# Transition to Delivery: Landowner Engagement

**Project Report**

**August 2025**

**Kerr Adams[1], Miriam Glendell, Paul Quinn, Camilla Negri & Mark Wilkinson**

**The James Hutton Institute Scientific Services**

[1] **Corresponding Author Contact:** kerr.adams@hutton.ac.uk

# Table of Contents

# Executive Summary

The Transition to Delivery: Landowner Engagement project was developed to support the River Eden Sustainability Partnership (RESP) in engaging with local landowners to identify and enable water management and river restoration projects across the Eden and Motray catchments. In response to increasing water-related challenges—such as flooding, drought, ecological degradation, soil erosion and nutrient pollution—the project engaged landowners through field visits and a stakeholder workshop to co-develop feasible, locally appropriate solutions.

Using a mixed-methods approach, the project combined evidence reviews, participatory fieldwork, and collaborative scoring of management options to assess their environmental, economic, and social impacts of identified water management and restoration measures. The findings highlight both the complexity of catchment-scale water issues and the opportunities for nature-based water attenuation features to help address flooding and drought risks, which can enhance habitat and biodiversity, and work within an agricultural landscape. The project has laid the groundwork for RESP to transition from planning to implementation, with a clear set of recommendations and a five-year strategy to guide future action.

# Highlights

- We conducted eight landowner field visits and a stakeholder workshop attended by 19 local stakeholders to better understand water-related issues and feasible management options in the Eden and Motray catchments.
- Water attenuation features such as leaky barriers, retention ponds, wetlands, and water storage for irrigation use were found to be both effective and widely supported by landowners and wider stakeholders.
- A five-year strategy for the River Eden Sustainability Partnership is proposed, including short, medium, and long-term actions, with a focus on developing landowner clusters to enable partnership working, supporting knowledge exchange events, and pursuing innovative funding through Nature Finance Fife to deliver feasible water management actions.

# 1. Introduction

## 1.1. Catchment overviews

The River Eden and Motray Water catchments are located in Fife, in eastern central Scotland (Figure 1). The River Eden flows in a northeasterly direction through a 400km$^2$ catchment, where flow begins in Burnside (NO162077) and drains into the Eden estuary at Guardbridge (NO451190). The Motray Water catchment is smaller (60km$^2$) than the Eden catchment and flows northeast from Mount Hill (NO331164), before flowing south and draining into the Eden at the Guardbridge estuary.

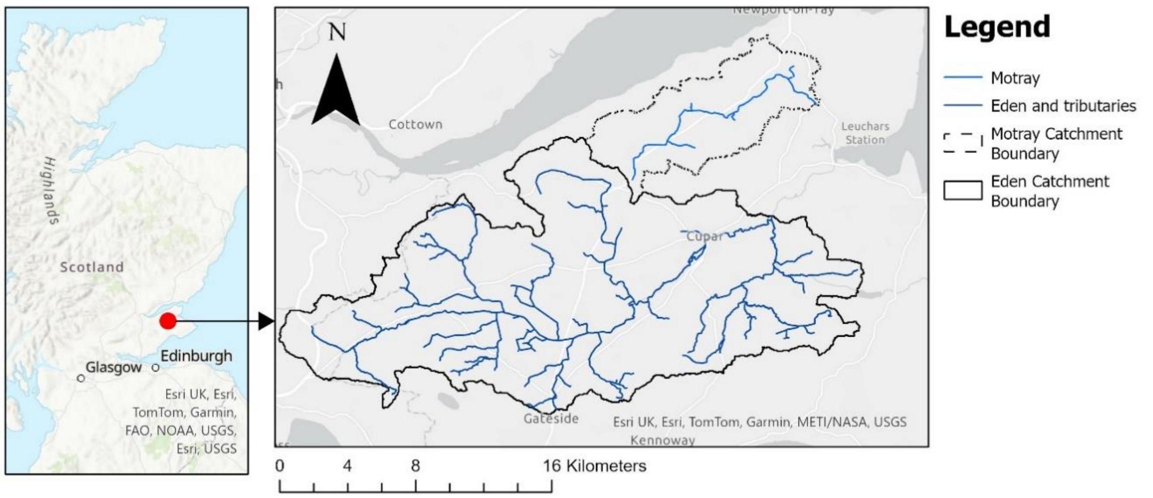



Figure 1: Map of the Motray and Eden catchments. Map created in ArcGIS Pro 3.5.0 (Esri Inc, 2022) using catchment boundaries provided by the National River Flow Archive (Copyright UKCEH, 2024). River network provided by the EU-Hydro River Network database (Gallaun et al., 2019))

Both the Eden and Motray Water catchments share similar gently sloping and low-lying topography (Image 1). Both catchments have areas of steeper sloping hills, including the Lomond Hills to the south of the Eden catchment. Agriculture is the main land use in both catchments, with arable crops, vegetables and fruit grown on the low-lying floodplains and hill slopes. Livestock farming and forestry are also present in both catchments. Of particular agricultural interest is the Howe of Fife in the Eden catchment. Once a landscape home to large lochs, including the Rossie Loch, the Howe was drained from the 17$^{th}$ century, leaving behind fertile soils supported by fluvio-glacial sands and gravels (McEwen et al., 2021), which are utilised for agricultural production. Straightening, realignment and embankment works have historically been carried out on both rivers (The Forth Rivers Trust, 2024), while weirs used to support historic water mills and navigation are still present.

The geology, climate and natural environment in both catchments support agricultural production. Maintaining a healthy natural environment, particularly the water environment, can underpin its value to rural economies and the social value of food production. Fertile soils and harnessed water are two examples of natural factors that support crop and grassland production, both of which aid livestock production.

Image 1: Typical landscape topography if the catchments, with rolling hills transitioning into lowland floodplains

## 1.2. Current and future catchment challenges

Crop, water and soil interactions are critical factors for crop growth, with healthy soils holding water for crop root absorption (Abdallah et al., 2021). Too much water can lead to soil waterlogging, preventing access for field preparation and planting, and increased surface run-off can lead to soil and nutrient loss, resulting in reduced crop yields (Kaur et al., 2020). In contrast, not enough water results in limited crop water uptake, which, if it occurs during key growth periods, can lead to crop failure (Dietz et al., 2021). Irrigation using either surface or groundwater sources can supplement crop water demands, and is practised in both catchments, but is mainly economically viable for vegetable and fruit crops, such as potatoes.

A range of water-related challenges impact landowners and the wider local community in both catchments. Due to changes in climatic conditions, the frequency of high-intensity rainfall events and the frequency and duration of drought conditions are increasing. These changes have implications for flood risk, drought and the ecological status of the water environment, leading to negative environmental, economic and social impacts.

### 1.2.1. Flood Risk

Flooding is a current issue in the Eden catchment, with Storm Gerrit in December 2023 leading to the flooding of neighbourhoods and residents' homes in Cupar (Fife Council, 2025) and across the Eden catchment. Rainfall persisted into the Winter and Spring of 2024, resulting in field waterlogging, limiting access for crop planting and instances of field soil erosion. A summary of climate trends and extremes for Scotland produced by Rivington et al., (2023), projects that the number of Very Wet Days – the number of precipitation events within the 5% largest precipitation events for a given month – will increase in January and February. Increased very wet days will not only have consequences for field saturation but will also increase surface water flows and local flood risk. A strategic flood risk assessment for Fife produced by Jeremy Benn Associates (2024), provides the potential people, homes and businesses at risk in the Eden catchment now and in the future (2080s), based on the Local Flood Risk Management Plan for the Tay Estuary and Montrose Basin. The statistics from the assessment are provided in Table 1 and indicate the extent of flood risk in the Eden catchment.

Table 1: Potentially vulnerable people, homes and businesses, now and in the future in the Eden catchment (Jeremy Benn Associates, 2024).

| **Potentially Vulnerable Area** | **Number of people and properties at risk (present day)** | **Number of people and properties at risk (2080's)** |
|---|---|---|
| Pitscottie and Kemback | 110 people; 70 homes and businesses | 120 people; 80 homes and businesses |
| Ceres | 20 people; 10 homes and businesses | 30 people; 15 homes and businesses |
| Cupar | 1,000 people; 680 homes and businesses | 1,300 people; 830 homes and businesses |
| Springfield | 80 people; 40 homes and businesses | No expected increase |
| Kingskettle and Kettlebridge | 80 people; 40 homes and businesses | 100 people; 50 homes and businesses |
| Dunshalt | 80 people; 60 homes and businesses | 110 people; 80 homes and businesses |
| Auchtermuchty | 260 people; 160 homes and businesses | 270 people; 170 homes and businesses |

### 1.2.2. Water Scarcity

Water scarcity is a current issue that's projected to worsen in the future. The Eden catchment has experienced significant historical droughts, including the summer drought of 1984, which led to the introduction of hosepipe bans (McEwen et al., 2021). More recently, during the summer of 2022, the Scottish Environment Protection Agency (SEPA) introduced a temporary surface water agricultural abstraction suspension due to a significant water scarcity event (BBC, 2022). Significant water scarcity is defined by SEPA as when the five-day mean flow at a river gauging station has been below the Q95 flow for 30 or more consecutive days (SEPA, 2025).

Glendell et al. (2024) provide a review of future projections for drought conditions in Scotland and their implications for the agricultural sector. The review indicates the frequency of drought events in the Eden catchment will change from one in every 5 years to one in every year by 2050 (Naha et al., 2025), risking further abstraction bans that could have significant impacts on farmers who rely on abstraction for irrigation. The report also indicates increased water deficits in climatic water balance – when evapotranspiration is greater than precipitation – from April to October, which is a risk for rainfed arable crops and grassland.

### 1.2.3. Ecological Status

The Scottish Environment Protection Agency (SEPA) provides an up-to-date ecological status classification of Scotland's surface waters in Scotland's Water Environment Hub. Ecological status is monitored and classified by SEPA for over 100 parameters across hydrological, ecological, chemical and hydromorphological indicators. The overall classification accounts for the combination of different parameter classifications.

As of 2023, the Motray Water catchment is classified as being in poor ecological status. The Eden catchment is divided into two main stretches of the River Eden and eight tributaries. The lower Eden, upper Eden, Ceres Burn, Craighall Burn, Fernie Burn, Kettle Burn, the Laprig Burn, and the Ballingall Burn are all classified as moderate ecological status, while the Foodieash Burn and Glassart Burn are classified as poor ecological status. Pressures described in the Water Environment Hub for each of the waterbodies are detailed in Table 2**.**

Table 2: The latest ecological status classification for waterbodies in the Eden and Motray catchments and their associated pressures.

| **Waterbody (ID)** | **Ecological Status (2023)** | **Pressures** |
|---|---|---|
| Motray Water (6102) | Poor | Invertebrate animals, macroinvertebrates, fish barriers, morphology and low lows. High status for reactive phosphorus and other water quality parameters, however, water quality status is determined as moderate. Freedom from Invasive species status 'high' |
| Lower Eden (6200) | Moderate | Reactive phosphorus, invertebrate animals and macroinvertebrates, invasive species (crayfish), phytobenthos, morphology and low flows. |
| Upper Eden (6201) | Moderate | Reactive phosphorus, phytobenthos and morphology. |
| Ceres Burn (6202) | Moderate | Invertebrate animals, macroinvertebrates, phytobenthos and morphology |
| Craighall Burn (6204) | Moderate | Morphology |
| Foodieash Burn (6205) | Poor | Reactive phosphorus, invertebrate animals and macroinvertebrates, morphology. |
| Fernie Burn (6206) | Moderate | Invasive species, phytobenthos and morphology |
| Kettle Burn (6209) | Moderate | Invertebrate animals and macroinvertebrates, morphology, high and low flows and invasive species |
| Laprig Burn (6211) | Moderate | Morphology |
| Glassart Burn (6212) | Poor | Fish barrier and morphology |
| Ballingall Burn (6213) | Moderate | Low flows and morphology |

The range of different pressures demonstrates the complexity of issues in the catchment. Reactive phosphorus is the key water quality pressure, particularly in watercourses in the Eden catchment. Sources of phosphorus include diffuse agricultural sources from crop nutrient application, diffuse private septic tanks and point sources from wastewater treatment works. Phosphorus loads to watercourses are projected to increase in the future due to increased run-off due to higher intensity rainfall events and increased wastewater loads from growing populations in areas such as Cupar, while concentrations will increase during periods of river low flows as diluting effects are reduced (Adams et al., 2024)

Figure 2 represents estimations of median reactive phosphorus (RP) (kg/day) from different source loads in the Lower Eden sub-catchment (6200) now and in the future to 2050. The estimations for arable and pasture RP loads (kg/day) are derived from the Phosphorus and Sediment Yield Characterisation In Catchments (PSYCHIC) model (Davison et al., 2008) used by SEPA to determine the current kg/day loads across different land cover types as part of their Source Apportionment-GIS tool (SAGIS) (SEPA, 2016). Diffuse sources include arable and pasture, where activities such as fertiliser application lead to RP entering waterbodies after rainfall events. Arable and pasture RP loads are derived by taking the load per hectare (ha) (kg/ha/day), which is summed for the total hectares in the 6200 Lower Eden sub-catchment. It's important to note that reactive phosphorus accounts for only a small proportion of the total phosphorus applied as fertiliser. For septic tanks, RP loads for each tank per day are summed by the total number of septic tanks in the sub-catchment. Wastewater RP loads are derived from RP effluent concentrations (milligram per litre) and daily effluent flows (litres per day), which are summed for all wastewater treatment works in the sub-catchment. The future estimations account for projected changes in climate, population and land cover change to 2050 (Adams et al., 2023).

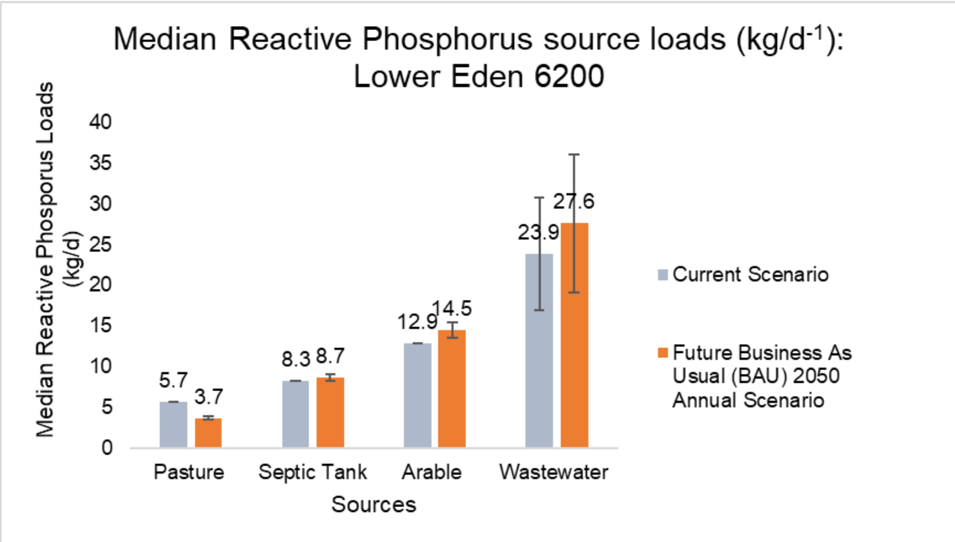



Figure 2: Median reactive phosphorus loads (kg/day) in the lower Eden sub-catchment (6200) now and in the future for different source loads from (Adams et al., 2024).

All waterbodies fail to achieve good status for morphology due to the historical channelisation, realignment and embankment works. While effective for land drainage, the modifications mean waterbodies don't follow their natural course, or their erosion and deposition processes. The current morphology is described as having a negative influence on other parameters, including river bank erosion, biodiversity loss and flooding (The Forth Rivers Trust, 2024). The combination of water quality, morphological and invasive species pressures will result in negative impacts on invertebrates and macroinvertebrates, which is a regular pressure across the catchment waterbodies.

Between May and September of 2024, The Forth Rivers Trust (2024), in collaboration with the River Eden Sustainability Partnership, surveyed riparian habitats and invasive non-native species (INNS) in the River Eden and Motray Water catchments. The survey extended 200 km of the main Eden and Motray reaches, up to 250m up every tributary in the catchments, and a further 15 km of inaccessible riverbank surveyed by drone. A significant presence of Himalayan Balsam, Giant Hogweed, Japanese Knotweed and Few-flowered Leek was identified. The spread of INNS, the habitat survey, and pressures and opportunities are captured in a ArcGIS Storymap.

To complement the habitat and INNS survey, the River Eden Sustainability Partnership collaborated with Buglife to conduct a species-level survey of benthic macroinvertebrates in six locations on the River Eden in May and October of 2024 (Macadam et al., 2025). Benthic macroinvertebrates live on, in or near the bottom of waterbodies and are considered indicators of water quality (Medupin, 2019). The survey conducted by Buglife indicated that the observed abundance and total number of invertebrates were generally lower than expected, which may be a result of poor water quality, sedimentation, pesticides and increased water temperature.

## 1.3. Project Background

Given the multiple water-related pressures in the study area, the River Eden Sustainability Partnership (RESP) was established in 2022 by local residents motivated to improve water conditions through a coordinated source-to-sea approach. The vision for the partnership is a restored river corridor, rich in biodiversity, free from invasive non-native species, resilient to climate change and connected to the community for well-being and economic benefit.

Since its establishment, the River Eden Sustainability Partnership have utilised the previously mentioned INNS, habitat and benthic macroinvertebrate surveys to provide a baseline of conditions in the Eden and Motray catchments that provide a baseline to support the monitoring of any restoration work that is undertaken in the future. Further, the partnership has provided training to local volunteers in citizen science approaches to continue monitoring the water quality and ecology in the catchments, and manage INNS in the future (Sustianable Cupar, 2025).

The vision recognises the need for management action to balance local environmental, social and economic benefits. For the partnership to achieve its vision and implement sustainable and balanced management options, acceptance and collaboration with local landowners are critical. Landowners have an understanding of the water issues and flows on their land, and can both implement management practices and allow access for management. Importantly, landowners can also help ensure that management options are not only beneficial for nature and society but also support the important agricultural sector that supports the local economy, community and culture. The partnership has conducted a series of events since its inception that aim to bring the local community, including landowners, together to discuss how to effectively address water-related issues in the catchments, including a landowner event attended by 120 people, of which 70 were local landowners. To further support engagement with landowners, the partnership worked with Alison Hannah Ecology to map landownership in the catchments. The landowner mapping exercise identified over 400 landowners in the Eden catchment and over 40 in the Motray. Our project will build on the landowner mapping and engagement conducted to understand landowner views on water-related issues and management in the Eden and Motray catchments.

### 1.3.1. Project Aim

To deliver stakeholder engagement activities to gather local landowner perspectives and expertise to facilitate the identification of water management projects in the Eden and Motray Water catchments to support the RESP vision.

### 1.3.2. Project Objectives

The following objectives will be addressed to achieve the aim:

- To collate and communicate the current water-related evidence base for the Eden and Motray Water catchments with local stakeholders.

- To gain the perspectives and knowledge of local stakeholders regarding ongoing and future water management in the catchments.
- To identify feasible water management projects to support the development of a catchment plan and prioritised delivery strategy for RESP.

## 2. Method Overview

To achieve the aim and objectives of the project, we conducted the following mixed methods approach, which is summarised in Figure 3:

- A rapid evidence review of both academic and grey literature to identify evidence related to current water-related challenges in the catchments, and to identify evidence for the effectiveness of potential management options. Much of the evidence has been presented in the introductory section of this report, while the management options are presented in Section 4; Table 3.
- The research team attended two RESP landowner meetings in each catchment to introduce the project to landowners and gain their perspectives on water-related issues and management approaches in the catchments.
- Field visits with landowners were conducted to gain a nuanced understanding of water-related issues in the catchment, the impacts they have on landowners, their businesses and local communities, the water management options they have already adopted and their willingness to adopt further water management practices. Management practices discussed were added to those identified during the rapid literature review. Attendance at the RESP landowner meeting supported field visit recruitment.
- A workshop with landowners and wider local actors, including the local authority, environmental protection agency, local NGOs and nature capital investors, to discuss barriers and opportunities for the resourcing, implementation, governance and monitoring of identified water management practices.

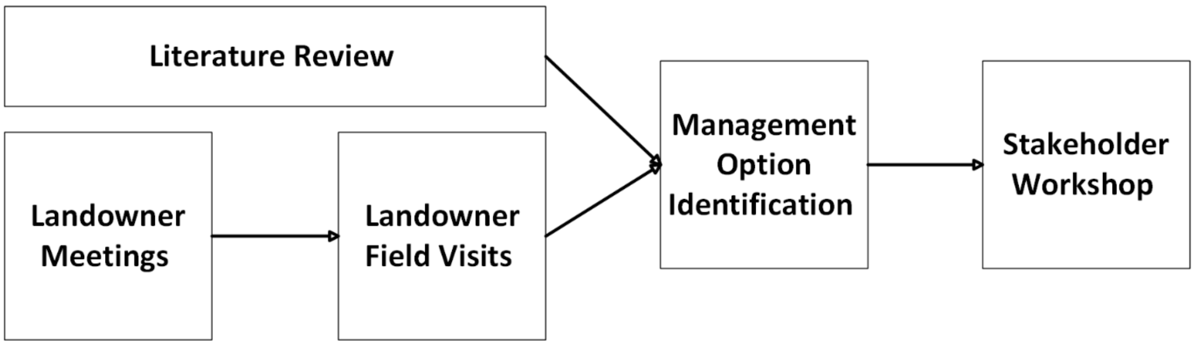



Figure 3: Overview of methods used to engage with landowners and local stakeholders.

## 3. Landowner Field Visits

Between February and May of 2025, we conducted a total of eight landowner visits; three in the Motray catchment and five in the Eden catchment (Figure 4). During each visit, landowners were asked to describe water-related issues on both their land and the wider catchment. Management actions to address identified issues were discussed, including actions already taken by landowners, to inform the identification of feasible projects that deliver restoration opportunities while sustaining agricultural practices.

The following sub-sections provide an overview of the landowner visits, and the water management recommendations made. The site visit summaries highlight the diversity of the water-related challenges landowners face, the management practices already being implemented and the range of further water-management opportunities that could be implemented. The field visits are a first opportunity to conceptualise potential water management opportunities and present ideas for discussion. Additional work would be required to produce detailed designs for implementation, for example, to inform appropriate placements and sizing. A description of the management options discussed can be found in Section 4; Table 3.

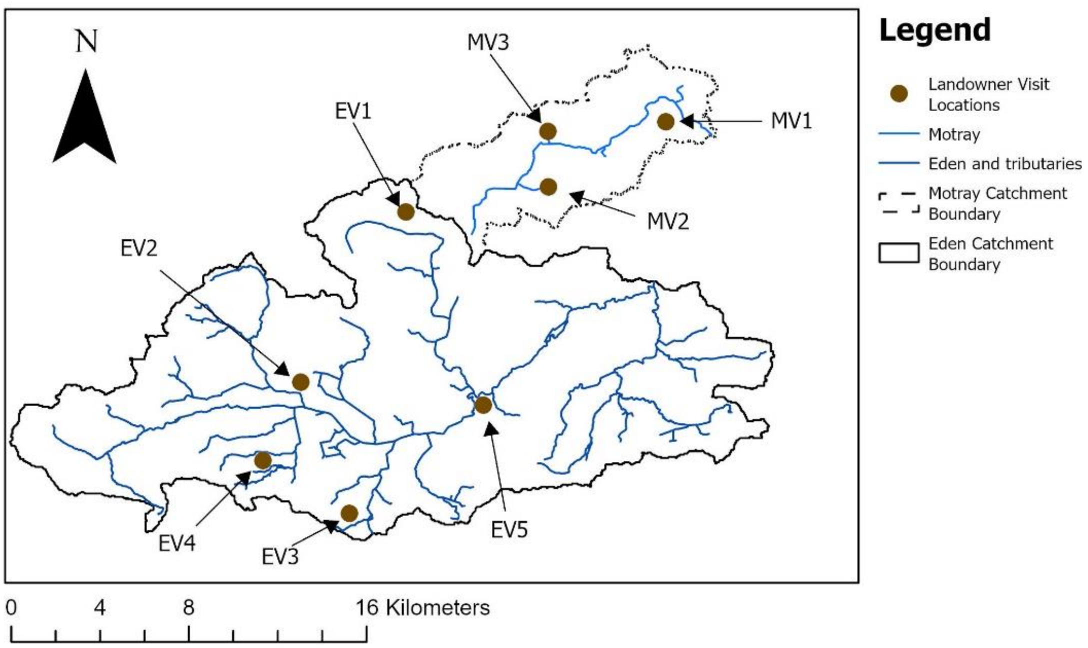



Figure 4: Location of landowner visits in the Motray (MV) and Eden (EV) catchments. Map created in ArcGIS Pro 3.5.0 (Esri Inc, 2022) using catchment boundaries provided by the National River Flow Archive (Copyright UKCEH, 2025). River network provided by the EU-Hydro River Network database (Gallaun, 2019).

## 3.1. Motray Visit 1 (MV1) – 5 February, 2025

The site of the first Motray visit (Figure 5) was a mixed agricultural enterprise comprising of sheep, arable production and vegetable production. The area of interest was 363 hectares. The landowner described ongoing water and soil management practices, including the use of cover crops to improve soil health and reduce surface water runoff, and utilising sheep to graze early arable crop growth in short periods to reduce crop fungal issues and provide natural nutrient application. Land, including wooded areas, is used to store and attenuate water during high-intensity rainfall events to prevent flooding in lowland areas.


Figure 5: Motray visit 1 location area of interest (yellow). Map created using Google Earth (2025). Data attribution: AirbusData SIO, NOAA, U.S. Navy, NGA, GEBCO

Despite the previously mentioned water management, high-intensity rainfall conditions and the prolonged rainfall period during the winter of 2023 resulted in soil erosion and extensive flooding on the farm. The zone of water management interest is to the southwest of the farm buildings and highlighted in red. (Figure 6).


Figure 6: Area of soil erosion and flooding issues of interest (red). Map created using Google Earth (2025). Data attribution: AirbusData SIO, NOAA, U.S. Navy, NGA, GEBCO

Flow pathways developed for the area indicate how water flows from higher ground, where soil erosion occurs, during high rainfall events, down to the upslope area with pathway contributions from the east (Figure 7).

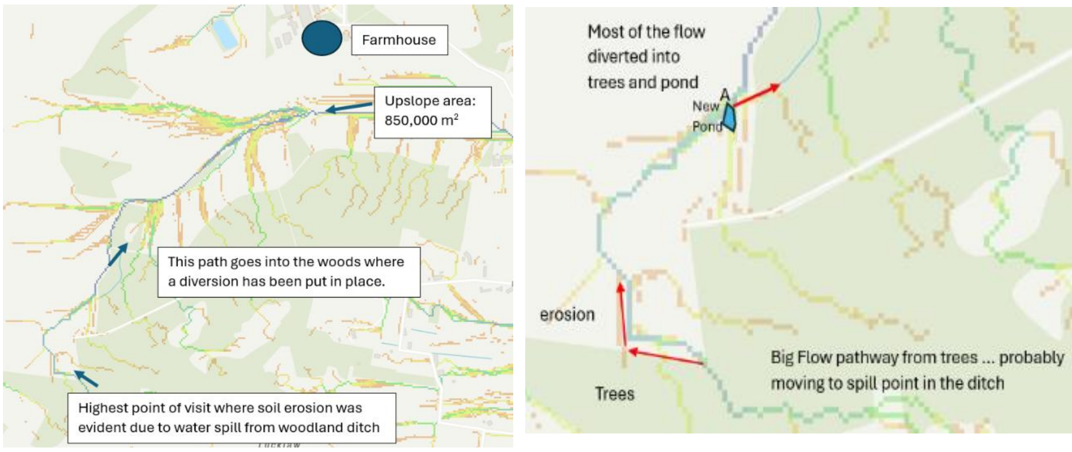



Figure 7: Overview of flow pathways in the area of concern. Map created in ArcGIS Pro 3.5.0 (Esri Inc, 2022) using LiDAR data from the Scottish Government (2022) Remote Sensing Portal using a 2m digital elevation model, resampled to 4m grid resolution for flow accumulation analysis.

Slowing the flow along selected flow pathways in the steeper gradients can be achieved with bunds and small ponds (scrapes), measures also known as temporary storage areas (TSAs) (Roberts et al., 2023b). The priority is to divert water into the woodland area in a natural hollow at the field edge (Figure 8), using a bund at the top of the field to prevent soil erosion. Temporarily storing water can also provide benefits for reducing nutrient losses (Djodjic et al., 2025). A good-sized 'new pond' would be possible where there is a slight depression in the land, with outflow into the wooded area (Figure 8). The pond would attenuate flow and capture any sediment from the field before entering the woodland. Leaky dams (LDs) (or leaky barriers) can be placed along flow pathways in the wooded area (Figure 8) to slow flows (Quinn et al., 2022).

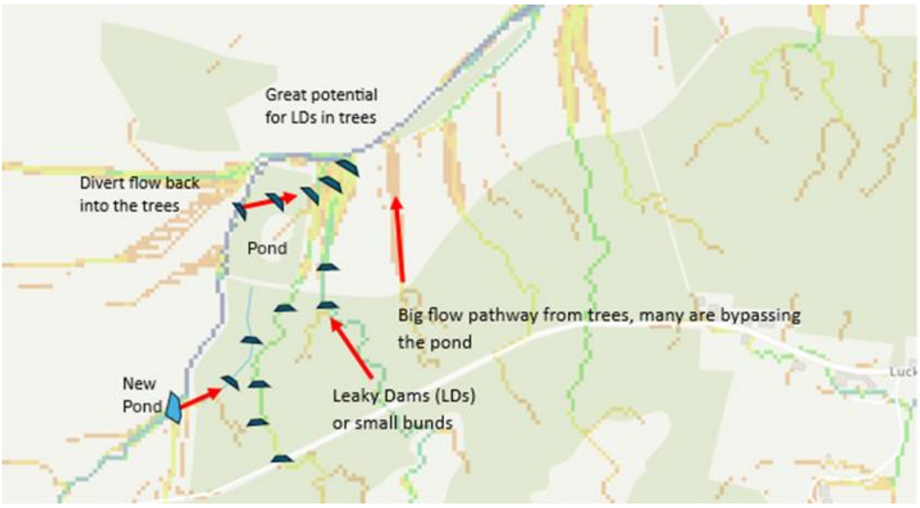



Figure 8: Overview of water management options in the upper areas of the land to attenuate water and reduce soil erosion. Map created in ArcGIS Pro 3.5.0 (Esri Inc, 2022) using LiDAR data from the Scottish Government (2022) Remote Sensing Portal using a 2m digital elevation model, resampled to 4m grid resolution for flow accumulation analysis.

Bunds, ponds and leaky barriers are recommended in the hollow of the field below the woodland (Figure 9). There are multiple options as to how this area could be utilised. Option A would be small check dams used for slowing flow and trapping sediment (Figure 10). Option B is a magic margin (Farm Advisory Service (a), 2025) 6-12m wide with potato furrows to provide an infiltration zone with shrubs and/or hedgerow in the middle (Figure 11). A pond could be added to the woodland below, utilising fallen trees in this area to create more leaky dams.


Figure 9: Overview of water management options for infield pathways. Map created in ArcGIS Pro 3.5.0 (Esri Inc, 2022) using LiDAR data from the Scottish Government (2022) Remote Sensing Portal using a 2m digital elevation model, resampled to 4m grid resolution for flow

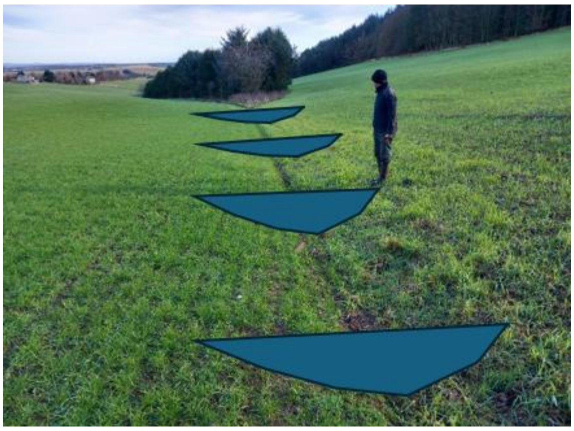


Figure 10: Option A – small check dams

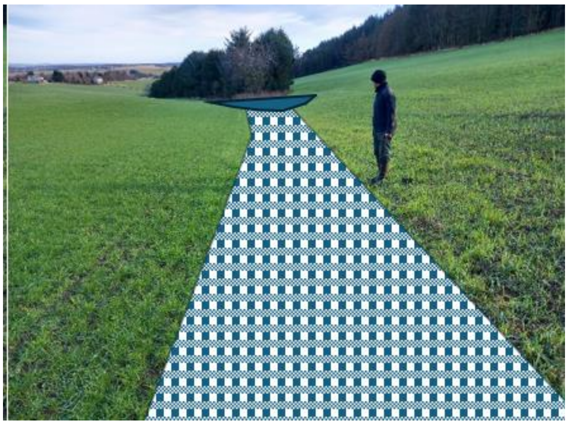


Figure 11: Option B – area for magic margins

Further check dams or ponds are recommended beyond the wooded area in the lower areas of the field, where joining flow pathways are contributing to the flooding zone (Figure 9; Figure 12). These temporary ponds would have little effect on crop yields, possibly increasing yields due to trapped sediment and nutrients. For the flooded zone, a conveyance channel, with a bund edge is recommended to restrict the volume of flooding. It’s assumed that previously suggested water attenuation features will have already slowed the water flow to this area.

Upon visiting the areas of the land to the North of the site, a visual assessment indicated that the site could buried in highly permeable glacial sand (and maybe gravels), with little evidence of any surface flow. Potentially, there is still a lot of water, but possibly underground. This does mean that it may contain dissolved phosphate and nitrate. There is little potential for nature-based solution (NBS) features here, but care on nutrient application rates is needed, as most of what is going into the soil may well be coming out quickly into the nearby Motray. The use of cover crops, soil testing and the practice of using natural fertilisers where possible suggest nutrient care is taken by the landowner.

Figure 12: Water attenuation recommendations in the lower field.

## 3.2. Motray Visit (MV2) – 5 February, 2025

The location of the second Motray visit is a smallholding surrounded by sheep-grazed land (Figure 13). The area of interest was approximately 32 hectares. The landowner was keen to increase habitat and biodiversity on the farm through water management. An understanding of where the property's septic tank is draining and the impact this may have on the Lochmaloney Burn, which flows east along the south of the property, was also a priority.


Figure 13: Motray visit 2 location. Map created using Google Earth (2025). Data attribution: AirbusData SIO, NOAA, U.S. Navy, NGA, GEBCO

The property is surrounded by small pockets of broadleaved woodland. An array of songbirds were present during the visit, along with sightings of a bird of prey and deer. Potential management options target the riparian area to the South of the house and gardens (Figure 14).

There are several management options, but they follow the basic option of creating an engineered buffer zone with water-holding potential and the ability to spread and clean the flow using leaky dams (LDs in Figure 14). The options to create a zone of wet woodland would seem best, with the lower end of the property already functioning as a wet woodland. Planting more woodland in wet woodland area would further increase water-holding potential. Flow pathways show a zone of water concentration entering the burn. The network of leaky dams will disperse this flow and create an expanded riparian zone at the bottom of the field, allowing for an expanded wet wooded zone (Figure 15).

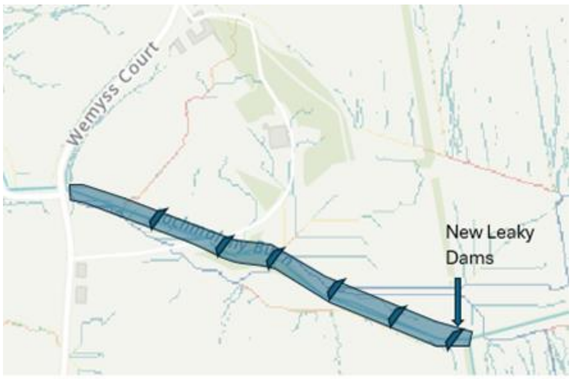



Figure 15: Phase 1 area (blue) introduction of leaky dams (LDs; orange). Map created in ArcGIS Pro 3.5.0 (Esri Inc, 2022) using LiDAR data from the Scottish Government (2022) Remote Sensing Portal using a 2m digital elevation model, resampled to 4m grid resolution for flow accumulation analysis.

Figure 14: Area where riparian zone would be created with leaky dam (LD) introduction (green)

The expanded riparian zone will not only increase water holding potential but could also increase habitat on the holding. The new wet woodland zone can be 10-20m across, depending on landowner preference. A previously used zone for watering animals, resulting in watercourse poaching, was observed. Poaching can have negative impacts on water quality through the introduction of bacteria from animals, as well as sediment and nutrients from soil erosion (and reduced infiltration leading to surface run-off). Further information and guidance on poaching is provided by Farming and Water

Scotland (n.d). The poached area will easily be subsumed into the proposed wet woodland would be fenced, addressing the issues and allowing for natural regeneration of the area.

Within the wet woodland, a small obstruction to flow was noted and removal is recommended. A bund on the outside edge of the wet woodland would reduce the propagation of flood flow onto the wider floodplain. A smaller channel within the wet woodland would also help disperse and calm the flow.

A floodplain is already evident near the road leading to the property. The area is already 70% on the way to being a wet woodland. The new leaky dam would replace the current obstruction in this area to back up flow. The zone needs planting with more trees. New trees, such as willow, could go along the front of the leaky dam to turn it into a living barrier (Figure 16).

Figure 16: Proposed leaky dam in wet woodland (orange).

To address concerns regarding septic tank sources to Lochmaloney Burn, we recommend conducting a conductivity test and water quality assessment along the burn to locate the outfall. Once the outfall has been determined, upstream and downstream water quality tests can be taken. The River Eden Sustainability Partnership have testing kits available, and Lochmaloney Burn would be an ideal location for training citizen scientists in water quality testing.

### 3.3. Motray Visit 3 (MV3) – 14 March, 2025

The third Motray visit was to an approximately 385 hectare farm comprised mainly of arable and vegetable crops towards the north of the Motray catchment (Figure 17). Two main watercourses from both a north-westerly and north-easterly direction join and flow southbound to the Motray Water (Figure 18).

On the north-westerly burn, there was evidence of the non-native invasive species, Giant Hogweed (*Heracleum mantegazzianum),* which was the main water-related issue identified by the landowner (Figure 18; Image 3). Giant Hogweed outcompete native riparian vegetation, reducing bank stabilisation and increasing erosion risk (Animal and Plant Health Agency, 2018).


Figure 17: Motray visit 3 location. Map created using Google Earth (2025). Data attribution: AirbusData SIO, NOAA, U.S. Navy, NGA, GEBCO

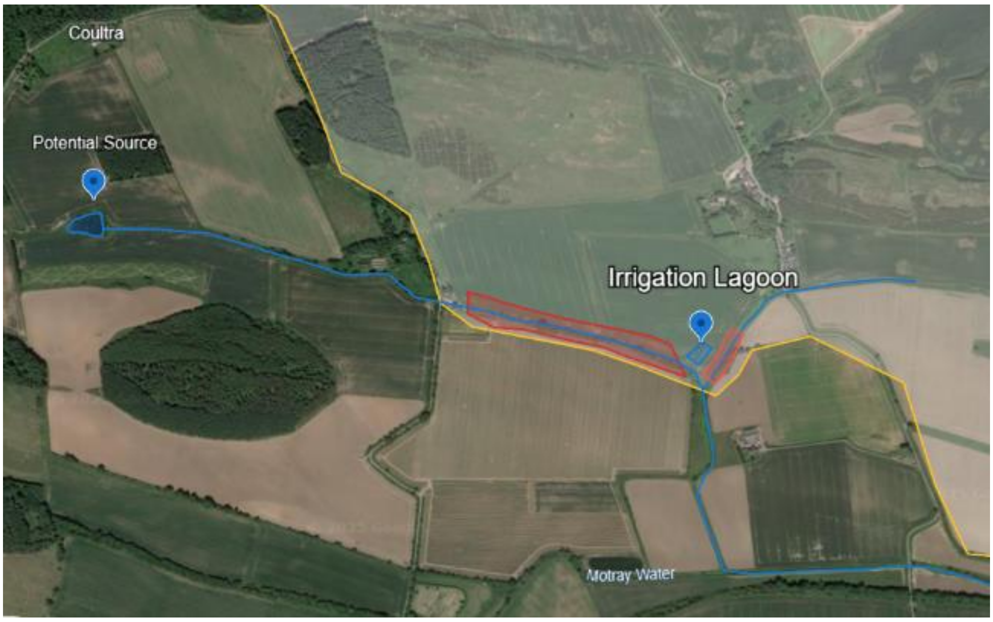



Figure 18: Area of Giant Hogweed issues (red) along each burn (blue lines) with potential source area identified. Map created using Google Earth (2025). Data attribution: AirbusData SIO, NOAA, U.S. Navy, NGA, GEBCO.

The landowner believes the source of the Giant Hogweed could have spread from a pond approximately 600m upstream (northwest) of the visited stretch and is now starting to spread towards the north-easterly burn where it flows around an irrigation lagoon. The issue hasn't spread beyond the identified areas towards the Motray water, however, there is a possibility if the issue isn't managed.

Attempts have been made to manage the issue, however, as a persistent species, re-emergence occurred the following year. It was noted during the visit that the density of Giant Hogweed was lower in areas shared by trees or other vegetation, supporting previous findings that Giant Hogweed prefer full sunlight or partial shade conditions, and growth often doesn't occur in deeply shaded areas (Gucker et al., 2009). Increasing riparian shading, particularly in upper reaches, could be part of a long-term solution for reducing Giant Hogweed prevalence.

Image 2: Giant Hogweed on north-westerly burn. Stand from the previous year and new growth is evident.

Further actions discussed during the visits included the guidance provided by the Scottish Invasive Species Initiative (n.d.), including herbicide application (March-July), cutting flowerheads (prior to seeing) and sheep grazing. The application of herbicides could have negative impacts on water quality, cutting flowerheads was seen as labour intensive and sheep grazing was not an option due to poaching risks and the inability to control sheep migration.

The most viable option discussed was digging and cutting roots, a measure also recommended by the Scottish Invasive Species Initiative. Roots must be cut 15cm below ground level and could be achieved by a recommendation proposed by the landowner to plough the area and plant natural vegetation. The Animal and Plant Health Agency (APHA) recommend deep ploughing (up to 24cm) as a highly effective management tool (Animal and Plant Health Agency, 2018) for managing Giant Hogweed, as it cuts the root and buries seeds to depths that limit re-emergence. Ploughing methods should be carried out in the autumn before seeding and when colder temperatures will degrade roots. It's important to highlight that care must be taken when managing Giant Hogweed, as the sap from the roots causes the skin to burn. When using machinery, any equipment used must be cleaned to avoid the spread to other areas of the farm.

After ploughing, the landowner could consider planting grasses and legumes such as clovers or bird's-foot trefoil in the field water margin, and riparian trees such as willow to prevent re-establishment and increase shading. Additional benefits of creating a species-rich margin include increased pollination, reducing diffuse pollution, slowing the flow of water and increasing bank stabilisation and soil structure (Forestry Research, 2024, Nadiu Tushaani et al., n.d.)

Any areas that can't be managed via ploughing would need to be managed by manual digging using a spade cut (15-20 cm below ground) to sever and dig out the top 15cm of the root in early spring. Manual digging increases the risk of sap skin burns, so appropriate invasive species management consents and health and safety measures should be considered. Stopping the spread from the upstream source, and continued monitoring of the impact that management measures are having on reducing re-establishment are urgently required. Collaboration with the River Eden Sustainability Partnership can be established to support manual digging and monitoring of the site.

The landowner demonstrated an irrigation lagoon that has been constructed to increase resilience to water scarcity (Image 4). In 2022, water abstractions were restricted in the neighbouring Eden catchment due to significant surface water low flows. Restrictions can lead to the failure of crops reliant on irrigation. Storing water in irrigation lagoons during periods of higher rainfall and surface water flows provides a source of water during scarcity events, increasing the resilience of crop production.

Image 3: Irrigation lagoon used to increase resilience to water scarcity.

The irrigation lagoon is placed in the bottom west side corner of the field edge and is filled by abstracting water from both burns. With water gravity-fed from the bed of north-easterly flowing burn, management controls should be put in place to ensure water isn't abstracted from below baseflow conditions, otherwise the burn could run dry and impact local hydrology and ecology.

The field where the lagoon is placed has a steep gradient, creating a potential issue for nutrient and sediment run-off. There is opportunity to capture field water run-off, and reduce the risk of sediment and nutrient inputs to the lagoon. Excessive nutrient inputs could lead to algal growth, which can block pumps and, in extreme cases, produce toxins harmful to humans, particularly if used to irrigate crops.

Options to reduce nutrient loads to the irrigation lagoons include the use of vegetated embankments and margins between the field and the lagoon. Increasing tree cover surrounding the lagoon could increase shading, reduce water temperature and limit algal growth. Sediment traps at the edge of the lagoon can be applied to reduce sedimentation. Allowing vegetation to colonise can remove nutrients from the water, while floating solar panels could increase shading while providing a source of energy for pumping (Kent County Council, n.d.).

### 3.4. Eden Visit 1 (EV1) – 6 February, 2025

The location of the first Eden visit sits below Normans Law, in the north of the Eden catchment (Figure 19). The area of interest is approximately 30 hectares. Two burns flow within the site, one from the North and the other from the Northwest. The two burns join to flow South, feeding into the Fernie Burn, joining the Eden near Pitlessie (Figure 20). The land falls within the Nitrate Vulnerable Zone (NVZ), which are areas designated at risk from agricultural nitrate pollution.

Figure 19: Eden Visit 1 location. Map created using Google Earth (2025). Data attribution: AirbusData SIO, NOAA, U.S. Navy, NGA, GEBCO

Cattle and sheep farming is the main practice on the farm and grassland is grown on two fields to the west of the farm to produce hay for livestock. Practices are below stocking density and nitrate application levels are below requirements for the NVZ. The property was teeming with wildlife, particularly songbirds.

The main concern for the landowner is that during high flows, the burns flood the road, causing damage. The potential for flooding the cottages to the south was also a concern. The burn runs dry in the summer.

Figure 20: Areas of significance on the site, including burn (blue), woodland areas (orange), riparian zone (green) and area of flooding concern (red). Map created using Google Earth (2025). Data attribution: AirbusData SIO, NOAA, U.S. Navy, NGA, GEBCO.

The burn from the Northeast runs from a spring located in a woodland created by the landowner (Figure 20). The spring is used for drinking water and for filling cattle troughs. The burn follows west along a treeline past a private house before running south towards a woodland area, which is saturated surrounding the burn as the land levels off, creating a wet woodland. The wet woodland is fenced off, and waterlogging was described along the fence line, which matches the flow pathways on the land (Figure 21; Image 5, Image 6). The attenuation of water within the wet woodland can be achieved by diverting water using soil bunds into the wooded area to prevent waterlogging at the field edge.

The burn then continues southwest down a gentle slope through a well-established fenced-off margin, which includes trees planted by the landowner. The banks of the burn are steep towards, in and beyond the bend.

The burn then joins another watercourse running from the north along the roadside. After joining, the burn runs through a property into a dammed pond. Water is then piped under the road and remerges along the roadside, flowing through cottages to the south and another landholding before draining into the Fernie burn. Cottages to the South of the property are where the flood risk is a concern.

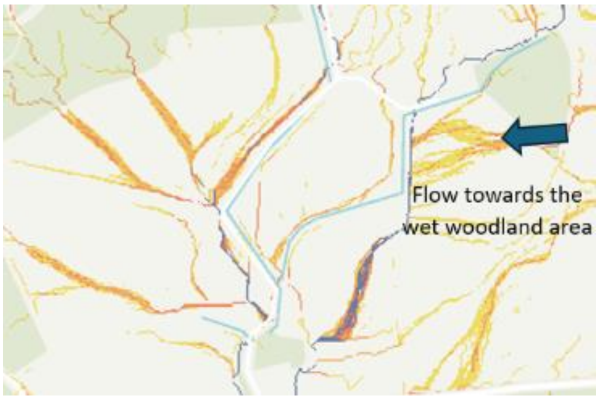



Figure 21: Flows towards wet woodland. Map created in ArcGIS Pro 3.5.0 (Esri Inc, 2022) using LiDAR data from the Scottish Government (2022) Remote Sensing Portal using a 2m digital elevation model, resampled to 4m grid resolution for flow accumulation analysis.

Given the concern for flooding during high-flow events, leaky dams were discussed as a recommended option for attenuating flow. Leaky dams are an option given steep-sided slopes within the fenced-off margin (Figure 22). Concerns regarding the potential for leaky dams to cause flooding beyond the margins were raised by the landowner, as well as the potential for sediment build-up behind the barriers. Given the size of the margin (Image 7), flooding beyond these margins should not occur, however, monitoring would be recommended. Further, additional tree and shrub planting is encouraged along the margin, which would provide a habitat corridor across the field, connecting the pond and the created woodland.

Image 5: Potential wet woodland area at the bottom of the flow pathway

Image 4: Saturated area surrounding the burn, with burn pathway arrows provided.

Enhancing the wet woodland area and introducing a series of leaky dams will increase the attention of flows and reduce the risk of flooding downstream. Both measures are considered TSA's, as mentioned in recommendations for previous visits.


Figure 22: Potential placement of leaky dams (orange) to slow the flow downstream. Map created using Google Earth (2025). Data attribution: AirbusData SIO, NOAA, U.S. Navy, NGA, GEBCO

Image 6: Riparian zone where leaky dams can be placed and increased tree and shrub cover is encouraged.

## 3.5. Eden Visit 2 (EV2) – 10 April 2025

The second Eden visit focused on the prime agricultural area of the catchment in the Howe of Fife, in the low-lying valley of the River Eden (Figure 23). The approximate area considered during the visit was 1,117 hectares and spanned multiple holdings. The land neighbours the Rossie Loch, which was drained as early as 1635 before completion in the early 19th century, to increase agricultural land (Rossie Estate, n.d.). Arable and vegetable crops are now grown on the flat expanse (Image 8), which includes two main ditches that join to form the Rossie drain (Figure 24).


Figure 23: Eden Visit 2 location. Map created using Google Earth (2025). Data attribution: AirbusData SIO, NOAA, U.S. Navy, NGA, GEBCO

Image 7: Drained area in the Howe of Fife, now prime agricultural land.

The Rossie drain then flows to the River Eden near Ladybank. The landowner described previous issues with flooding on the low-lying agricultural land, providing images of extensive flooding during the winter of 2002. Saturated fields in late winter and early spring prevent machinery access for field preparation and planting, an issue experienced across Scotland with the prolonged wet weather in the spring of 2024. Flooding issues in early 2002 led to the creation of a local ditch cleaning group of six local landowners to maintain the Rossie drain and its contributing north and south ditches in 2010.

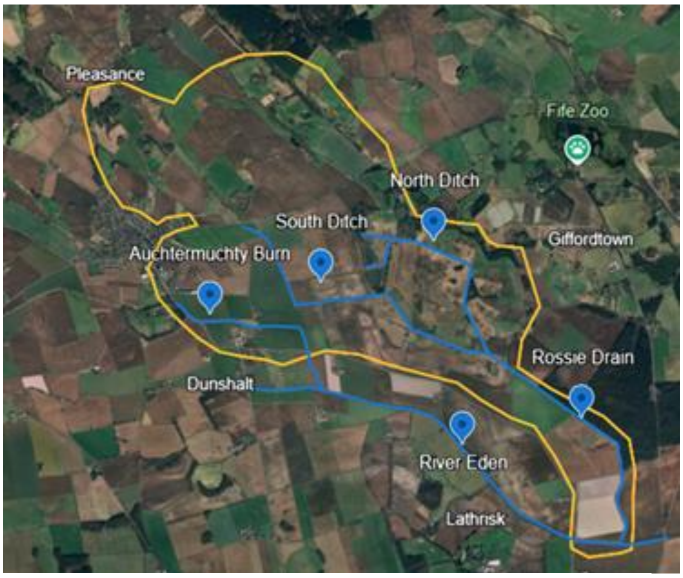



Figure 24: Areas of significance for the site, including labelled ditches, burns and drains (Blue). Map created using Google Earth (2025). Data attribution: AirbusData SIO, NOAA, U.S. Navy, NGA, GEBCO

The landowner believed the lack of ditch maintenance within and downstream of the drainage area was resulting in localised flooding. Increasing rainfall patterns in the area, which is monitored by the landowner, are viewed as another contributing factor. Water backing up downstream of the Eden and higher flows raises the water table, resulting in waterlogging. Ultimately, without maintenance and increasing rainfall, the land attempts to transform to its pre-drained state as the extended Rossie Loch and floodplain of the River Eden.

Clearing ditches of vegetation increases water conveyance, allowing water to move off the land and drain to the River Eden (Image 9), lowering the water table and reducing the risk of waterlogging. Preventing waterlogging reduces soil erosion from surface water runoff, however, vegetated ditches are preferred for reducing downstream flooding and conserving biodiversity (Dollinger et al., 2015). Vegetated and non-vegetated ditches can reduce nutrient loads to receiving waterbodies downstream (Moore et al., 2010), with vegetated ditches being considered more effective at reducing nutrients (Dollinger et al., 2015). Given the benefits and drawbacks of both vegetated and non-vegetated ditches, there is an opportunity to consider hybrid ditch management options.

Image 8: The maintained Rossie Drain

Potential hybrid options include two-staged ditch channels and controlled drainage water management structures. A comparison of traditional trapezoidal cross-section channels and two-stage channels is provided in Figure 25. A two-staged channel is perceived to maintain important drainage within the channel, and increase vegetation for biodiversity and nutrient retention on the channel bench (USDA, 2008). The capital cost to design and implement the two-stage channel would be significant, however, drainage maintenance costs are reduced.

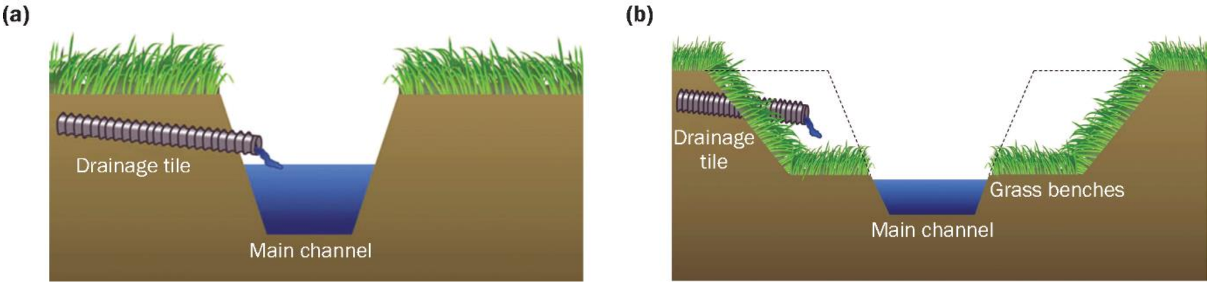



Figure 25: Diagram comparison of a) traditional trapezoidal drainage ditch and b) two-stage channel ditch taken from (Indiana Watershed Initiative, n.d.).

Controlled drainage water management structures allow control of the water table, compared to traditional free-draining systems (Figure 26; (Frankenberger et al., 2006)). Water table control could support in-field and downstream flood-risk control during high-intensity events, periods of prolonged wet weather and periods when drainage is required for field preparation and planting. Further, sub-surface drainage could be controlled to allow water uptake of crops during the growing season and reduce nutrient losses (Helmers et al., 2022). Real-time control options, informed by soil moisture or downstream flow volumes to ensure land can both be drained to support crop production and alleviate downstream flood risk (Blanc et al., 2012).

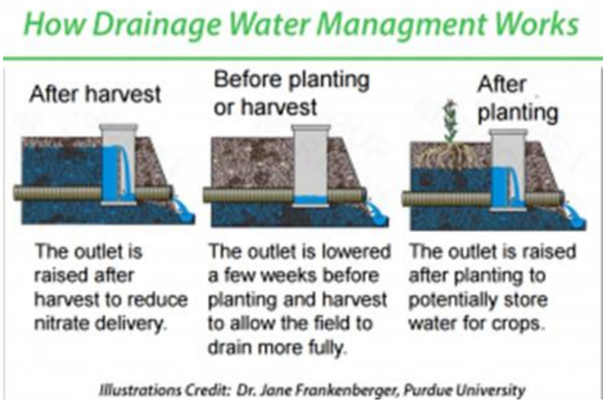



Figure 26: Illustration of controlled drainage provided by (Frankenberger et al., 2006).

The adoption of both measures are limited in Scotland and mainly practised in North America, with the exception of two-stage channels in the River Nith and Pow Burn of the River South Esk (Van, 2023; Esk Rivers & Fisheries Trust, n.d.). A full site investigation and design process would be required, along with conceptual acceptance from the local drainage group, before recommendations are made for both two-stage ditches and controlled drainage. In theory, the approaches could bring economic benefits, through reduced ditch maintenance costs and bring resilience to changing seasonal climate conditions through improved control over field waterlogging and increased crop resilience to drought conditions. Environmental benefits could be achieved through nutrient retention and increased biodiversity in channel margins, while also achieving the social benefit of reducing downstream flooding. A research project to further understand the benefits and limitations of the two approaches is recommended.

Beyond the current drainage maintenance, the landowner highlighted opportunities to attenuate flows in the steeper land above the drained area, which could help prevent flooding issues on the Howe. Three burns were identified as contributing to the drained area (Figure 27). Upon inspection of one of the burns, it was noted that there was an opportunity to restore a retention pond. Leaky dams were suggested upstream of the pond. Further inspection of site-specific measures across the three burns would be required, however, based on previous visits in both the Motray and Eden catchments, there is high potential for the adoption of temporary storage in the steeper gradients.

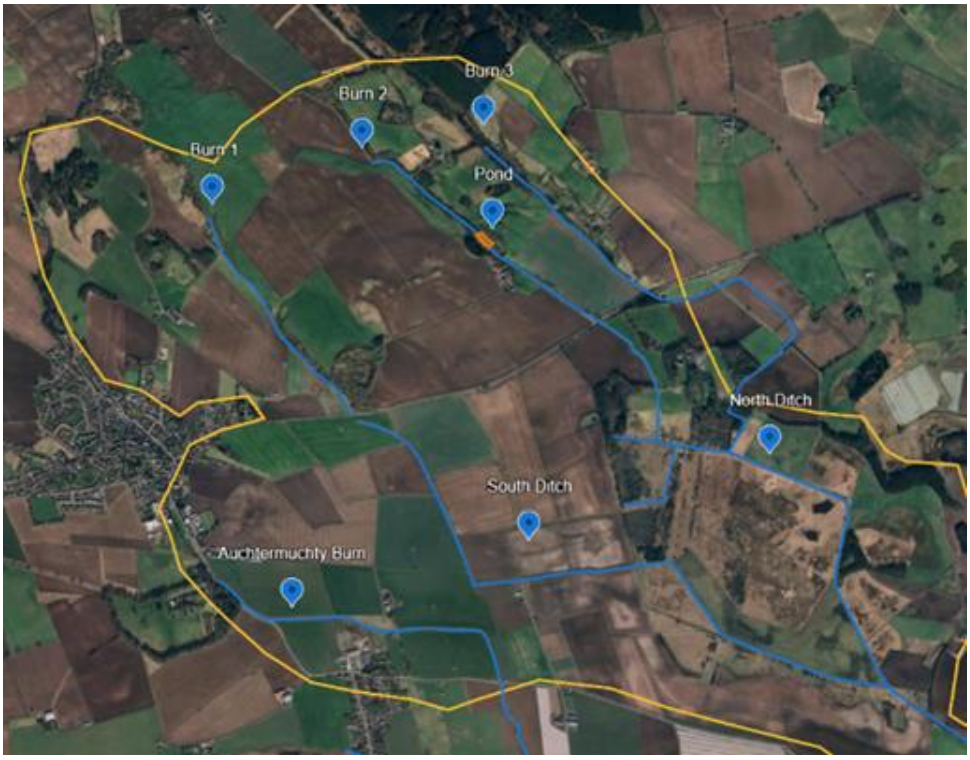



Figure 27: Three burns (blue) flow off steeper slopes to the drained area and contribute to north and south ditches. Potential area for restored pond on Burn 2 is highlighted (orange). Map created using Google Earth (2025). Data attribution: AirbusData SIO, NOAA, U.S. Navy, NGA, GEBCO

The described coordination and management of the local ditch cleaning group acts as a case study for how local landowners can come together to address water-related issues. Collaborative efforts in other areas of the catchment could increase knowledge sharing and the adoption of water management measures to co-address water-related risks.

## 3.6. Eden Visit 3 (EV3) – 10 April 2025

The third Eden catchment visit was to the South of the catchment at the southwest foot of the Lomond hills (Figure 28). Of the total area of the location, 220 hectares were within the Eden catchment and of interest during the visit. The land within the Eden is predominantly used for grazing cattle, however, other areas of the farm are utilised for growing arable and vegetable crops. The Pittillock Burn is the main water body flowing through the land, which flows to the Freuchie Burn, and then joins the Eden at Ladybank.


Figure 28: Location of Eden Visit 3. Map created using Google Earth (2025). Data attribution: AirbusData SIO, NOAA, U.S. Navy, NGA, GEBCO

The landowner didn't highlight any current water-related issues, but did highlight measures that have been adopted on the farm that have additional water-related benefits. The first measure described was mob-grazing (Image 10). Mob-grazing, considered a form of regenerative agriculture, allows livestock to graze intensively for short periods, followed by prolonged pasture rest periods (70-90 days), resulting in increased regrowth and allowing increased photosynthesis, improved root structure and increased soil organic matter (Wagner et al., 2023, Zaralis and Padel, 2019).

Image 9: Mob-grazing practices increasing grass growth

The benefits of mob-grazing described by the landowner, include reduced water run-off and increased infiltration from longer grass and improved rooting structures. Increased growth attenuates water flow from the land and reduces soil erosion, which is beneficial for increasing resilience to high-intensity precipitation events. With mob-grazing, the landowner explained that no nutrients are applied to the land, which benefits water quality. Additional benefits of mob-grazing described by the landowner include increased habitat for wildlife, such as nesting birds, reduced ground temperature on warm days to reduce livestock heat stress and the removal of nutrient application costs. The landowner explained that, this year, cattle will be out on the pasture year-round utilising the mob-grazing techniques, which will save costs and labour time associated with winter feeding.

The landowner indicated that a system of regenerative practices is used across the site, of which mob-grazing is a component. Regenerative agriculture also applies approaches such as minimised tillage, maintaining soil cover, biological nutrient cycling and avoiding pesticides to restore soil health, increase crop yields and increase biodiversity (Giller et al., 2021). Concerning water, the practice aims to increase water infiltration and reduce the application of nutrients, which have benefits for water storage and quality. Increased costs compared to conventional farming systems, particularly for compost to increase soil organic matter, resulting in reduced farm income margins (Roberts et al., 2023b), have been noted in the literature, however, the landowner indicated that their full regenerative system has comparable margins to conventional systems. There is an opportunity for knowledge-sharing on how the approaches described could be implemented, where suitable, across the catchment to achieve the associated water-related benefits.

## 3.7. Eden Visit 4 (EV4) - 14 April 2025

The fourth visit to the Eden catchment was to the southwest of the catchment, below the Lomond Hills (Figure 29). The site covers 1,006 hectares with a diversity of habitats including native woodland and wetlands. There is a variety of land uses, but of particular note is organic meat, crop, vegetable and fruit production. Land is divided into two farms, one with a larger mixed arable and livestock operation, and another smaller operation used to stock an organic farm shop. There are also mixed tenement farms across the site.


Figure 29: Location if Eden Visit 4. Map created using Google Earth (2025). Data attribution: AirbusData SIO, NOAA, U.S. Navy, NGA, GEBCO

Five main water bodies flow through the site, including the Ballingal, Arraty, Mapsie, Mill and Forthear burns, which flow into the Falkland Burn. The Falkland Burn then flows to the River Eden east of Dunshalt (Figure 30). The land is typical of the catchment, with steep slopes leading to areas with low-lying gradients used for agricultural production.


Figure 30: Overview of notable water bodies contributing to the River Eden. Map created using Google Earth (2025). Data attribution: AirbusData SIO, NOAA, U.S. Navy, NGA, GEBCO

A variety of water-related issues were discussed, including the impact of high-intensity rainfall events on flooding and waterlogging of agricultural land in lower gradients, and large sediment losses and debris flows in steeper gradients. Private water supplies were also highlighted as an issue, particularly when competition for the resource between irrigating crops, farm shop and private accommodation on the site is increased.

There is evidence of flow attenuation in the steeper gradients across the site, while opportunities for further attenuation exist. On the Arraty Burn, a pond has been constructed at the bottom of the steep slope to hold water and create an area for wildlife (Figure 31; Image 11). Flooding of houses downstream has occurred when the pond has been breached during a high-intensity rainfall event in the past. Introduction of a sediment trap and leaky barriers upstream of the pond could further attenuate flows and prevent the risk of flooding.  An overflow mechanism and routing of overflows to the currently unused field strip (Image 12) could be used to store overflow and further prevent flooding.

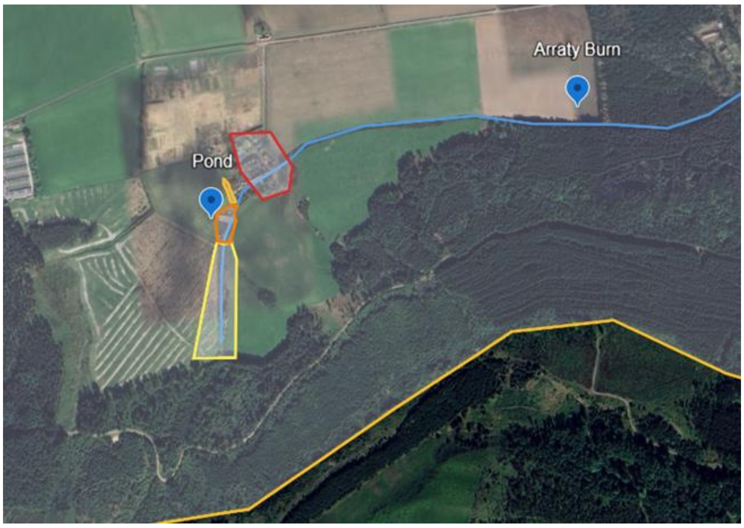



Figure 31: Constructed pond (orange) that leads to flooding of houses downstream (red). Options to reduce overflow (yellow) include leaky barriers and a sediment pond upstream of the pond, while overflow could be diverted to a fenced-off field margin. Map created using Google Earth (2025). Data attribution: AirbusData SIO, NOAA, U.S. Navy, NGA, GEBCO

Image 10: Image of the constructed pond

Image 11: A fenced field buffer strip could be used to store pond overflows.

A wetland has been created within an area of native forest to the West of the site (Figure 32, Image 13). The forest bed is covered in lichen and mosses, acting as a sponge to absorb and attenuate water flows. The functioning of the wetland has been recently impacted by sedimentation, which could be a legacy of the high debris flow damage on the Forthear burn due to high-intensity rainfall in August 2020 (Kirkbride et al., 2021). Sediment management of the Forthear burn upstream of the wetland could increase the functionality of the wetland. Flows and margins in the agricultural fields adjacent could be managed to reduce sedimentation sources to the Forthear burn and wetland. Sediment traps at the end of field boundaries would reduce sediment runoff to the wetland while allowing captured run-off to fill the wetland (Duffy et al., 2016). Invasive species are evident upstream of the wetland, where management is ongoing; however, the River Eden Sustainability Partnership could work with and support the landowner to address the issue.

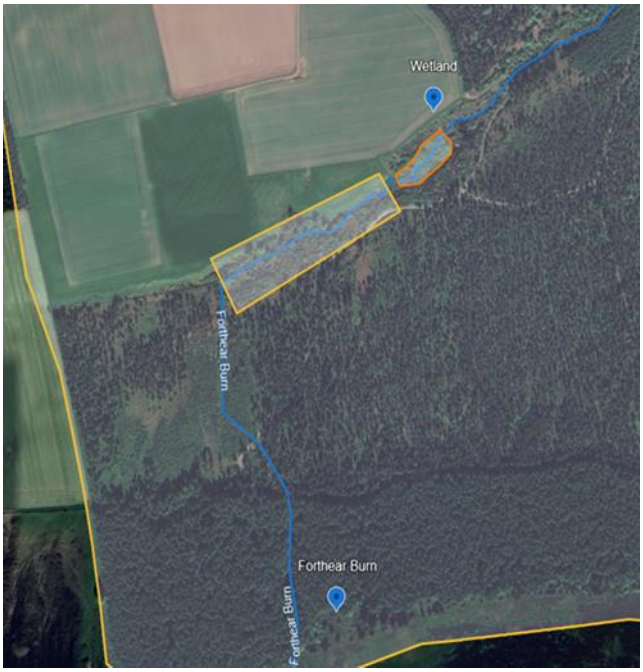



Figure 32: Location of Drumdreel wetland (orange) with opportunity areas for sediment management (yellow). Map created using Google Earth (2025). Data attribution: AirbusData SIO, NOAA, U.S. Navy, NGA, GEBCO

Image 12: Wetland area created at Drumdreel

A visit to the Cash Loch in the lowlands of the site was a unique opportunity to view how managed water environments can work within an agricultural setting (Image 14). The loch is surrounded by native woodland species and a haven for mosses, lichen and habitat for birds, amphibians, mammals and insects. The loch is sourced by a field drain (Image 15) and surrounded by agricultural land. The landowner noted they would like to see environments similar to the Cash Loch in the area that can work with agricultural production.


Image 13: Cash Loch


Image 14: Field drainage feeding into Cash Loch

The site has a unique opportunity to work with its tenant farmers to increase on-farm wetlands, ponds and species-rich riparian zones. Organic farming is practised on the site, meaning no inorganic fertilisers are added to crops. Mob grazing could be introduced on organic pastures to increase grass growth, which in turn reduces run-off on steeper slopes and increases water infiltration with increased root growth.

To increase resilience to water shortages and the supply of private drinking water on the site, water used to irrigate crops could be stored in an irrigation lagoon over winter, when rainfall is greatest. Water is supplied from a spring in Lomond Hills, but supply issues have occurred during low water availability and increased demand. Removing the demand for crop irrigation could increase the resilience of private water supplies. At the time of reporting (2025), applications were open for the Scottish Government's Agri-Environment Climate Scheme (AECS), where up to £40k in support was being offered for irrigation lagoon adoption. The landowner was made aware of the support and encouraged to speak with the local agricultural consultant and the Scottish Environment Protection Agency to understand eligibility, water storage requirements, and optimal and legal placement of the lagoon. Rainwater harvesting could be utilised for general washing and cleaning across the site grounds and within the farm shop area, again to reduce reliance on the spring water supply.

The area of the location, the diversity of habitat and land use and access to the public, and its popularity with visitors to the farm shop and cafe, make the area an ideal place to showcase ongoing water-related management activities. There is an opportunity to implement wider water management features to increase natural capital, enhance organic food production and offer community engagement.

### 3.8. Eden Visit 5 (EV5) - 19 May 2025

The site of the fifth Eden visit is located in the centre of the Eden Catchment, with the River Eden flowing through and surrounding the site (Figure 33). The land spans approximately 206 hectares, encompassing a range of mixed farming practices and pockets of woodland. The area covers the low-lying floodplain where vegetable and arable crops are grown, including potatoes, carrots and spring barley. Crops are grown on the slopes to the south of the catchment, where sheep also graze.

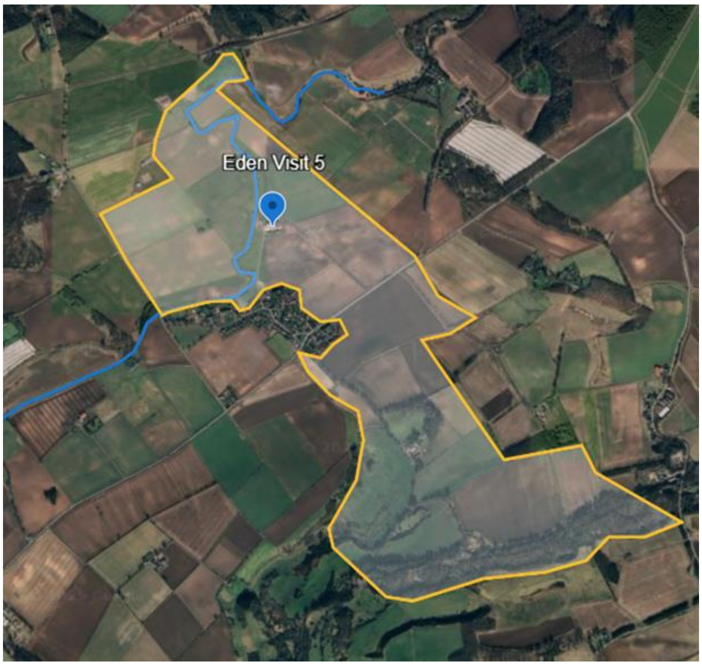



Figure 33: Farm visit location in context of the River Eden (blue). Map created using Google Earth (2025). Data attribution: AirbusData SIO, NOAA, U.S. Navy, NGA, GEBCO

A variety of water-related issues were discussed, starting with the recent drought conditions (April-May 2025), and the potential negative impact on arable crop yields. The landowner demonstrated that due to the drought occurring during the early growth stage of spring barley, crop tillers were maturing too early (Ogrodowicz et al., 2023), and additional new tillers, post-drought, were emerging. The new emerging tillers will mature later than the already maturing tillers, meaning landowners either have to wait for the later emerging tillers to mature, delaying harvest, or apply glyphosate to kill the later emerging tillers to harvest on time and overcome uneven maturity. Landowners are moving away from the use of glyphosate due to associated negative environmental and water impacts; however, future spring droughts could mean its application is deemed necessary by some at harvest.

With the latest future climatic projections for Scotland suggesting more frequent and increased water deficits in early spring (Glendell et al., 2024), there is an increasing risk to crop yields. Soil management practices to increase soil water holding capacity are typically recommended as the main viable measure to increase drought resilience for arable crops, however, the sandy soil characteristics of the site mean soil water holding capacity is limited. The use of biochar on sandy soils has been reported to increase soil water holding capacity under certain conditions (fine biochar particle size and low carbon content (Ibrahimi and Alghamdi, 2022).

An option to achieve adequate crop water availability during crop growing months is the previously mentioned technique of controlled drainage (see previous Figure 26). The benefits for water table control to allow water uptake of crops during the growing season are applicable in this situation. The landowner explained that during the 2022 drought, which occurred later in the growing season (July), the spring barley crop responded to drought conditions by increasing root depth. By increasing root depth, nitrogen uptake was also increased. Consequently, increased nitrogen uptake by the crop increased protein content of spring barley, making the quality unsuitable for malting (Bertholdsson, 1999), which reduces the price return for the crop. A potential negative impact of controlled drainage is that nitrogen and other nutrients are stored, therefore, further investigations regarding its application in the Scottish context are required.

A key issue for the landowner was riverbank erosion. With the River Eden historically being channelised, river stream power in straightened sections is increased, leading to channel incision and erosion (Heritage and Entwistle, 2020). The landowner highlighted bank erosion from trees on the opposing bank (Figure 34). Despite trees being beneficial for reducing bank erosion (Farm Advisory Service, n.d. (b)) overhanging trees and woody debris can divert flow to opposing banks with no tree cover and increase erosion (Montgomery, 1997). Creating uniform vegetation cover along riverbanks and in riparian zones can help reduce bank erosion while delivering multiple services to the environment (SAC Consulting, n.d. (a)). Native trees, such as Willow, are deep-rooting and support bank stabilisation, while emergent vegetation like reeds, rushes, grasses, and sedges further support bank stabilisation (Farming & Water Scotland, n.d. , SEPA, 2009)

Figure 34: Overhanging tree resulting in opposing riverbank erosion (yellow arrow).

A range of effective riparian management options is available to landowners and can be informed by site-specific conditions. The Smart Buffer tool (Stutter et al., n.d.) collects site-specific information to identify the best available options. Riparian management is often aimed at addressing water quality issues, however, it was clear during the visit that the landowner was going above and beyond the regulatory 2m riparian field to watercourse buffer zone. The landowner was implementing at least 8-10m buffers (Image 16), and is expected to have a positive impact on reducing nutrient losses and improving water quality. Management recommendations, therefore, focus on increasing bank stabilisation while allowing for sufficient land drainage to prevent flooding.

Image 15: Buffer margin between the field and watercourse.

One option to achieve improved bank stabilisation and reduce flood risk is the creation of a two-stage channel. A comparison of traditional trapezoidal cross-section channels and two-stage channels and the benefits of the modification are provided previously (Figure 25). Implementation of the two-stage channel leads to the loss of land at the field margin (Powell et al., 2007), however, the land loss is less than the potential losses from ongoing erosion in the longer term.

The presence of the invasive signal crayfish is also contributing to riverbank erosion through burrowing. Currently, there are limited management options to combat the invasive species (Marine Scotland, 2016). The River Eden Sustainability Partnership is currently carrying out eDNA testing to establish the upper limit of crayfish in order to monitor their presence and reduce the likelihood of further spread upstream. The landowner has been managing Giant Hogweed present on the riverbank, which will allow native vegetation to flourish and support bank stabilisation.

## 4. Identified Management Options

We list potential water management options, the water-related challenges they can address and associated advantages and disadvantages from economic, social and environmental perspectives in Table 3. Information collected for each management option is based on our review of key literature and discussions with landowners during field visits.

Table 3: Identified water management options, their descriptions, associated advantaged and disadvantages, and supporting information sources.

| Measure | Description | Associated Advantages | Associated Disadvantages | References for further guidance |
|---|---|---|---|---|
| Two-stage channel | A reprofiled channel with flat sides to hold water and capture sediments and pollutants during high flows, as seen in Figure 25. | Reduced flood risk, bank stabilisation, and provides habitat. | Implementation costs, small land sacrifice, limited application in the UK, and temporary water quality habitat during construction. | (Maclean et al., 2015, Stutter et al., n.d.) |
| Restoring natural channel morphology | Allowing the river to take its natural course, in the context of the Eden and Motray catchments, would involve re-meandering channelised sections. Natural erosion and deposition processes are reinstated, and flows are slowed compared to straightened channels. Restoration would lead to the loss of agriculturally productive land. | Reduced flood risk and improved morphology and stabilised erosion and deposition processes after site recovery. | Implementation costs, large land sacrifice, and temporary water quality degradation and habitat loss during construction. | (Maclean et al., 2015, SAC Consulting, n.d. (b)), SEPA, 2015, The Forth Rivers Trust, 2024) |
| Drainage maintenance | Removal of vegetation and material from drainage channels to support land drainage and increase water flow. | Local flood risk benefits, improved land drainage, improved crop production, and reduced soil erosion. | Initial capital and continuous maintenance costs, degradation of morphological status, cycles of habitat removal, and increased flood risk downstream. | (Dollinger et al., 2015, Maclean et al., 2015, Moore et al., 2010) |

| | | | | |
|---|---|---|---|---|
| Controlled drainage | A control fitted onto a major artificial subsurface soil drain used to control the water table, allowing for water drainage, storage and nutrient control. | Improved land drainage, controls crop water availability and reduces diffuse nitrate pollution. | Initial capital costs, limited application in the UK, potential negative run-off and water quality if mismanaged. | (Abdallah et al., 2021, Frankenberger et al., 2006, Stutter et al., n.d.) |
| Removal of constrictions | Constrictions are considered anything that blocks the flow of water and can include weirs, bridges or natural blockages such as fallen trees. Constrictions can cause water to back up or divert the flow of water. | Reduced flood risks, improvement of morphological processes, and prevention of fish barriers to migration. | Initial capital costs, temporary water quality degradation, habitat loss during demolition and may increase downstream flood risk. | (Maclean et al., 2015) |
| Leaky barriers (or leaky dams) | Barriers, often made of natural material, are laid in streams to temporarily store water and reduce flood risk. | Reduced flood risk and can encourage groundwater recharge. | Small initial capital and maintenance costs and can cause temporary flooding in adjacent land. | (Maclean et al., 2015, Quinn et al., 2022, Roberts et al., 2023a) |
| Retention ponds & wetlands | The permanent pooling of water to store and treat runoff water nutrients and collect sediment. Placement can be in pockets of unproductive land and can vary in size depending on runoff volumes. | Improves water quality, reduces flood risk, and habitat creation. | Initial capital costs, sacrifices land and requires time for establishment. | (Duffy et al., 2016, SEPA, 2015, Stutter et al., n.d.) |
| Riparian buffers, field margins (including magic margins), sediment traps and bunds | Used to intercept surface runoff and provide a barrier between agricultural activities and the watercourse to prevent nutrient and soil loss. A 2m, 5m and 10m buffer must be maintained between a field edge and a watercourse for crop cultivation, livestock poaching and slurry or manure applications, respectively. There are multiple options for how buffers are designed and vegetated, as well as how they are integrated with traps and bunds. | Prevents soil loss and re-utilisation of sediments for crop production, reduces nutrient runoff, and increases habitat and biodiversity. | Small capital and maintenance costs, and requires land sacrifice either temporarily or permanently. | (Cole et al., 2020, Maclean et al., 2015, SEPA, 2015, Stutter et al., n.d.) |

| | | | | |
|---|---|---|---|---|
| Regenerative agriculture – cover crops, minimum tillage, mob grazing | An agricultural production system that focuses on improving soil health and structure as a basis for food security and delivering ecosystem services. | Reduces soil erosion and improves soil health, increases resilience to drought by increasing infiltration, reduces runoff with benefits for flood risk and water quality, stores carbon and increases habitat and species diversity. | Short-term yield reduction, requires the purchase of new machinery, increased weeds, cover crop seed and labour costs. | (Maclean et al., 2015, SAC Consulting, n.d. (b)), Wagner et al., 2023, Zaralis and Padel, 2019) |
| Aeration/ Mole ploughing | The use of aerator machinery and mole ploughs to remove soil cores to improve soil drainage, reduce waterlogging and runoff, and regenerate soil. | Reduced flood risk through reduced surface run-off, reduced nutrient run-off, improved soil health, and great water infiltration for crop uptake. | Capital cost of machinery and not suitable for all soil types. | (Maclean et al., 2015) |
| Nutrient monitoring and management planning | Involves the analysis of soil for pH level, Phosphate (P), Potash (K) and soil carbon content at least once every five years, which will inform the creation of a nutrient management plan to optimise nutrient applications, under Whole Farm Plan requirements for Region 1 land which the majority of the Eden and Motray catchments fall. More frequent soil testing and analysis can be done, however, once every five years is the minimum under the current Whole Farm Plan. | Nutrient efficiency and reduced excess nutrients entering waterbodies. Associated savings from nutrient input reductions. | Cost for soil testing and analysis, or the latest soil sensors. | (Farm Advisory Service, n.d. (a)), Scottish Government, 2025) |
| Irrigation Lagoons | Constructed reservoirs are designed to store water during times of high rainfall or flows for agricultural irrigation during drier months. | Increases crop resilience to drought and habitat creation, using a lined zone and an unlined zone can result in the lagoon being | Capital and maintenance costs, increased GHG emissions and reduced water quality from nutrient and sediment loads. | (Farm Advisory Service, 2025 (b)) |

| | | | | |
|---|---|---|---|---|
| | | used as a recharge area, a flood storage area and an irrigation pond for droughts. | Disadvantages can be addressed by introducing measures to reduce nutrient and sediment inputs. | |
| Precision Irrigation | Alternatives aim to increase the uniformity of water application across fields. Precision irrigation uses alternative irrigation types such as boom or sprinkler irrigation and takes into account soil moisture and crop water demand. | Improve water use efficiency with benefits for crop production. | Costly to set up and requires labour to set up and remove equipment | (AHDB, 2018, González Perea et al., 2018) |

# 5. Stakeholder Workshop

## 5.1. Overview

After identifying the range of management options from the literature review and landowner engagement, a workshop was conducted to bring stakeholders together to share their views on the potential water-related management options. The aim of the workshop was to discuss water-related issues and the identified management options with local stakeholders to support collaborative water management and explore how delivering, resourcing and monitoring of feasible management options can be achieved.

The workshop was attended by 19 participants, four of whom participated in a landowner field visits. Wider attendance included Fife Council, Fife Coast and Countryside Trust, Scottish Water, the Tay Rivers Trust, the National Farmers Union for Scotland, SAC Consulting, the University of St Andrews, a local drainage expert and members of the River Eden Sustainability Partnership. Each organisation was able to give local perspectives on the water-related issues and potential management options to address the multiple issues.

Before and during the workshop, participants were provided background information on the identified water management options presented in Table 3. After the presentation and discussion of water-related issues presented in Section 1.2, the first workshop activity was to score each management action on its ability to address the water-related issues. The scoring was framed on the environmental, economic and social impacts of adopting management options, as optimal options would have positive impacts across all three pillars of sustainable development. Impact was measured on a scale of -3 to 3, with values -3 to -1 having a negative impact, a score of 0 having no, or an unknown impact, and a score of 1-3 having a positive impact. An example of the scoring sheet with guiding questions provided to participants is presented in Appendix A.

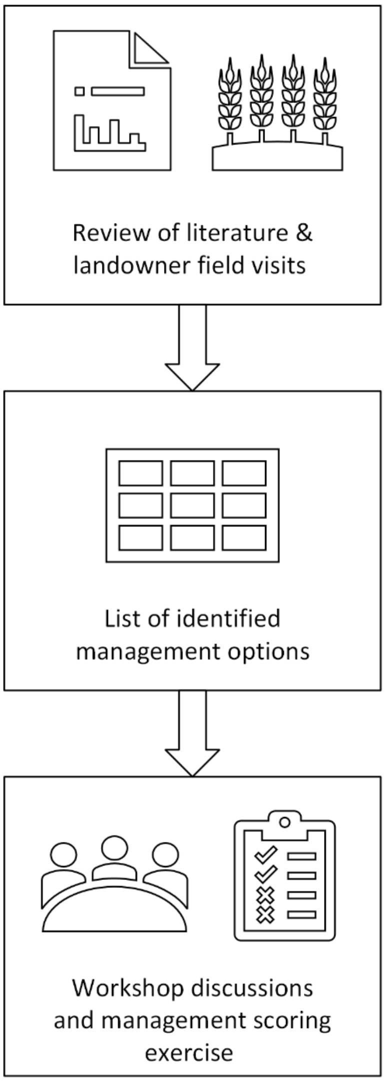


Figure 35: Stakeholder workshop process

Participants were divided into three groups and asked to discuss each management option before providing their individual scores. An individual and anonymous scoring system was adopted to gain a full representation of scores in the room, while group discussions allowed for wider knowledge sharing amongst participants. A full representation of the management scoring exercise is provided in Figure 35. Please note, that after workshop discussions, it was highlighted that mole and aeration ploughing were not suitable in the Eden and Motray catchments due to the prevalence of sandy soil types, and were therefore not included in the scoring exercise results.

After the scoring exercise, an open discussion on views of the most feasible management options and how to overcome barriers for transitioning from recommendations to delivery was conducted (Image 17). Key themes from the conversations are used to inform the later discussion in Section 6 of the report, while helping to inform recommendations for the River Eden Sustainability Partnership in Section 7.


Image 16: Discussions during the stakeholder workshop

## 5.2. Management Option Scoring Results

We use heatmaps to visualise environmental, economic, and social impact scores provided by workshop participants across the different management options, along with their summary statistics (Environmental: Figure 36, Table 4; Economic: Figure 37, Table 5; Social: Figure 38, Table 6). A total of 14 workshop participants completed the scoring exercise. An alternative representation of the management scoring exercise is provided in Appendix B.

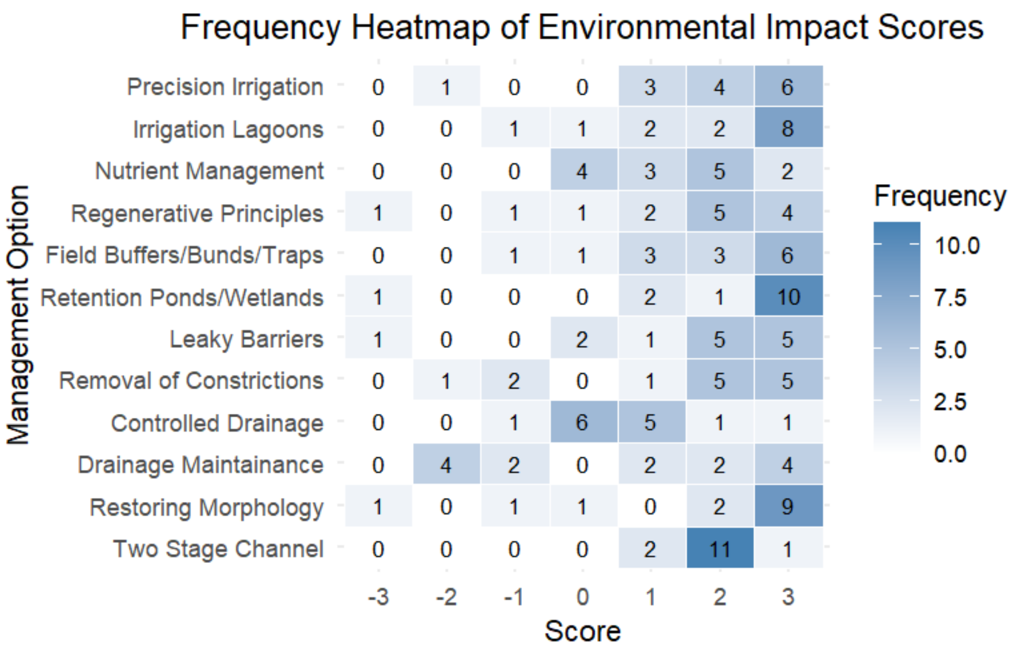



Figure 36: Heat map of environmental impact scoring across different management options n=14. Reminder: Values -3 to -1 having a negative impact, a score of 0 having no, or an unknown impact, and a score of 1-3 having a positive impact

Table 4: Summary statistics for environmental impact scores.

| Management Option | **Two-stage channel** | **Restoring Morphology** | **Drainage Maintenance** | **Controlled Drainage** | **Constriction Removal** | **Leaky Barriers** |
|---|---|---|---|---|---|---|
| Median | 2 | 3 | 1 | 0.5 | 2 | 2 |
| Standard Deviation | 0.46 | 1.83 | 2.06 | 0.97 | 1.64 | 1.63 |
| | | | | | | |
| Management Option | **Retention Ponds/ Wetlands** | **Buffers/ Bunds/ Traps** | **Regenerative Principles** | **Nutrient Management** | **Irrigation Lagoons** | **Precision Irrigation** |
| Median | 3 | 2 | 2 | 1.5 | 3 | 2 |
| Standard Deviation | 1.61 | 1.25 | 1.68 | 1.04 | 1.28 | 1.33 |

All management options identified had a positive environmental impact, as demonstrated in the heatmap and positive median scores. Restoring morphology, retention ponds and wetlands, and irrigation lagoons were viewed as having the greatest positive environmental impact, with each receiving a median score of 3. The heatmap indicates that retention ponds and wetlands had the highest frequency of top positive scores (n=10), followed by restoring morphology (n=9) and irrigation lagoons (n=8).

Two-stage channels received the greatest consensus regarding their positive environmental impacts, which is evident in the standard deviation of 0.46, no negative scores and the largest frequency of the specific score (2; n=11). Drainage maintenance had the lowest level of consensus across participants, with a standard deviation of 2.06. Despite a median positive score of 1 and four participants providing a maximum positive score (3, n=3), it received the highest number of negative environmental impact scores (n=6). Controlled drainage received the lowest median score of 0.5, however, the highest frequency of responses was a zero score (n=6), and could reflect the limited application of the management option across Scotland.

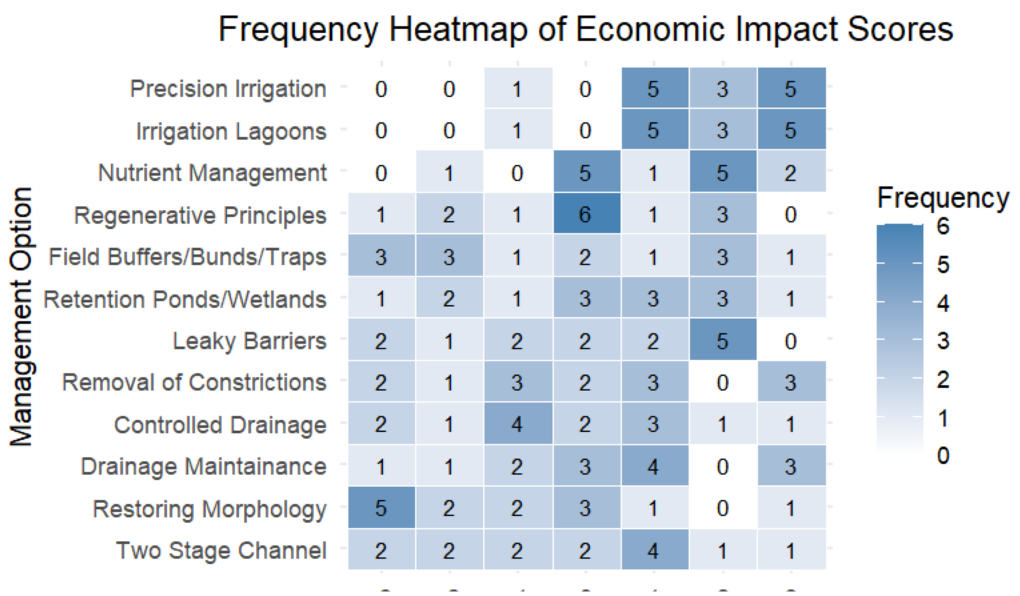



Figure 37: Heat map of economic impact scoring across different management options n=14. Reminder: Values -3 to -1 having a negative impact, a score of 0 having no, or an unknown impact, and a score of 1-3 having a positive impact

Table 5: Summary statistics for economic impact scores.

| Management Option | Two-stage channel | Restoring Morphology | Drainage Maintenance | Controlled Drainage | Constriction Removal | Leaky Barriers |
|---|---|---|---|---|---|---|
| Median | 0 | -1.5 | 0.5 | -0.5 | 0 | 0.5 |
| Standard Deviation | 1.78 | 1.78 | 1.78 | 1.71 | 1.98 | 1.81 |
| | | | | | | |
| Management Option | **Retention Ponds/ Wetlands** | **Buffers/ Bunds/ Traps** | **Regenerative Principles** | **Nutrient Management** | **Irrigation Lagoons** | **Precision Irrigation** |
| Median | 0.5 | -0.5 | 0 | 1.5 | 2 | 2 |
| Standard Deviation | 1.71 | 2.06 | 1.49 | 1.39 | 1.15 | 1.34 |

For economic impacts, there was a smaller proportion of positive scores across the different management options. Irrigation lagoons and precision irrigation options were seen as having the greatest positive economic impact, each receiving a median score of two. Restoring morphology received a -1.5 median score and the highest frequency of -3 scores (n=5), making it the lowest-scoring economic impact option. Buffers, bunds and sediment traps, and controlled drainage options both received a -0.5 median score. Buffers, bunds and traps had the lowest level of consensus across participants, with a standard deviation of 2.06.

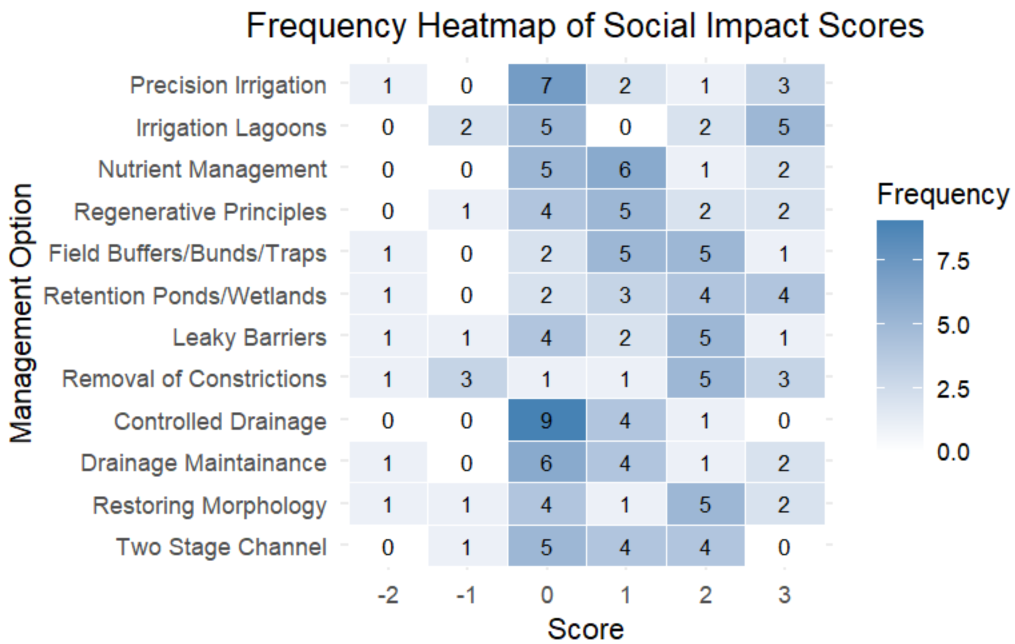



Figure 38: Heat map of social impact scoring across different management options n=14.Reminder: Values -3 to -1 having a negative impact, a score of 0 having no, or an unknown impact, and a score of 1-3 having a positive impact

Table 6: Summary statistics for economic impact scores.

| Management Option | **Two-stage channel** | **Restoring Morphology** | **Drainage Maintenance** | **Controlled Drainage** | **Constriction Removal** | **Leaky Barriers** |
|---|---|---|---|---|---|---|
| Median | 1 | 1.5 | 0.5 | 0 | 2 | 1 |
| Standard Deviation | 0.94 | 1.46 | 1.28 | 0.62 | 1.67 | 1.36 |
| | | | | | | |
| Management Option | **Retention Ponds/ Wetlands** | **Buffers/ Bunds/ Traps** | **Regenerative Principles** | **Nutrient Management** | **Irrigation Lagoons** | **Precision Irrigation** |
| Median | 2 | 1 | 1 | 1 | 1 | 0 |
| Standard Deviation | 1.40 | 1.19 | 1.13 | 1.00 | 1.57 | 1.42 |

Most of the management options had a positive median score for social impacts, except for controlled drainage and precision irrigation, which each scored a zero. Retention ponds and wetlands, and the removal of constrictions received the highest median score of 2. Irrigation lagoons had the greatest frequency of the maximum positive score (n=5). A possible explanation for the overall neutral scores for social impact across the management options compared to environmental and economic aspects is that social impacts often can't be directly measured, or because the management options weren't scored in the context of a specific location in the catchments, it was difficult to relate impacts to a social context.

## 5.3. Open Discussion Key Themes

Following the management option scoring exercise, the main themes from the open discussion are presented in Table 7. The listed themes form the key sections of the general discussion (Section 6), which brings together insights from the literature review and landowner field visits with the workshop discussions. Each discussion theme is tagged as either an implementation, resourcing, governance and monitoring talking point, as per the purpose of the open discussion.

Table 7: Key workshop discussion themes and their descriptions

| Theme | Description | Tag(s) |
|---|---|---|
| Management action trade-offs, conflicting views and agreement | As evidenced in the management scoring exercise, trade-offs between management actions exist, particularly regarding environmental and economic impacts. There were also conflicting views regarding the effectiveness of different management options and agreement in others. | Implementation and Monitoring |
| Taking a source-to-sea approach | The need to take a holistic source-to-sea approach is required to gain the maximum and multiple benefits of management action in both catchments. Participants emphasised the need for the correct placement and design of certain management options to achieve optimal impact. | Implementation, Governance |
| Landowner clusters | Landowner clusters or cooperatives were discussed as an effective way to achieve efficient implementation and governance of water and its management, while also sharing knowledge. | Implementation, Governance and Resourcing |

| | | |
|---|---|---|
| Innovative financing | Opportunities for innovative and blended finance options were discussed that could bring landscape-scale benefits to the environment, society and the economy. | Implementation, Resourcing and Monitoring |

# 6. Discussion

## 6.1. Management option trade-offs, conflicting views and consensus

Trade-offs between environmental and economic impacts for certain management options were evident in the scoring exercise, workshop discussions and landowner field visits. The trade-off is most apparent for restoring channel morphology, where the environmental benefits, including reducing flood risk by slowing the flow and encouraging natural erosion and deposition processes (SEPA, 2015), were recognised by the majority of participants. Despite these benefits, stakeholders recognised the high costs associated with making major modifications to river channels and the economic costs from the loss of agricultural land that comes with channel restoration, such as the re-meandering watercourses.

The same discussion can be drawn from field buffers, bunds and sediment traps. Participants reflected that 2m buffers are already widely applied across both the Eden and Motray catchments. Larger buffer widths, such as the buffers demonstrated by Motray Landowner Visit 3 and Eden Visit 5, may have greater water and environmental benefits; however, wider buffers require more agricultural production land, resulting in an economic cost to the landowner (Spray et al., 2015). At the time of writing (2025), funding was available for implementing and maintaining water margins in arable land for up to 18 meters, with compensation of £495.62 per hectare per year via the Agri-Environment Climate Scheme (AECS), funding (Scottish Government, 2018). Bunds and sediment traps are often placed in areas of unproductive land, and funding is available via AECS of £10.50 per square metre for a sediment trap and £7.20 per linear metre to create a bund. Given that these measures typically don't often require prime agricultural land and can retain sediments and nutrients, further knowledge sharing on the environmental and economic benefits of these types of measures would be beneficial for wider acceptance and adoption. Landowners highlighted that the AECS funding is competitive, making it a risk to spend time and resources applying for the funding to be unsuccessful.

The main differing views between stakeholders relate to drainage maintenance and are evident particularly in the scoring of environmental impacts. Many stakeholders in the study area attribute the reduction in maintenance of drainage ditches and the removal of sediment and vegetation build-up in watercourses to having negative impacts on water levels and flooding, including the December 2023 flooding. The reduction in maintenance is considered an outcome of both the reduction in resources towards maintenance activities and the increasing environmental regulations against maintenance activities. Those who argue for increased maintenance believe that water should be conveyed through the catchments quickly without obstruction from sediment and vegetation build-up. It's believed that increasing water conveyance would prevent water levels from rising, resulting in saturated land, increased surface run-off and flooded communities.

Other stakeholders believe that slowing the flow of water by holding water in the landscape and reintroducing natural river processes upstream of communities would reduce the risk of flooding. By slowing the flow upstream, peak flows – the maximum volume of water in a watercourse during a storm event - may be reduced in downstream communities (Black et al., 2021). Further, some participants believe that channel morphology restoration would reintroduce an equilibrium to erosion, transportation and deposition processes. The channelisation of watercourses and encouraging faster water conveyance leads to channel incision and increased bank erosion (Heritage and Entwistle, 2020), resulting in increased sediment buildup at pinch points of the system, such as bridges.

Common ground was found between stakeholders concerning the benefits and potential implementation of two-stage channels. The two-stage approach would still require land, but not as much as restoring morphological processes. The main associated benefits of two-stage channels are an increase in water holding capacity while also capturing sediments and nutrients (USDA, 2008). Implementation costs would still be high, and there is limited application of the approach in Scotland. Further, some workshop participants raised concerns that their implementation could require the removal of bankside vegetation, such as trees. Given the range of views and potential management options, a full hydraulic study and modelling exercise is recommended to understand the impacts of different management and maintenance techniques in the catchments, and the influence the different combinations of measures would have in reducing flood risk now and in the future It’s recommended that the study be conducted by incorporating the range of different views in the catchment and adopting a source-to-sea approach that recognises the need for a combination of measures. The study and consultation with local residents and landowners could be conducted in the planned Fife Phase 2 Strategic Flood Risk Assessment (Jeremy Benn Associates, 2024).

Related to the previous discussion are differing views regarding constriction removal and the relationship with bankside vegetation, specifically trees. In the scoring exercise, constriction removal scored highly on environmental benefits, neutral on economic impacts and was seen to have a positive social impact. Delving deeper into the conversations with stakeholders, it was clear that conflicting views on the removal of natural constrictions, mainly trees in the watercourse and in riparian areas, were evident. Those in favour of moving water quickly through the catchments believe that trees reduce riverbank stability, resulting in trees falling into watercourses and blocking water flow, increasing water levels and contributing to flooding. Trees, if sparsely populated along the riverbank, can alter water flows and increase riverbank erosion (Montgomery, 1997), as demonstrated in image 19 from Eden Landowner Visit 5. Further, trees are also seen as damaging and blocking field drainage, while preventing access for maintaining watercourses.

In contrast, others believe that certain tree species increase riverbank stability, while providing wider benefits such as habitat creation, watercourse cooling and the extraction of $CO_2$ from the atmosphere (Dybala et al., 2019, Farming & Water Scotland, n.d., Hutchins et al., 2024, Stutter et al., 2019). Additionally, woody debris in watercourses is seen as a beneficial habitat for fish. Despite in-stream debates, the current literature supports the benefit of deep-rooting trees, such as willow, in supporting bank stabilisation (Farming & Water Scotland, n.d. , SEPA, 2009). Creating uniform vegetation cover along riverbanks and in riparian zones can help reduce bank erosion (SAC Consulting, n.d. (a)). To find balance, appropriate trees placed uniformly in riparian zones - ensuring they don’t interfere with field drains and access to maintain field drains - can be encouraged to reduce bank erosion and wider environmental benefits.

A diversity of views on regenerative principles were identified across the project, particularly concerning alternative tillage methods. Despite the soil structure and soil health benefits of zero or minimum tillage and the positive impact this can have on increasing soil water holding capacity (George et al., 2022), concerns about weed suppression and the impact on crops were raised during the workshop. There was an agreement that options such as mob-grazing and cover crops would have benefits for reducing water and sediment run-off in the catchment, where appropriate. Visiting the catchment during the winter months, a significant proportion of both catchments with bare soil was evident. During high-intensity rainfall events, bare fields result in increased water and sediment run-off, which results in the loss and erosion of valuable soil while also resulting in increased sedimentation in watercourses (Panagos et al., 2021). Positive experiences of using cover crops to reduce erosion issues, while also supporting water infiltration, were evident in Motray Landowner Visit 1. The landowner from Eden Visit 3 highlighted a positive experience of utilising a regenerative system, particularly mob-grazing, noting that implementing a system of regenerative practices can address issues associated with weeds. Knowledge sharing on how to implement regenerative principles effectively within the catchments is a recommendation.

Overall, leaky barriers, retention ponds and wetlands scored positively across environmental, economic and social pillars. There was greater acceptance for these types of measures during landowner field visits and the workshop discussions. For leaky barriers, stakeholders indicated they would have a limited impact on the catchment scale, however, wider application across the catchments could have greater positive impacts on attenuating flows. Opportunities for the implementation of leaky barriers, retention ponds and wetlands have been identified during many of the landowner field visits. Given the consensus and opportunities for implementation, we recommend a transition to delivery for these measures.

Management options specifically aimed at increasing resilience to drought – irrigation lagoons and precision irrigation – were the highest scoring across environmental and economic pillars. The benefits of increasing water storage in irrigation lagoons for utilisation during periods of drought were evidenced in Motray Landowner Visit 3. The difference between irrigation lagoons and ponds was raised during the stakeholder workshop. The main difference is that lagoons are often lined structures compared to ponds, which prevents the infiltration into groundwater. The multifunctional use of lagoons is an area for further research in Scotland. Lagoons with a lined and non-lined zone could allow for the recharge of aquifers and deeper soils, a source of irrigation, a flood storage area (Khardi et al., 2024), as well as an area for improving habitat, biodiversity and water quality.

At the time of conducting our study, capital funding was available to landowners to support the construction of irrigation lagoons under AECS funding, which could influence the positive economic scoring for the measure. Concerns have been raised that AECS the funding doesn't go far enough, and there's difficulty in meeting the criteria to access the funding (Glendell et al., 2024). Our results show there is an appetite from landowners to utilise the funding incentive. There was less evidence of the adoption of precision irrigation methods, despite positive responses from stakeholders. The AECS scheme could be extended to increase support for the adoption of precision irrigation methods. A case study on the adoption of precision irrigation methods could also increase adoption of the measures.

## 6.2. Taking a source-to-sea approach

It's important to highlight that despite the discussed difference in views and opinions, no one management action will solve the multiple water-related issues in the catchments. Rather, it will be the combination of appropriate management actions that will deliver the multiple benefits required and increase resilience to changing climatic conditions. It was clear during landowner visits and the workshop open discussion that the need for a source-to-sea approach is recognised by stakeholders, which is aligned with the objectives of the River Eden Sustainability Partnership. Further, differing views of landowners in approaches to water management, particularly flood management, have been recognised previously by Holstead et al. (2017), who recommend a catchment-scale approach to flooding.

Building on the need for a holistic catchment system approach, stakeholders indicated the need for optimal placement of management actions during the workshop's open discussion. Rather than blanket adoption of certain measures, such as leaky barriers, there is a need for a more strategic approach to management implementation. The landowner visits have identified areas of both catchments where specific measures could be implemented, however, we recognise that increased engagement will be required to achieve the scale of multiple measures required to address the water-related issues now and in the future.

Recognising that our next discussion point may contradict the need for strategic, place-based implementation of management options, discussions throughout the project have indicated two distinct catchment typologies. The two typologies are the steeper sloping and lowland areas of the catchments, which may help determine where best to implement different management options and achieve a source-to-sea approach. Image 1 and the description of landscapes in Motray Visit 1 and Eden Visits 2, 3, 4 and 5 are typical of the two typologies and how they transition.

In the steeper sloping areas, there are opportunities to attenuate flows with the introduction of leaky barriers, sediment traps and bunds, as demonstrated in Motray Visit 1, Eden Visit 1, Eden Visit 2 and Eden Visit 4. A coordinated effort in the implementation of attenuation features across the catchments could have a positive impact during high-intensity rainfall events in reducing peak flows downstream, reducing soil erosion and capturing sediments.

As the steeper slopes transition into the lowlands, the introduction of retention ponds and wetlands in areas of lower agricultural value can further help attenuate flows. Motray Visit 1 and Eden Visit 2 demonstrate opportunities for retention ponds, Motray Visit 2 demonstrates an opportunity for a wet woodland and Eden Visit 4 presents an opportunity for a range of retention ponds and wetlands. These features help attenuate flows, improve water quality and can provide habitat for wildlife (Duffy et al., 2016). The Cash Loch and Rossie Loch examples from Eden Visit 2 and Eden Visit 4, respectively, show how productive agricultural land and wetlands in the lowlands can work together. As far as implementation goes, the measures for water attenuation features previously described are most achievable for the River Eden Sustainability Partnership, as they have a greater level of landowner acceptability.

Given the high levels of acceptability for the adoption of irrigation lagoons, but highlighted limitation on access to supporting grants, a coordinated effort could be made to ensure landowners can come together to share lagoons, reducing the burden of adoption, encouraging the strategic placement of lagoons and the equitable sharing of water. With the projection for the increased frequency and duration of significant water scarcity events in the future, implementing water storage measures to increase the resilience of irrigation agriculture is required. Recommendations have already been made to establish finance options for precision irrigation techniques. Additionally, a demonstration farm for the adoption of precision irrigation to understand irrigation water use, savings and the time and resources required would be an interesting research project.

There are some management options where blanket adoption could be encouraged. Nutrient management plans will be adopted across the catchment under Whole Farm Plan requirements for Region 1 land (Scottish Government, 2025). Where possible, regenerative practices such as the use of cover crops and mob-grazing techniques could be encouraged across the catchment to reduce soil erosion and increase soil water infiltration and holding capacity. For wider regenerative practices such as alternative tillage methods, the diversity of views indicates there is a need for further discussion and knowledge sharing across the catchment. The Centre for Sustainable Cropping, hosted at the James Hutton Institute, can support knowledge exchange on the opportunities and challenges of adopting agro-ecological practices compared to conventional systems.

A key component of the source-to-sea approach is in-stream and channel management. Given the diversity of views on best practice to reduce flooding, riverbank erosion and sedimentation buildup, a catchment-scale hydrological survey and modelling exercise that tests different combinations of climatic and management scenarios is required. We reiterate that no one management action will solve the described issues; rather, a combination of restored morphology, two-stage channels and drainage maintenance, combined with water storage and soil management measures, could be required. The exercise should consider the current and future flood risks in the catchments, and the feasibility and optimal placement of the different options. Additionally, the exercise should be collaborative and transparent, to ensure that all views, including those of local landowners and the community, are considered.

With the management of riverbank vegetation another area of debate, the River Eden Sustainability Partnership should focus and expand efforts to address invasive non-native species**.** Management of invasive species wasn't a major focus for discussion during the landowner workshop due to the achievements of the Partnership in mapping invasive species, training local community members and obtaining licences to address the issue in the catchment. Once consensus has been achieved on best practice for channel management, the Partnership can focus on supporting implementation in the longer term. In the short term, continued coordination of events and consultations for discussion and knowledge exchange to support consensus-building is recommended.

## 6.3. Landowner Clusters

Given that catchment scale source-to-sea approaches require effective coordination, appropriate governance structures to support coordination and implementation were discussed during the stakeholder workshop. An example of effective landowner collaboration in the Eden catchment to manage land drainage was described in Eden Visit 2 and highlighted during the workshop. It was discussed that a shared vision to address a shared problem and effective governance are what make the drainage group a success.

During the workshop, stakeholders highlighted that a similar model of landowner clusters could be replicated across the catchments. Clusters could be developed based on shared interests. Examples include, but are not limited to, the application of regenerative agriculture, the sharing of water for irrigation or the management of invasive species. An alternative model could be developing clusters by watercourse, where landowners work together to implement a range of different management options on their specific area of the catchment. Each method could allow for the sharing of resources, equipment and expertise, operating in a similar fashion to smaller-scale farm cooperatives and developing joint approaches to new business models, including the emerging nature finance landscape. The latter is discussed in detail in the next section.

The benefits of farm clusters include the effective coordination of implementing management actions and monitoring of both water-related issues and management action effectiveness. The River Eden Sustainability Partnership can initiate and coordinate farm clusters, bringing clusters together to report on the impacts of management action or knowledge sharing**.** The cluster approach could bring an important additional benefit of encouraging landowner interaction to reduce the negative impacts of isolation in agricultural communities (King et al., 2023). Landowners often reflected that there was limited interaction between the landowner community during visits. Clusters and knowledge exchange events could provide a space for landowners to share ideas and issues, while increasing opportunities for collaboration to address shared issues. Stakeholders during the workshop highlighted that clusters should 1) have a clear objective - ideally a single objective, 2) be simple in their governance set-up, and 3) bring a clear benefit to the participating famers, otherwise, they may not be viable.

## 6.4. Innovative Funding

The workshop scoring exercise demonstrated that the economic costs of the implementation of measures were mainly neutral; exceptions include larger river modification measures that were seen to have a larger negative economic cost, and changes in irrigation methods and adoption of lagoons were seen as generating a positive economic impact. For management options discussed that are not expected to result in a clear positive economic impact, their adoption or implementation by landowners will require additional funding support. The previously mentioned AECS scheme is the key funding source for the implementation and adoption of water management actions by landowners. Despite the AECS funding available to implement water margins and grass strips in arable fields, ponds, wetlands, sediment traps, bunds, irrigation lagoons, and reconnect floodplains, landowners highlighted that the schemes are competitive and limited, meaning there is lower widespread adoption.

A potential option discussed during the stakeholder workshop that could overcome the mentioned barriers is the local Nature Finance Fife coalition. The coalition aims to mobilise a blend of finance from public, philanthropic and corporate sources to support place-based, landscape-scale projects that address the nature and climate crises and benefit local nature people and a green economy (Fife Coast & Countryside Trust, 2023). The objective of the blended finance approach is to fund and empower land managers and local community groups to support the implementation of projects. Given the aligned objectives with the River Eden Sustainability Partnership to take a landscape-scale source-to-sea approach, Nature Finance Fife could present an opportunity to implement the feasible water management options identified, while testing and developing the blended finance approach.

The Nature Finance Fife approach recognises the need for the development of appropriate monitoring, reporting and verification processes to measure the impact of any implemented changes. To understand the impact of any implemented measures at the local scale, the River Eden Sustainability Partnership should continue to invest in water quality testing and flow monitoring equipment, and training in aquatic species monitoring to understand the local impacts of any future management implementation. At the catchment scale, water quality and flow monitoring by SEPA can help the Partnership understand the impacts of landscape-scale changes. For example, after the introduction of the Whole Farm Plan, the required soil analysis will inform management plans to optimise the application of nutrients, including phosphorus, within the next five years. The optimisation of nutrient application across the catchments, along with investments by Scottish Water to reduce Reactive Phosphorus loads from wastewater treatment works in the Eden catchment, should lead to reductions in Phosphorus sources and improvements in water quality, which can be monitored by the River Eden Sustainability Partnership using the national monitoring sources available.

# 7. Summary of Recommendations

Throughout the discussion, a range of recommendations are provided, which are summarised below:

- The River Eden Sustainability Partnership should focus on encouraging and enabling the implementation of water attenuation features such as leaky barriers, ponds and wetlands, as they can address flooding, drought and water quality issues, provide opportunities to increase biodiversity and have the greatest levels of acceptability by landowners.
- Given recognition of a source-to-sea approach to address multiple water-related issues, The River Eden Sustainability Partnership should explore facilitating landowner clusters to support the effective coordination of management action implementation, monitoring both the water-

related issues and the management action effectiveness, sharing of resources, and increasing funding opportunities.

- To fund feasible water management projects, the River Eden Sustainability partnership should work with Nature Finance Fife to support delivery of measures and monitoring of their impact.
- The River Eden Sustainability Partnership should deliver and support landowner-focused knowledge exchange events that allow landowners to share their experiences of adopting new practices, for example, mob-grazing, giving space for landowners to connect and share their views. Knowledge-sharing events can encourage healthy discussion on water-related issues to support increased resilience to water management issues.
- The River Eden Sustainability Partnership should continue to build on their successful landowner engagement efforts to control non-native invasive species in watercourse channels across the Eden and Mortay Catchments. By securing further formal agreement from landowners for a catchment-wide control strategy, which will contribute to improved riverbank biodiversity and reduce erosion.
- A full hydraulic study and modelling exercise is recommended to understand the impacts of the different channel management scenarios and maintenance techniques to reduce flooding risk in the catchments now and in the future. The study could be incorporated into the planned Fife Phase 2 Strategic Flood Risk Assessment.
- There was a high level of interest in irrigation lagoons and precision irrigation options. The AECS funding should be made more flexible to enable the strategic placement of irrigation lagoons in the catchments, allowing for joint applications. The fund could be expanded to provide capital funding for the adoption of alternative, water-efficient irrigation technologies. The River Eden Sustainability Partnership can lobby local representatives and organisations to expand funding available for water management projects and capital investments.

For recommendations relevant to the River Eden Sustainability Partnership, we provide a suggested 5-year strategy for core activities, and short (0-2 years), medium (2-4 years) and long-term (4-5+ years) objectives in Table 8. Impacts and risks of each activity, regarding making a positive impact in both catchments and developing positive relationships with local landowners, are described and scored from low, moderate and high. We include information on resources required to implement and monitor the impact of the activity, which is also scored using the low (£0-50k), moderate (£50-200k) and high (£200k+) scale.

Table 8: Recommendations for the River Eden Sustainability Partnership

| Activity | Description | Timescale | Impact (Low, Moderate, High) | Risk (Low, Moderate, High) | Resource Requirements (Low, Moderate, High) |
|---|---|---|---|---|---|
| Non-native invasive species control | Coordinating, implementing and monitoring the control of non-native invasive species on watercourses over the next 5 years and beyond. | Core Activity | High positive impact as controlling non-native species can help improve native biodiversity and address issues related to riverbank erosion. Addressing the issue can involve landowners and the local community, and positive outcomes can be communicated. | Low to moderate risk, as addressing the issue will require a sustained source-to-sea effort from local volunteers and landowners. The benefits of action will take time, and monitoring will be important. Risks can be mitigated through strategic planning of control events and partnership working. | High:<br>Volunteer hours from both the local community and landowners.<br><br>Long-term funding for monitoring, control events, training, licensing and impact communications. |
| Knowledge exchange events | Hosting knowledge exchange events with local landowners, local communities and associated organisations to share, learn and raise awareness about water-related issues, management techniques or projects. | Core Activity | Moderate positive impact as knowledge exchange events may not lead to direct action, but knowledge sharing may encourage awareness raising of water-related issues, generate ideas on how to address issues and the wider adoption of effective water-related management practices. Further, such events allow landowners to come together in a social environment. Follow-up | There is a low risk that such events could widen the differences in options identified. Hosting specific themed events and communicating events as a respectful space to share ideas can mitigate risks. | Low:<br>Paid or volunteer staff time to coordinate, manage and facilitate events.<br><br>Funding for event space hire and catering. |

| | | | | | |
|---|---|---|---|---|---|
| | | | monitoring and feedback will be important for increasing impact. | | |
| Preparation for water attenuation features | Collaborating with partners, including landowners, to identify funding to prepare costings, optimal placement, technical planning and monitoring of attenuation features such as leaky barriers, ponds and wetlands. | Short Term | Medium to high impact depending on scale and potential connectivity. Implementing multiple projects will yield greater benefits for nature and contribute to reducing flood risk. | There is moderate risk that the implementation of water attenuation features are viewed as solving catchment-scale flooding issues, whereas in reality, they are only a contribution to the issue. Sustained maintenance and monitoring will require longer-term resource allocation. Effective communication and ensuring adequate resources for effective implementation can mitigate risks. | Moderate to high: Funding for preparation, implementation, maintenance and monitoring. Additional resources to communicate positive impacts will be required. |
| Implementation of water attenuation features | Collaborating with partners to implement, monitor and maintain the impact of water attenuation features. | Medium term | | | |
| Farm cluster scoping exercise | Understanding the level of interest in farm clusters and the different aims or themes of each cluster. | Short term | Moderate to high impact if multiple farm clusters are working on a range of different management actions to address water-related issues in the catchments. Clusters could have a positive impact on landowners through interactions and sharing resources with other landowners. | Low to moderate risk depending on the interest of landowners to participate in a cluster. There is a risk of disputes within clusters that would need to be managed. To mitigate risk and gain interest in the establishment, RESP could first create clusters for managing non-native invasive species and | Low: Staff or volunteer hours required to establish, communicate with and maintain farm clusters. |
| Farm cluster coordination | Coordinating the management activities of each cluster and the reporting of activities. | Medium term | | | |

<table>
<tr><td></td><td></td><td></td><td></td><td>widen the scope for management as clusters begin to effectively operate.</td><td></td></tr>
<tr><td>Hydraulic Modelling Exercise</td><td>Advocating for a full source-to-sea hydraulic study and modelling exercise to understand the impacts of the different channel management scenarios and maintenance techniques to reduce flooding risk and deliver wider benefits in the catchments.</td><td>Medium term</td><td rowspan="2">High potential impact as the exercise and implementation can deliver positive impacts for local communities, the economy and nature.</td><td rowspan="2">High risk, as despite the modelling exercise, there may still be differences in opinion on what management options should be implemented, which could further delay action and leave local communities at risk to water-related issues. To mitigate risks, the modelling exercise should be collaborative and transparent to ensure a range of views are captured during the methodology development and analysis of results. Consultations prior to implementation with local stakeholders would also mitigate risks.</td><td rowspan="2">High:<br>Staff time to conduct the hydrological modelling exercise, consultations, implementation, monitoring, reporting and maintenance would be required.</td></tr>
<tr><td>Coordinating channel management</td><td>Supporting and coordinating the recommendations from the hydraulic modelling exercise</td><td>Long term</td></tr>
</table>

## 8. Conclusions

The Transition to Delivery: Landowner Engagement project has supported the River Eden Sustainability Partnership's (RESP) on their journey to achieve their vision of resilient catchments that deliver for nature, the local community and economy. The project was initiated in response to the need for landowner engagement to help understand how to best work with landowners to tackle the range of complex water-related challenges in the catchments, including increasing flood risk, water scarcity, ecological degradation, and sediment and nutrient pressures. By engaging with landowners, the project has helped gather landowner perspectives on water-related issues, identify feasible water management actions, and develop strategies for how a source-to-sea approach can be delivered.

The rapid evidence review, landowner meetings, landowner field visits, and stakeholder workshop have developed a robust understanding of local water-related issues and the practical realities of implementing management options on the ground. A diverse range of water management options has been identified along with their associated challenges and opportunities. The workshop provided a platform for scoring and discussing the environmental, economic, and social impacts of various management options, fostering consensus and highlighting areas of contention.

While there is a need for further engagement and collaboration to understand the appropriate management of watercourse channels and the impact this will have on flooding in the catchment, the dialogue with landowners has helped identify significant landowner interest in implementing water attenuation features such as leaky barriers, ponds, and wetlands. Additionally, we have identified a wide range of management actions currently ongoing in the catchment that can be promoted to encourage wider adoption.

Recognition by local stakeholders and landowners of the need for a source-to-sea approach to water management, with strategic placement of interventions across the catchments and opportunities for collaborative governance through landowner clusters and knowledge-sharing events, justifies the role of the River Eden Sustainability Partnership. The recommendations outlined provide a clear roadmap for the partnership to transition from planning to implementation. The River Eden Sustainability Partnership can continue to deliver its core activities of controlling invasive non-native species, conducting citizen science surveys, and continue to engage and share knowledge on water-related issues and management options with landowners and local stakeholders. Opportunities to build on the core offering through the implementation of water attenuation features and creation of farm clusters mean the River Eden Sustainability Partnership is well-positioned to deliver collaborative landscape-scale improvements.

## 9. Acknowledgements

We thank all of the landowners and stakeholders who provided their valuable time, knowledge and views in supporting the development of key findings and recommendations during meetings and workshops. The research team are appreciative of all the landowners who participated in farm visits, and we thank them for the warm welcome and hospitality during the visits. Thanks to the University of St Andrews for kindly hosting the stakeholder workshop. Finally, we are grateful and give thanks to Sustainable Cupar, the Eden Angling Association, and the Neighbourhood Ecosystem Fund and Inspiring Scotland partners for the valuable support, collaboration and funding of this exciting project.

THE CARMAN FAMILY FOUNDATION NRF NATURE RESTORATION FUND Net Zero Scotland Scottish Government LET'S DO NET ZERO INSPIRING SCOTLAND

## 10. References


Abdallah, A. M., Jat, H. S., Choudhary, M., Abdelaty, E. F., Sharma, P. C. & Jat, M. L. 2021. Conservation Agriculture Effects on Soil Water Holding Capacity and Water-Saving Varied with Management Practices and Agroecological Conditions: A Review. *Agronomy,* 11**,** 1681.

Adams, K. J., Macleod, C. A. J., Metzger, M. J., Melville, N., Helliwell, R. C., Pritchard, J. & Glendell, M. 2023. Developing a Bayesian network model for understanding river catchment resilience under future change scenarios. *Hydrol. Earth Syst. Sci.,* 27**,** 2205-2225.

Adams, K. J., Metzger, M. J., Helliwell, R. C., Melville, N., Macleod, C. J. A., Pritchard, J., Edwards, K. & Glendell, M. 2024. Identifying and testing adaptive management options to increase river catchment system resilience using a Bayesian Network model. *Discover Geoscience,* 2**,** 62.

AHDB. 2018. Seasonal water management for potatoes. Available: https://projectblue.blob.core.windows.net/media/Default/Imported%20Publication%20Docs/Seasonal%20water%20management%20for%20potatoes.pdf

Animal and Plant Health Agency. 2018. Good Practice Management Guide For Giant Hogweed (Heracleum mantegazzianum) Available: https://yisf.org.uk/wp-content/uploads/2020/07/Good_Practice_Management_-_Giant_hogweed.pdf

BBC. 2022. Water scarcity: Fife farmers banned from using River Eden. Available: Water scarcity: Fife farmers banned from using River Eden - BBC News

Bertholdsson, N. O. 1999. Characterization of malting barley cultivars with more or less stable grain protein content under varying environmental conditions. *European Journal of Agronomy,* 10**,** 1-8.

Black, A., Peskett, L., MacDonald, A., Young, A., Spray, C., Ball, T., Thomas, H. & Werritty, A. 2021. Natural flood management, lag time and catchment scale: Results from an empirical nested catchment study. *Journal of Flood Risk Management,* 14**,** e12717.

Blanc, J., Arthur, S. & Wright, G. 2012. Natural flood management (NFM) knowledge system: Part 3–The effect of land drainage on flood risk and farming practice.

Cole, L. J., Stockan, J. & Helliwell, R. 2020. Managing riparian buffer strips to optimise ecosystem services: A review. *Agriculture, Ecosystems & Environment,* 296**,** 106891.

Davison, P. S., Withers, P. J. A., Lord, E. I., Betson, M. J. & Strömqvist, J. 2008. PSYCHIC – A process-based model of phosphorus and sediment mobilisation and delivery within agricultural catchments. Part 1: Model description and parameterisation. *Journal of Hydrology,* 350**,** 290-302.

Dietz, K.-J., Zörb, C. & Geilfus, C.-M. 2021. Drought and crop yield. *Plant Biology,* 23**,** 881-893.

Djodjic, F., Geranmayeh, P., Lannergård, E. E. & Futter, M. 2025. Estimating landscape-level water storage potential as a tool to mitigate floods and nutrient losses. *Journal of Environmental Management,* 388**,** 126055.

Dollinger, J., Dagès, C., Bailly, J.-S., Lagacherie, P. & Voltz, M. 2015. Managing ditches for agroecological engineering of landscape. A review. *Agronomy for Sustainable Development,* 35**,** 999-1020.

Duffy, A., Moir, S., Berwick, N., Shabashow, J., D'Arcy, B. & Wade, R. 2016. Rural sustainable drainage systems: a practical design and build guide for Scotland's farmers and landowners.

Dybala, K. E., Steger, K., Walsh, R. G., Smart, D. R., Gardali, T. & Seavy, N. E. 2019. Optimizing carbon storage and biodiversity co-benefits in reforested riparian zones. *Journal of Applied Ecology,* 56**,** 343-353.

Esk Rivers and Fisheries Trust. n.d. (b). Pow Burn Restoration. Available: eskriversangus.uk/wp-content/uploads/2019/03/Pow-Burn-Project.pdf

Esri Inc. 2020. ArcGIS Pro (3.5.0). Available: https://www.esri.com/en-us/arcgis/products/arcgis-pro/overview

Farm Advisory Service. n.d. (a). Farming for the future. Available: https://www.fas.scot/preparing-for-the-future/

Farm Advisory Service. n.d. (b). Riparian Planting. Available: https://www.fas.scot/environment/water-management/water-margins-2/riparian-planting/

Farm Advisory Service. 2025. (a) Reducing Surface Runoff and Erosion with 'Magic Margins'. Available: Reducing Surface Runoff and Erosion with 'Magic Margins' | Helping farmers in Scotland

Farm Advisory Service. 2025. (b) Securing your Water Supply with Boreholes and Lagoons. Available: https://www.fas.scot/article/securing-your-water-supply-with-boreholes-and-lagoons/#:~:text=Irrigation%20lagoons%20are%20specially%20constructed%20ponds%20or%20reservoirs,in%20Scotland%2C%20especially%20in%20areas%20prone%20to%20drought.

Farming & Water Scotland. n.d. Sustainable solutions to bank erosion: how trees can help protect Scotland's riverbanks. Available: https://www.farmingandwaterscotland.org/resource/sustainable-solutions-to-bank-erosion/

Farming and Water Scotland. n.d. Managing Water Margins. Available: https://www.farmingandwaterscotland.org/resource/managing-water-margins/

Fife Coast & Countryside Trust. 2023. Nature Finance Fife. Available: https://fifecoastandcountrysidetrust.co.uk/projects/nature-finance-fife/

Fife Council. 2025. River level monitoring system will help Cupar residents. Available: https://www.fife.gov.uk/news/2025/river-level-monitoring-system-will-help-cupar-residents#:~:text=Fife%20Council%20has%20taken%20action%20to%20monitor%20water,of%20properties%20and%20roads%20over%20the%20festive%20season.

Forestry Research. 2024. Creating and managing riparian woodland. Available: https://cdn.forestresearch.gov.uk/2024/07/UKFSPG028_Riparian-woodland_web-compressed.pdf

Frankenberger, J., Kladivko Eileen, Sands Gary, Jaynes Dan, Fausey Norm, Helmers Matt, Cooke Richard, Strock Jeff, Nelson Kelly & Brown Larry2006Questions and Answers About Drainage Water Management for the Midwesthttps://www.extension.purdue.edu/extmedia/WQ/WQ-44.pdf#page=7.41

Gallaun, H., Dohr, K., Puhm, M., Stumpf, A. & Hugé, J. 2019. EU-hydro-river net user guide 1.3. *Copernicus Land Monitoring Service*.

George, S. T., Hawes Cathy , Valentine Tracy A. , Karley Alison J. , Iannetta Pietro P. M.  & Brooker Robin W. 2022. Harnessing Ecological Principles And Physiologic Mechanisms In Diversifying Agricultural Systems For Sustainability: Experience From Studies Deploying Nature-Based Solutions In Scotland. *Front. Agr. Sci. Eng.,* 9**,** 214-237.

Giller, K. E., Hijbeek, R., Andersson, J. A. & Sumberg, J. 2021. Regenerative Agriculture: An agronomic perspective. *Outlook on Agriculture,* 50**,** 13-25.

Glendell, M., Blackstock, K., Adams, K., Brickell, J., Comte, J.-C., Gagkas, Z., Geris, J., Haro, D., Jabloun, M. & Karley, A. 2024. Future predictions of water scarcity in Scotland: impact on distilleries and agricultural abstractors. Available: https://www.crew.ac.uk/publication/water-scarcity-impacts-distilleries-agricultural.

González Perea, R., Daccache, A., Rodríguez Díaz, J. A., Camacho Poyato, E. & Knox, J. W. 2018. Modelling impacts of precision irrigation on crop yield and in-field water management. *Precision Agriculture,* 19**,** 497-512.

Gucker, Corey L. 2009. Heracleum mantegazzianum. In: Fire Effects Information System . U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory (Producer). Available: https://www.fs.usda.gov/database/feis/plants/forb/herman/all.html

Helmers, M. J., Abendroth, L., Reinhart, B., Chighladze, G., Pease, L., Bowling, L., Youssef, M., Ghane, E., Ahiablame, L., Brown, L., Fausey, N., Frankenberger, J., Jaynes, D., King, K., Kladivko, E., Nelson, K. & Strock, J. 2022. Impact of controlled drainage on subsurface drain flow and nitrate load: A synthesis of studies across the U.S. Midwest and Southeast. *Agricultural Water Management,* 259**,** 107265.

Heritage, G. & Entwistle, N. 2020. Impacts of River Engineering on River Channel Behaviour: Implications for Managing Downstream Flood Risk. *Water,* 12**,** 1355.

Holstead, K. L., Kenyon, W., Rouillard, J., Hopkins, J. & Galán-Díaz, C. 2017. Natural flood management from the farmer's perspective: criteria that affect uptake. *Journal of Flood Risk Management,* 10**,** 205-218.

Hutchins, M., Qu, Y., Seifert-Dähnn, I. & Levin, G. 2024. Comparing likely effectiveness of urban Nature-based Solutions worldwide: The example of riparian tree planting and water quality. *Journal of Environmental Management,* 351**,** 119950.

Ibrahimi, K. & Alghamdi, A. G. 2022. Available water capacity of sandy soils as affected by biochar application: A meta-analysis. *CATENA,* 214**,** 106281.

Indiana Watershed Initiative. n.d. Two-Stage Ditch. Available: https://www.indianawatershedinitiative.com/two-stage-ditch.html

Jeremy Benn Associates (JBA). 2024. Fife Stage 1: Strategic Flood Risk Assessment Final report. Available: https://www.fife.gov.uk/__data/assets/pdf_file/0035/550988/2023s0549-Fife-Stage-1-Strategic-Flood-Risk-Assessment-Final.pdf

Kaur, G., Singh, G., Motavalli, P. P., Nelson, K. A., Orlowski, J. M. & Golden, B. R. 2020. Impacts and management strategies for crop production in waterlogged or flooded soils: A review. *Agronomy Journal,* 112**,** 1475-1501.

Kent County Council. n.d. Design Guide for Irrigation Reservoirs. Available: https://www.kent.gov.uk/__data/assets/pdf_file/0007/71656/design-guide-for-irrigation-reservoirs.pdf

Khardi, Y., Lacombe, G., Dewandel, B., Hammani, A., Taky, A. & Bouarfa, S. 2024. Conjunctive use of floodwater harvesting for managed aquifer recharge and irrigation on a date farm in Morocco. *Irrigation and Drainage,* 73**,** 1424-1436.

King, E., Lamont, K., Wendelboe-Nelson, C., Williams, C., Stark, C., van Woerden, H. C. & Maxwell, M. 2023. Engaging the agricultural community in the development of mental health interventions: a qualitative research study. *BMC Psychiatry,* 23**,** 399.

Kirkbride, M. P., Black, A. R., Brazier, V. & Pickering, B. S. 2021. Intense rainfall and debris flows in the Lomond Hills, Fife, 11–12 August 2020. *Scottish Geographical Journal,* 137**,** 210-227.

Macadam, C. R., Dodd, K., Lewis, R. & Smith, E. 2025. The invertebrate fauna of the River Eden. Buglife, Stirling.

Maclean, L., Beevers, L. C., Waylen, K., Wright, G. & Wilkinson, M. 2015. Learning from community-led flood risk management. Available: https://www.nfm.scot/sites/www.nfm.scot/files/CREW_COS_fullreport.pdf.

Marine Scotland. 2016. Signal Crayfish - an unwelcome addition to scottish streams. The Scottish Government. Available: https://www.gov.scot/binaries/content/documents/govscot/publications/factsheet/2019/11/marine-scotland-topic-sheets-freshwater/documents/signal-crayfish---an-unwelcome-addition-to-scottish-streams-updated-october-2016/signal-crayfish---an-unwelcome-addition-to-scottish-streams-updated-october-2016/govscot%3Adocument/signal-crayfish.pdf

McEwen, L., Bryan, K., Black, A., Blake, J. & Afzal, M. 2021. Science-Narrative Explorations of “Drought Thresholds” in the Maritime Eden Catchment, Scotland: Implications for Local Drought Risk Management. *Frontiers in Environmental Science,* Volume 9 - 2021.

Medupin, C. 2019. Distribution of benthic macroinvertebrate communities and assessment of water quality in a small UK river catchment. *SN Applied Sciences,* 1**,** 544.

Montgomery, D. R. 1997. What's best on the banks? *Nature,* 388**,** 328-329.

Moore, M. T., Kröger, R., Locke, M. A., Cullum, R. F., Steinriede, R. W., Testa, S., Lizotte, R. E., Bryant, C. T. & Cooper, C. M. 2010. Nutrient mitigation capacity in Mississippi Delta, USA drainage ditches. *Environmental Pollution,* 158**,** 175-184.

Nadiu Tushaani, Fisher Harry & Cole Lorna. n.d.Harnessing the power of nature: arable edges and hedges. Address: https://www.sruc.ac.uk/media/kdrh0mse/104558-sruc-hedges-edges-report_10.pdf#page=12.05

Naha, S., Monteagudo, D. H., Lau, T., MacCarthy, B. & Glendell, M. 2025. [Preprint]. Using Reported Water Use Data to Map Future Water Scarcity in Scotland. *Available at SSRN 5214283*.

Ogrodowicz, P., Kuczyńska, A., Krajewski, P. & Kempa, M. 2023. The effects of heading time on yield performance and HvGAMYB expression in spring barley subjected to drought. *Journal of Applied Genetics,* 64**,** 289-302.

Panagos, P., Ballabio, C., Himics, M., Scarpa, S., Matthews, F., Bogonos, M., Poesen, J. & Borrelli, P. 2021. Projections of soil loss by water erosion in Europe by 2050. *Environmental Science & Policy,* 124**,** 380-392.

Powell, Ward, A., Mecklenburg, D. & Jayakaran, A. 2007. Two-Stage Channel Systems: Part 1, A Practical Approach for Sizing Agricultural Ditches. *Journal of Soil and Water Conservation,* 62**,** 27-286.

Quinn, P. F., Hewett, C. J. M., Wilkinson, M. E. & Adams, R. 2022. The Role of Runoff Attenuation Features (RAFs) in Natural Flood Management. *Water,* 14**,** 3807.

Rivington, M., Jabloun, M., Aitkenhead, M., Gimona, A., Martino, S., Gagkas, Z., Matthews, K., & Waylen, K. 2023. Summary of the Climate Trends, Future Projections and Extremes in Scotland. (Project D5-2 Climate Change Impacts on Natural Capital). Available: Zenodo. https://doi.org/10.5281/zenodo.8132272

Roberts, M., Hawes, C. & Young, M. 2023a. Environmental management on agricultural land: Cost benefit analysis of an integrated cropping system for provision of environmental public goods. *Journal of Environmental Management,* 331**,** 117306.

Roberts, M. T., Geris, J., Hallett, P. D. & Wilkinson, M. E. 2023b. Mitigating floods and attenuating surface runoff with temporary storage areas in headwaters. *WIREs Water,* 10**,** e1634.

Rossie Estate. n.d. *Rossie Estate:* An Old Historic Site. Available: https://backhouserossie.co.uk/rossie-estate/

SAC Consulting. n.d. (a). Exploring Rural Ecosystem Services: 3D bufferstrips. Available: https://www.sruc.ac.uk/media/iwypycaa/3d-bufferstrips.pdf

SAC Consulting. n.d. (b). Natural Flood Management: A Farmers Guide. Available: https://www.farmingandwaterscotland.org/wp-content/uploads/37a9c7d9d3dde9337c6d0690229daa8799c11654bc38/2019_NFM_Guide_R.pdf

Scottish Government 2018. Water Margins in Arable Fields. Available: https://www.ruralpayments.org/topics/all-schemes/agri-environment-climate-scheme/management-options-and-capital-items/water-margins-in-arable-fields/#606105.

Scottish Government 2022. Scottish Remote Sensing Portal. Available: https://remotesensingdata.gov.scot/data#/list

Scottish Government. 2025. Whole Farm Plan full guidance. Available: https://www.ruralpayments.org/topics/all-schemes/whole-farm-plan/

Scottish Invasive Species Initiative. n.d. Giant Hogweed. Available: Giant hogweed | Scottish Invasive Species Initiative (SISI)

SEPA. 2009. Engineering in the Water Environment Good Practice Guide: Riparian Vegetation Management. Available: https://www.sepa.org.uk/media/151010/wat_sg_44.pdf#page=19.73

SEPA. 2015. Natural Flood Management Handbook. Available: https://www.sepa.org.uk/media/163560/sepa-natural-flood-management-handbook1.pdf

SEPA. 2025 Scotland's National Water Scarcity Plan. Available: https://view.officeapps.live.com/op/view.aspx?src=https%3A%2F%2Fbeta.sepa.scot%2Fmedia%2Fq2ufwqpy%2Fscotland-s_national_water_scarcity_plan_v12.docx&wdOrigin=BROWSELINK

SEPA. 2016. Supporting Guidance (WAT-SG-03). Data Analysis and River Quality Planning Model. Available: https://www.sepa.org.uk/media/219686/wat_sg_03.pdf.

Spray, C.J., Arthur, S., Bergmann, A., Bell, J., Beevers, L. andBlanc, J. (2015), Land management for increased flood resilience, CREW CRW2012/6. Available: crew.ac.uk/sites/www.crew.ac.uk/files/publication/CREW_Land_Management_for_increased_flood_resilience.pdf

Stutter, M., Baggaley, N., Donnelly, D., Lilly, A., Mellander, P.-E., Wilkinson, M. & Daire, Ó. n.d. A handbook for the riparian mitigation measures selection tool. Available: http://www.smarterbufferz.ie/HandbookTool.pdf.

Stutter, M., Kronvang, B., Ó hUallacháin, D. & Rozemeijer, J. 2019. Current Insights into the Effectiveness of Riparian Management, Attainment of Multiple Benefits, and Potential Technical Enhancements. *Journal of Environmental Quality,* 48**,** 236-247.

Sustianable Cupar. 2025. River Eden Sustainability Partnership Nature Restoration Fund Development Grant Final Report.

The Forth Rivers Trust. 2024. River Eden: Habitat and Invasive Non-native Species Report. Available: https://www.riveredenfife.org/wp-content/uploads/2025/03/App-3-Habitat-Survey-Report.pdf

USDA. 2008. Stream Restoration Design National Engineering Handbook: Two-Stage Channel Design. Available: https://directives.nrcs.usda.gov/sites/default/files2/1712931096/7318.pdf#page=19.17

Van, B. 2023. *By land, water, and air: an evaluation of the impact of embankment setbacks and two-stage channel design on flood characteristics of the upper River Nith.* University of Glasgow.

Wagner, M., Waterton, C. & Norton, L. R. 2023. Mob grazing: A nature-based solution for British farms producing pasture-fed livestock. *Nature-Based Solutions,* 3**,** 100054.

Zaralis, K. & Padel, S. Effects of High Stocking Grazing Density of Diverse Swards on Forage Production, Animal Performance and Soil Organic Matter: A Case Study. *In:* THEODORIDIS, A., RAGKOS, A. & SALAMPASIS, M., eds. Innovative Approaches and Applications for Sustainable Rural Development, 2019// 2019 Cham. Springer International Publishing, 131-146.

## Appendix A – Management Scoring Exercise Supporting Material

Table 9: Example scoring exercise sheet used to obtain scores and support workshop participants

| Measure | Environmental | | | | | | | Economic | | | | | | | Social | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Two-stage channel | | | | | | | | | | | | | | | | | | | | | |
| Restoring natural channel morphology | | | | | | | | | | | | | | | | | | | | | |
| Drainage maintenance | | | | | | | | | | | | | | | | | | | | | |
| Controlled drainage | | | | | | | | | | | | | | | | | | | | | |
| Removal of constrictions | | | | | | | | | | | | | | | | | | | | | |
| Leaky barriers | | | | | | | | | | | | | | | | | | | | | |
| Retention ponds & wetlands | | | | | | | | | | | | | | | | | | | | | |
| Riparian buffers, field margins, sediment traps and bunds | | | | | | | | | | | | | | | | | | | | | |
| Regenerative agriculture – cover crops, minimum tillage, mob grazing | | | | | | | | | | | | | | | | | | | | | |
| Aeration/ Mole ploughing | | | | | | | | | | | | | | | | | | | | | |
| Nutrient monitoring and management planning | | | | | | | | | | | | | | | | | | | | | |
| Irrigation Lagoons | | | | | | | | | | | | | | | | | | | | | |
| Precision Irrigation | | | | | | | | | | | | | | | | | | | | | |
| **Scale:** -3 being very negative, 3 being very positive impact and zero having no impact. | -3 | -2 | -1 | 0 | 1 | 2 | 3 | -3 | -2 | -1 | 0 | 1 | 2 | 3 | -3 | -2 | -1 | 0 | 1 | 2 | 3 |
| **Guiding questions** | What environmental impacts (on water, soil, habitat, etc) will this option have? | | | | | | | What economic impacts will this option have? Balancing the costs of implementation, maintenance and the potential cost savings, improvements and income to the landowner. | | | | | | | What impacts will this option have on the local community? Consider how this may influence food, water, shelter, amenity and intrinsic value. | | | | | | |

## Appendix B: Alternative representation of management option scoring

Box and whisker figures are provided in Figure 40, with a supporting representation on how to interpret the outputs in Figure 39.

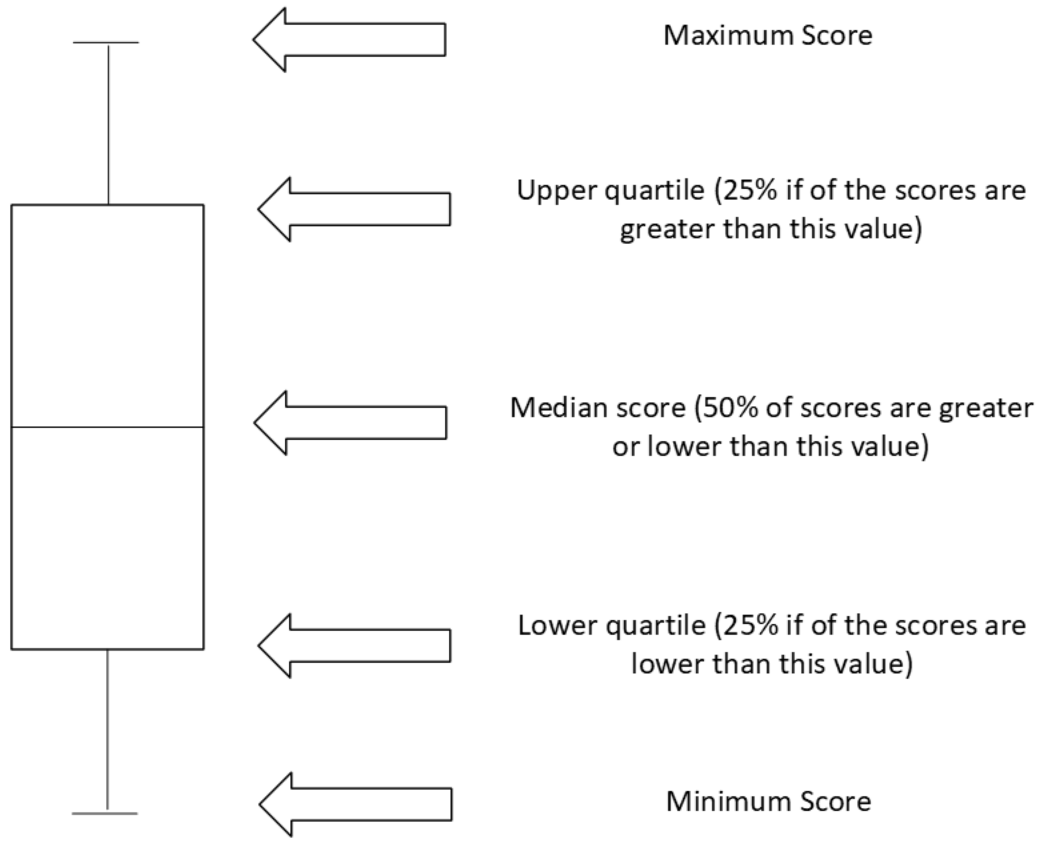
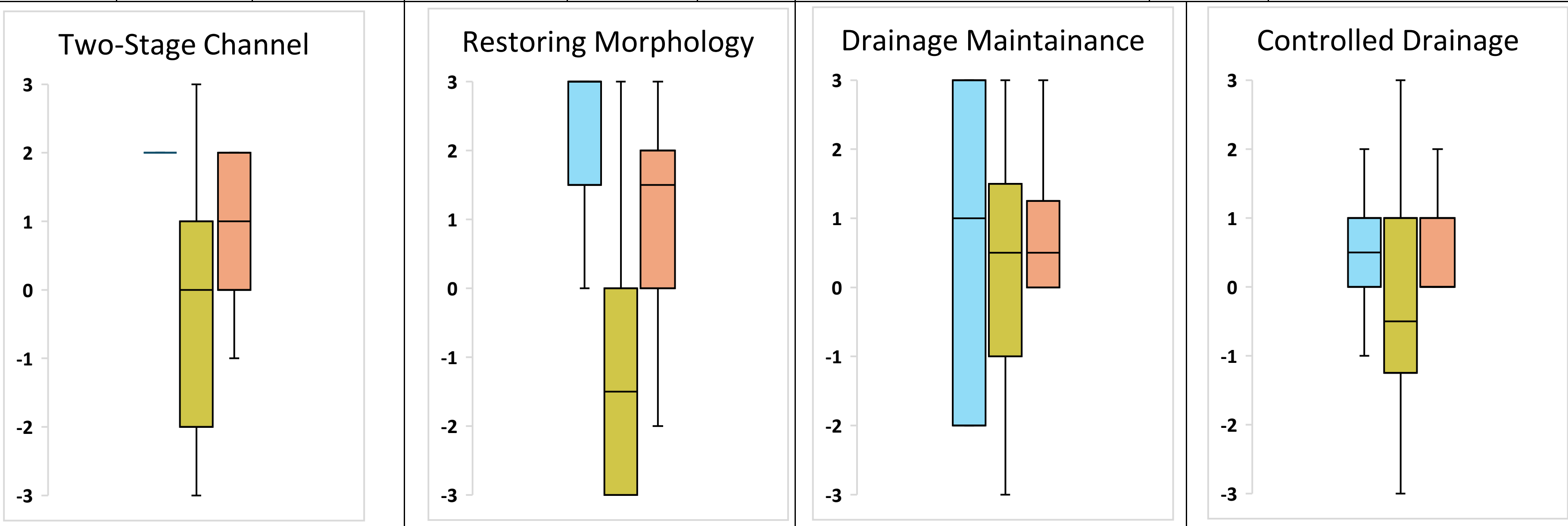
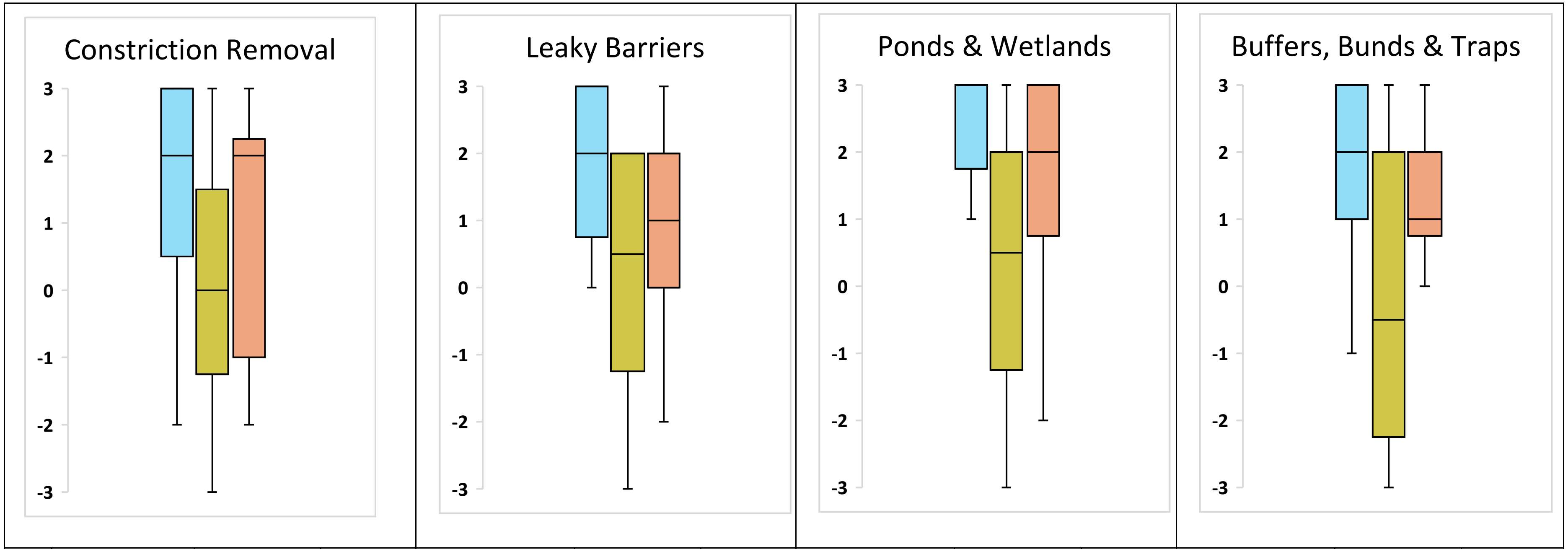



Figure 39: Guidance on how to interpret box and whisker figures

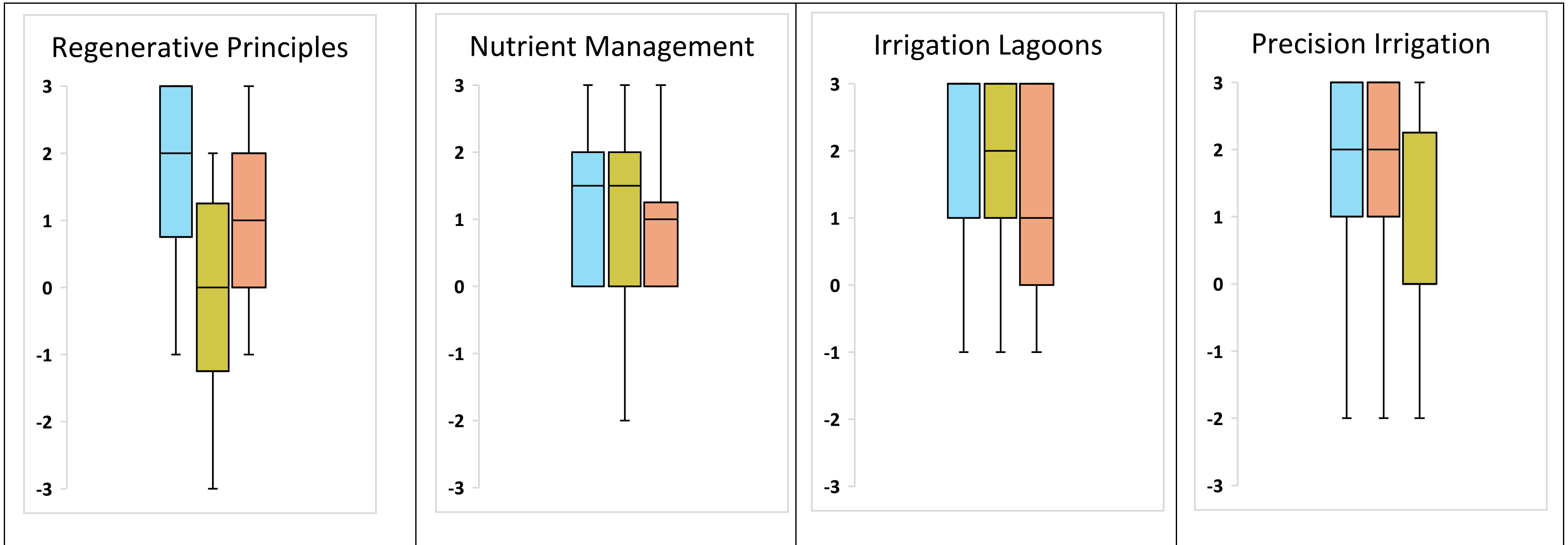
| Box and whiskers key | | | | | | -3 | -2 | -1 | 0 | 1 | 2 | 3 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| M | A | SD | Environmental | Economic | Social | Negative Impact | | | Neutral | Positive Impact | | |
| Median | Average | Standard Deviation | | | | | | | | | | |




| | Two-Stage Channel | | | Restoring Morphology | | | Drainage Maintainance | | | Controlled Drainage | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Environmental | Economic | Social | Environmental | Economic | Social | Environmental | Economic | Social | Environmental | Economic | Social |
| M | 2 | 0 | 1 | 3 | -1.5 | 1.5 | 1 | 0.5 | 0.5 | 0.5 | -0.5 | 0 |
| A | 1.93 | -0.21 | 0.79 | 1.93 | -1.21 | 1.00 | 0.57 | 0.43 | 0.71 | 0.64 | -0.29 | 0.43 |
| SD | 0.46 | 1.78 | 0.94 | 1.83 | 1.78 | 1.46 | 2.06 | 1.76 | 1.28 | 0.97 | 1.71 | 0.62 |




| | Environmental | Economic | Social | Environmental | Economic | Social | Environmental | Economic | Social | Environmental | Economic | Social |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| M | 2 | 0 | 1 | 2 | 0 | 2 | 2 | 0.5 | 1 | 3 | 0.5 | 2 |
| A | 1.93 | -0.21 | 0.79 | 1.57 | 0.07 | 1.07 | 1.64 | 0.14 | 0.86 | 2.21 | 0.29 | 1.50 |
| SD | 0.46 | 1.78 | 0.94 | 1.64 | 1.98 | 1.67 | 1.63 | 1.81 | 1.36 | 1.61 | 1.71 | 1.40 |




| | Environmental | Economic | Social | Environmental | Economic | Social | Environmental | Economic | Social | Environmental | Economic | Social |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| M | 2 | 0 | 1 | 1.5 | 1.5 | 1 | 3 | 2 | 1 | 2 | 2 | 0 |
| A | 1.43 | -0.07 | 1.00 | 1.36 | 1.07 | 1.00 | 2.07 | 1.79 | 1.21 | 1.93 | 1.64 | 0.79 |
| SD | 1.68 | 1.49 | 1.13 | 1.04 | 1.39 | 1.00 | 1.28 | 1.15 | 1.57 | 1.33 | 1.34 | 1.42 |

Figure 40: Box and whisker graphs with supporting summary statistics of the management option scoring exercise