the wider ecosystem services it provides; • [-] Local scale increases in turbidity are a result of certain management practices not working as intending (e.g. revegetating did not work at all sites). However, this needs to be explored further; • [-] Where woodland planting has been done without stock exclusion, there has been little growth; • [-] Where stock numbers have been reduced under agri-environment agreements, it is difficult to monitor compliance.
Costs	• The average restoration cost of the Exmoor moorlands was around £306 ha^{-1}, this figure is below the median national value for the UK [12]. However, local site variations (e.g. a deeper and wid er channel) can increase the costs of restoration locally. [*Note – prices may include ditch blocking works so must be read alongside ditch management*].

Table 5; Summary of findings for use of Gypsum to reduce DOC concentrations

Issue: DOC and Phosphate	
Approach: Use of Gypsum to reduce DOC concentrations	
Case: SAVE	
Measures and approaches	• The pilot area covers an area of 82 km². Application of gypsum to 1550 hectares of agricultural land as part of cultivation practices [18]; • 55 farmers (out of the 107) involved in the trial
Key message through monitoring and evidence (both qualitative and quantitative). For further references please refer to Appendix D (case study document) [+] positive finding, [-] negative finding or challenge in approach, [0] neutral finding/no change, [#] point for consideration	• [+] Gypsum reduces the run-off of both dissolved and particulate phosphorus, along with organic carbon run-off; • [+] Gypsum ($CaSO_4 \cdot 2H_2O$) enables phosphorus to remain in the soil. It increases the ionic strength of soil solution, creating larger aggregates of soil particles and, thus the phosphorus release to run-off is decreased; • [+] Phosphorus remains available for plants, but erosion will lessen, and the soil structure will improve; • [+] Gypsum reduces the run-off of both dissolved and particulate phosphorus, along with organic carbon run-off; • [#] The effects begin immediately after the dissolution of gypsum and last for several years; • [#] So far, gypsum has only been tested in fine (clayey) soils. The performance of gypsum in other soil and environmental conditions should be tested as should its effect on DOM quality. This could be done in laboratory studies; • [#] The original interest in gypsum was related to abatement of eutrophication in the coastal waters of the Baltic Sea by reducing the losses of P from the catchment. Additional sulfate does not do any harm there, because the marine systems are inherently rich in sulfate. To be on the safe side, in our catchment analyses on areas suitable for gypsum amendment we have included only those fields parcels that do not discharge to lakes; • [#] Whether gypsum (= sulfate) causes problems in freshwater systems depends on the trade-off between (1) the reduction of bioavailable phosphorus (possibly dissolved inorganic carbon) and (2) an increase in sulfate; • [#} Assuming that Scottish lakes and reservoirs are oligotrophic, sulfate should not be harmful, but here again there is no threshold value for the degree of primary production (availability of C) that is sufficient to trigger sulfate reduction in sediments. In rapidly flowing rivers the probability for sulfate reduction should be quite low; • [0] The potential ecological effects of sulfate on riverine biota has been extensively tested in the SAVE project. The laboratory and in situ ecotoxicological studies, involving the effects on fish, mussels and mosses, showed no harmful impacts at the concentration level anticipated to occur after gypsum amendment of agricultural fields.
Costs	• The costs include the gypsum itself and its transport and spreading. They vary markedly de pending on the availability of gypsum and the distance between the source and the target area. Gypsum application to fields is more cost-efficient at reducing phosphorus loading than any other water protection method currently in use

Table 6; Summary of findings for farm management plans to reduce nutrient loads

Issue: Taste and Odour	
Approach: Farm management plans to reduce nutrient loads	
Case: UST	
Measures and approaches	• Lowland farm catchment management advice and investigations; • Drawing up management plans with farmers and land managers to protect waterways whilst helping to keep farms profitable; • Co–funds the investments recommended in the farm plans which include standard catchment management interventions such as buffer strips, wetlands, farm yard infrastructure improvements, river bank fencing, new drinking points.
Key message through monitoring and evidence (both qualitative and quantitative). For further references please refer to Appendix D (case study document) [+] positive finding, [-] negative finding or challenge in approach, [0] neutral finding/no change, [#] point for consideration	• [+] The project estimates that the average farmer will be around £20,000 a year better off by engaging with the project [6]; • [+] For example, by using controlled-release fertilisers, one farmer in the Otter Valley halved the amount of fertiliser applied to first-cut silage from 108 to 49kg/N/ha [6]; • [+] 750 farm plans resulting in actively improved management and investment in the catchment; • [-] Advisor led approach is labour intensive, not practical to visit all farms and the potential for all the funds to be used on a small number of farmers. [#] Balancing size of grant to catchment needs and priorities is key;
Costs	• New novel funding mechanisms have been created. For example, new funding mechanism for paying for the delivery of ecosystem services ('reverse' auctions where farmers bid for environmental funding). Competition for investment allows the project team to champion the best bids and stimulate the biggest changes in water management [6]; • Another mechanism helped farms transition to more sustainable practices by making grants of up to 50% of related costs to areas where raw water quality improvements should result (e.g. through slurry stores) [6]; • Capital grants for on-farm infrastructure (2008-2015) 1,700 visits to farms and allocated 180 capital grants to farmers totalling £2.6m [21].

Table 7; Summary of findings for Safeguard zones

Issue: DOC, taste and odour	
Approach: Safeguard zones (SCaMP)	
Case: ScaMP	
Measures and approaches	• 31 Safeguard zones created across NW England [8]: o 12 of the surface water safeguard zones address the risk of colour in drinking water; o 5 safeguard zones address algae (taste and odour issues).
Key message through monitoring and evidence (both qualitative and quantitative). For further references please refer to Appendix D (case study document) [+] positive finding, [-] negative finding or challenge in approach, [0] neutral finding/no change, [#] point for consideration	• [#] Safeguard Zones are being driven by Article 7 of the Water Framework Directive [8]; • [#] If there is no improvement in water quality, then the EA may seek to designate these areas as Water Protection Zones and enforce mitigation measures; • [#] Some areas have been given "watching briefs" which means they potentially could become a safeguard zone; • [#] SCaMP 3 is ongoing and in the coming years the success of these Safeguard Zones will be evaluated [8]; • [-] Safeguard zones are not statutory; they rely on a voluntary approach; • [-] The EA are responsible for implementing the WFD, but their resource is limited, and the voluntary approach is not always the most effective when it comes to achieving standards.
Costs	• No identified costs

4.2. Delivery and legacy of best practice measures

Two core areas were identified from the analysis of the four core case studies and workshop discussion.

Partnership working and landowner engagement

A consensus was agreed between all four case studies and the workshop discussion that partnership working was important for the successful delivery of a prevention-led approach. There is a need to improve relationships between landowners, farmers, public and project partners. The project delivery partners in UST and SCaMP have been key to this, for example the WRT, who have acted as an honest broker. Certain partners are experts in farmer engagement and can offer one-to-one support. However, advisor-led approach can be labour intensive as it is not practical to visit all farms. This could lead to the potential for all restoration funds to be used on a small number of farms (if an advisor cannot visit all farms). Novel funding measures such as reverse auction approach have also been tried, but found to be difficult to engage with all catchment stakeholders. The success of using farm advisors is dependent on their personality, skills, knowledge and experience of the individuals delivering the management. Advice-led approaches are more successful for reducing a source contaminant such as pesticides, and the advice is most effective when coupled with wider advice for the farm business, e.g. nutrient management planning. It is difficult to engage farmers about pesticides as a single issue. Organisational priorities can be conflicting, which creates an issue when the water company is funding up to 100% of the activity delivered by a third party. Whilst it is often more efficient for water companies to deliver management activities in the catchment, short-term project work creates a risk around staff retention. This is an issue, particularly where successful delivery relies on engagement and relationships developed between the third party and the farmers.

Commitment to the long term: Evidence, maintenance and grant support

There must be a commitment to managing catchment as prevention-led approach in the long term as recovery rates can be slow (in the case of peatland restoration this could take decades). For example, the UK workshop participants believed that catchment-based approaches are more sustainable than investing in end of pipe solutions. Therefore, if the cost and benefits (including the wider ecosystem services) are better than investing in end of pipe solutions then this will be a key success criterion. However, our study has not found clear evidence for this from the available data to date, as many confounding factors prevent drawing unequivocal conclusions. All delivery partners should be aware that to gain valuable scientific knowledge on reductions of all pollutant DOC concentrations will take time. Also, the monitoring schemes need to be designed in a scientifically robust way. This needs to be considered at the outset of projects and included in the set-up and implementation costs. Benefits are measured through both delivery partner monitoring and quality of scientific information. The partnership usually includes local university research groups who have been monitoring and analysing the restorations works.

4.3. Gaps in knowledge, outlook and challenges

- We are just beginning to understand the impacts of these prevention-led approaches for reducing DOC, colour and nutrient levels within a range of catchments relevant to a Scottish context. Catchments are complex and the timeframes for recovery are long (especially in the case of peatland restoration). Therefore, there is a need to still collect further evidence on these measures and approaches in a scientifically robust way;
- Much of the current science suggests there is a continued need to further monitor catchments in a scientifically robust way (long term, with before-after-control-impact design) to ensure long term datasets are available;
- If further monitoring is undertaken, this needs to be done in a scientifically robust way, including controls (where possible);
- It is difficult to quantify cost-benefits for drinking water treatment from present data;
- The commitment of United Utilities and South West Water to monitoring, suggest that this knowledge is vital to understand the cost benefit of the measures they have installed. However, cost benefit analysis by United Utilities has already shown that peatland restoration is a very cost-effective measure if you consider the wider benefits of the measure such as carbon sequestration;
- Evidence is bound up in the context of the human-environment context, and this makes it difficult to extract advice for a Scottish context from these cases;
- The need to increase sharing of data in relation to how catchment management can improve (and negatively impact) drinking water was highlighted several times. Better sharing could potentially avoid duplication of effort in some cases;
- The workshop highlighted there is still much more to be done and those measures that have been installed must be maintained and managed correctly. Balancing size of grant to catchment needs and priorities is key ensuring grants are equally spread across farmers and not limited to a few. To ensure more equal spread of funding across farmers requires a commitment to sustaining farm advisors and honest brokers who can act as intermediaries between delivery groups and farmers;
- To sustain this there must be a continued appetite for partnership working. Consideration to land management schemes demonstrating sustainable agri-environment systems in a post-EU environment are required.

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