Mitigation options for reducing beaver burrowing impacts on agricultural land in the River Isla Catchment, Scotland

Collapsed beaver burrows on the banks of the River Isla

For

NatureScot

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Prepared by

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Disclaimer

These notes are compiled on the basis of the River Restoration Centre's (RRC) expertise and a walk over site visit to the lower River Isla catchment 7th – 11th March 2022. RRC seeks to provide advice and suggestions to facilitate river restoration progress, but is careful not to produce detailed design drawings. In this way the RRC limits its liability. Liability for any restoration designs should be with the consultants tasked with the detailed technical feasibility and design work which will be necessary to take forward any options identified in this document.

RRC is a national centre for information and advice and holds a dataset of river restoration and best practice management works. To inform this inventory please let us know of any progress with this project and also other projects which are planned in the future. Please send any information to the RRC (rrc@therrc.co.uk).

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Executive Summary

This document outlines the concerns related to beaver activity on agricultural land and provides advice for reducing the impact of beaver activity (in particular beaver burrowing) in the River Isla catchment, Scotland. Site visits were carried out to several locations across the catchment in March 2022 and involved observing the impacts of beaver activity and discussing with landowners/managers their concerns. Beaver burrowing was highlighted as a dominant concern for landowners/managers due to the impact and potential for impact on bank and embankment stability. Long-term beaver management is best focused where practicable on setting back embankments creating space for beavers and natural river processes and through the establishment or regeneration of riparian buffer zones with native vegetation along the rivers, streams and ditches to help stabilise river banks.

Introduction

The Eurasian beaver (*Castor fiber*) is native to Britain but became extinct around 400 years ago because of hunting predominantly. Beavers have now recolonised a substantial area of Scotland following both official reintroduction to Knapdale in 2009 and unauthorised escapes / releases in Tayside. The Eurasian beaver became a European Protected Species (EPS) in Scotland in May 2019.

The Scottish Beaver Forum was established by NatureScot in 2017 in preparation for beavers gaining EPS status and together produced the Beaver Management Framework. This includes the Beaver Mitigation Scheme which was set up to offer advice and practical assistance to those experiencing impacts associated with beaver activity. Through the scheme NatureScot provides free expert advice to help people experiencing problems such as tree damage, dam building, burrowing and where possible will provide measures to mitigate impacts.

Beavers construct lodges and burrows as a form of shelter, quite often a burrow can evolve into a lodge (Rosell, Campbell-Palmer, 2022). Beaver burrowing has been identified as a particular area of concern as some landowners/managers in Tayside have experienced flood embankment blowouts where the embankment stability has been weakened due to beaver burrowing, whilst others are concerned about the potential for these impacts. To date the mitigation scheme has had little in the way of solutions to try and deal with this and thus a technical subgroup of the Scottish Beaver Forum was set up to investigate the issue. Using existing casework reports, the Scottish Beaver Forum identified sites to characterise the extent and severity of beaver impacts. Upon looking at the results it became obvious that a cluster of sites around the Isla catchment presented some of the highest severity in terms of actual and potential impact. A decision was made to initially focus on this cluster of sites to investigate potential mitigation for beaver burrowing seeking advice from the River Restoration Centre providing specific expertise in river processes.

The lower River Isla and tributaries were visited in March 2022 (Figure 1) with Nature Scot, the River Restoration Centre and the landowners/managers to understand the concerns related to beaver activity and the impact it is having on land management.

Purpose of document

This document provides general guidance for managing agricultural land alongside rivers where beavers are present to help minimise the impacts of beaver activity (in particular, beaver burrowing). The notes are based on observations made during site visits within the River Isla catchment in March 2022.

Impacts of beavers

Beavers have both positive and negative impacts on environment and society (Brazier et al., 2020). Challenges arise where beaver activity interacts with human activity, particularly in areas of prime agricultural land (Tayside Beaver Study, 2015). This is mostly observed in the channel or riparian zone where human interests lie (e.g., infrastructure, agricultural land, homes). For example, ponding and storage of water behind beaver dams can contribute to flooding of valuable land. Beavers are able diggers and excavate burrows, chambers and canals into riverbanks (Wilson, 1971, Richard, 1967; Campbell et al., 2015). Beavers often excavate multiple burrows in the banks in a single territory which can create areas of localised bank weakness (Harvey et al., 2018). Burrows often collapse if inundated with water during flood flows or if the bank materials are easily erodible (Campbell et al., 2015). Other concerns related to beaver activity is the gnawing, coppicing and felling trees, and the grazing of arable crops (Campbell-Palmer et al., 2016; Campbell-Palmer et al., 2015). In these instances where conflicts occur, beaver presence is perceived as negative and therefore there is a need for practical management interventions in the beaver, agricultural land, and society interface.

On the other hand, beaver activity also has multiple environmental benefits. Often these benefits are most readily seen in non-prime agricultural land and smaller headwater systems. Beavers are commonly referred to as 'ecosystem engineers' with associated hydrological, geomorphological, ecological and societal impacts (Brazier et al., 2020). Beavers can build dams which pond water, store sediment and nutrients creating rich wildlife areas (Brazier et al., 2020). Beaver dams also slow the flow of water, helping to reduce peak flows downstream, or gently release flows during droughts (Geris et al., 2022). Canals excavated by beavers on the banks provide access to food or building resources and can enhance river channel lateral floodplain connectivity (Gorczyca et al., 2018; Pollock et al., 2014). Beaver tree coppicing provides deadwood material to the channel and allows sunlight to reach the channel creating habitats for insects, birds, bats and other wildlife plus can stimulate root re-growth helping to bind soils (Stringer and Gaywood, 2016). As a result, beavers are considered keystone species maintaining ecologically complex and functioning rivers or restoring degraded systems (Brazier et al., 2020).

There is a balance between living alongside beavers for the benefits and managing the impacts they can have on society. Therefore, an appraisal of the options available to mitigate the impacts of beaver burrowing particularly on prime agricultural land, and their applicability in a catchment facing these challenges, is required.

The River Isla Catchment

The River Isla flows from the southern Cairngorms and northern Sidlaw Hills to the River Tay (Figure 1). The Isla catchment is composed of a number of watercourses, with the largest ones being the River Isla (~75km long) and River Ericht (~53km long). The River Isla and Ericht are tributaries of the River Tay and lie within the River Tay Special Area of Conservation designated primarily for Atlantic Salmon, Brook Lamprey, River lamprey, Sea lamprey and Otter.

Site visits in March 2022 focused on the lower River Isla and tributaries (Figure 1) where beaver burrowing activity impacts were identified in previous casework reports commissioned by NatureScot. Nine sites on the River Isla, two sites in the River Ericht, and one site each on the Dean Water and Baikie Burn were visited. The site visits provided an indication of the issues relevant to each location. Common issues were observed between sites which have been combined in this document to provide some general guidance on managing the impacts of beavers.

Beavers have been present in the River Isla catchment for well over a decade with some reports dating from the 2000's. An initial beaver population survey undertaken in 2012 estimated 38-39 active family groups in Tayside (Campbell et al. 2012). By the 2020/21 population survey there were estimated to be 251 active territories with an average group size of 3.8 which gives a population estimate of approximately 954 individuals (range 602 -1381 individuals) with an estimated 30% annual increase from previous surveys. Although these figures comprise a far larger area than just the Isla catchment, including the Tay, Earn and to an extent the Forth.

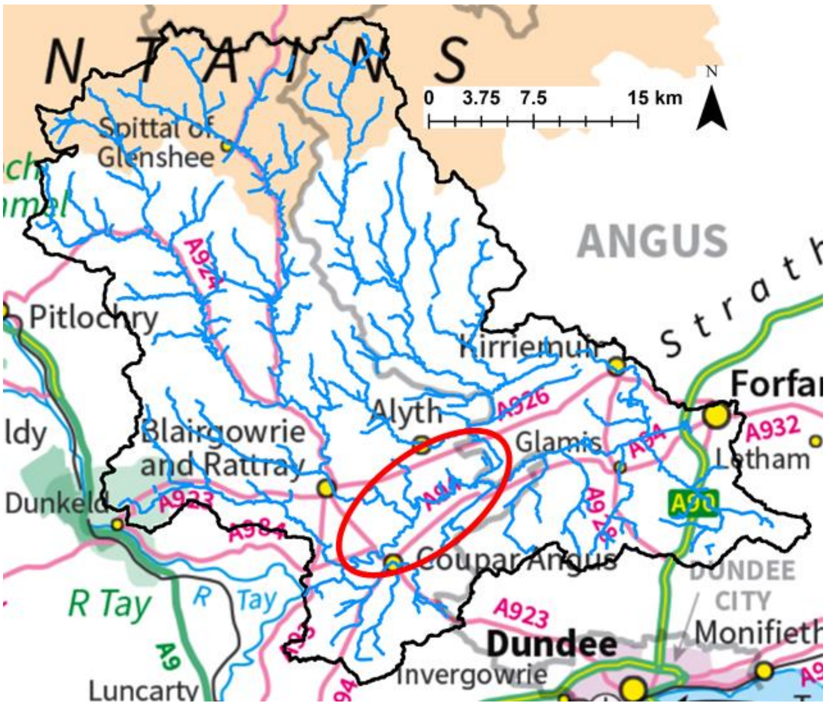


Figure 1. The River Isla catchment area (black line), river network (blue lines), and red oval indicates the approximate area where the site visits took place in March 2022. Base map: OS Open Raster 2020 (Crown Copyright and database right 2020).

Geology

The predominant bedrock geology in the lower River Isla catchment is a mix of the Teith Sandstone Formation, Cromlix Mudstone Formation (part of the Strahmore Group) and Scone Sandstone Formation (Arbuthnott-Garvock group) therefore the bedrock geology is composed of mudstone, sandstones, and siltstones (British Geological Society - https://www.bgs.ac.uk/geological-data/map-viewers/). The superficial geology of the lower Isla catchment is predominantly fluvial deposits – clay, silt sands and gravels, with some glacio-fluvial deposits, these sediments are very easily erodible. The sites visited in the lower River Isla catchment were generally topographically unconfined with an approximate valley bottom width of 1000m (based on Scottish LIDAR data – phase 1 2011-2012 1m DTM source - https://remotesensingdata.gov.scot/data#/).

River Channel Changes

One of the earliest historic maps providing an indication of river channel planform in the River Isla catchment is William Roy's Military Survey of Scotland map (1747-55), Figure 2. This map shows the River Isla with an active meandering planform with sediment bars. In the more recent maps (Figure 2) parts of the meanders have been cut off, in some locations this is due to natural processes (meander neck cut off during large floods), or due to human modifications where the channel has been straightened. Remnant oxbow lakes are present in the floodplains and old meander scars can be detected in the topographic data (e.g., LIDAR).

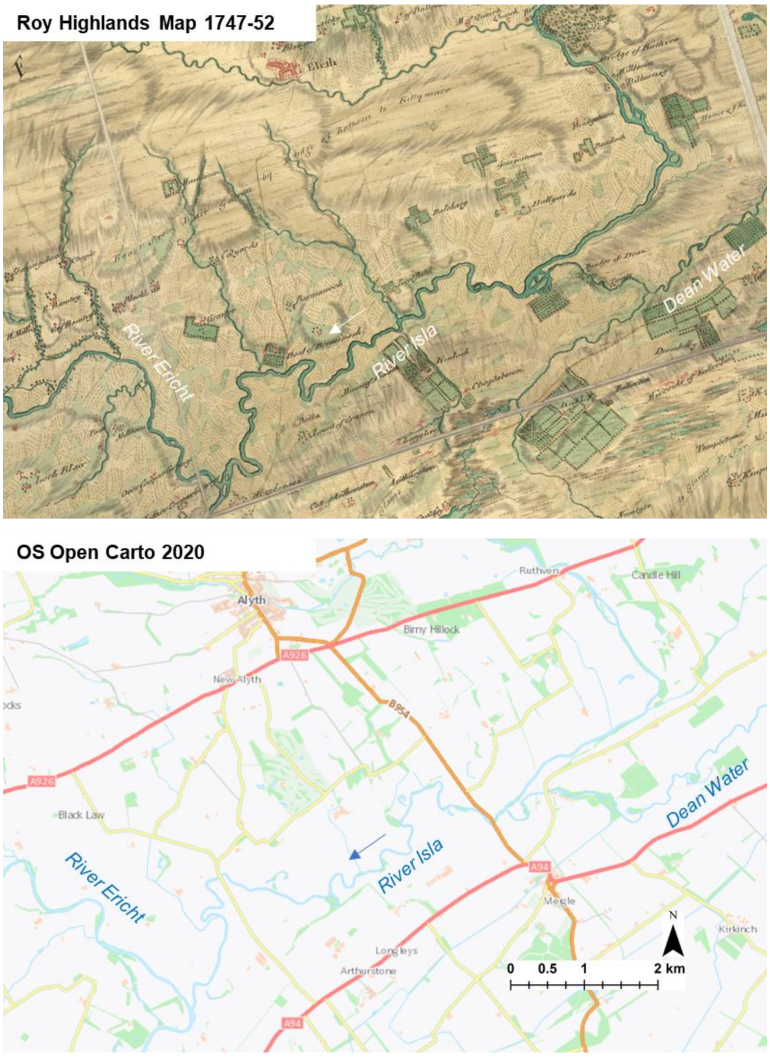


Figure 2. Roy Map of Scotland (1747-52) (top) (source: National Library of Scotland) compared to the OS open carto 2020 map (bottom). Arrows indicate flow direction.

Land use

The predominant land use in this area is high value (prime) agriculture land with a mix of traditional arable crop rotation, vegetables, berries and good quality livestock grazing. Prime agricultural land (PAL) is defined as Classes 1 - 3.1 on the Macaulay system of land capability for agriculture, land within these classes produces a wide range of crops because of favourable conditions such as friable soil, good drainage and limited slope. PAL equates to ~10% of Scotland's land area and so is recognised as a nationally important finite resource.

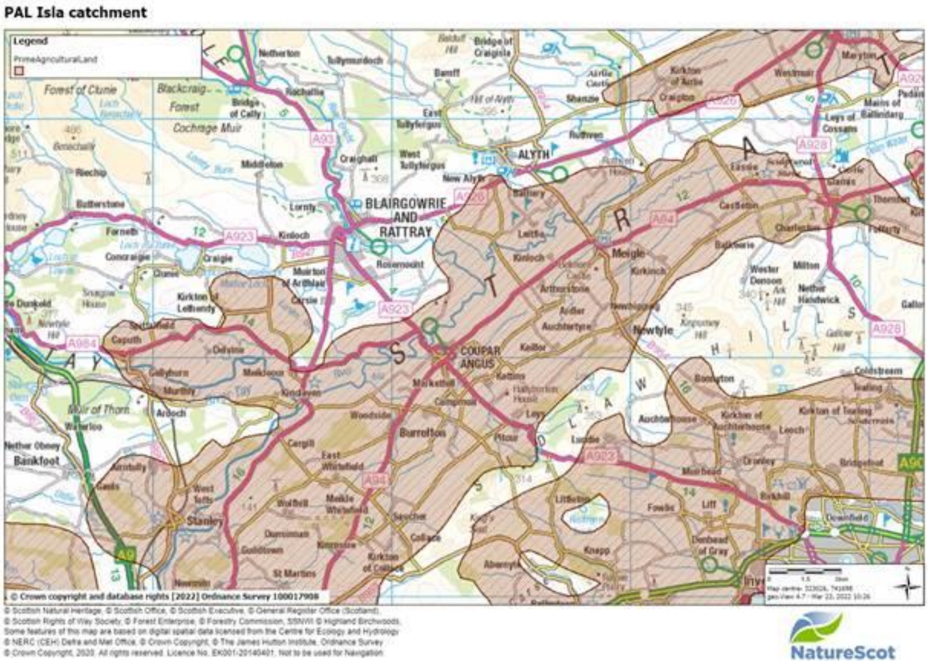


Figure 3. Area of prime agricultural land (shaded brown) in the lower Isla catchment.

SEPA Hydromorphological Assessment of the River Isla Catchment

In 2019, SEPA carried out a catchment and reach scale assessment of the hydromorphology of the River Isla catchment in response to a group of farmers enquiring about a potential sediment management licence. The report identified that the River Isla catchment was historically a depositional system, which was actively meandering and has since shifted to an erosional dominated system. This is attributed to changing climate and the associated impact on flood frequency, but also due to human modifications and management such as embanking, straightening, reinforcing the banks, dredging and installation of weirs that have constricted natural river processes and altered the natural sediment regime. In the SEPA report, sediment accumulation was not found to be a significant issue overall, but the removal of sediment is likely to result in excess channel energy, further exacerbating erosion. Erosion was also noted to be most severe where there was a lack of dense tree cover and thus increasing tree cover was recommended. The report recommended to address the cause of issues linked to the modification of river processes, rather than symptoms of erosion by setting back embankments to give the river more room, to help reduce energy in the channel as well as potentially reducing the frequency of embankment overtopping and flooding of prime agricultural land. The work highlighted the importance of considering the wider sediment regime, existing pressures and river history when carrying out works within the catchment.

Concerns arising from beaver activity in the River Isla catchment

During the site visits, the main concerns discussed with the landowners/managers were in relation to beaver impacts on valuable land and crops. Generally, the direct impact of tree damage was not perceived as an economic impact whereas damming of agricultural ditches that could subsequently affect the field drainage systems and cause upstream flooding for areas of PAL was seen to be a more serious concern. Weakened or compromised flood embankments were the greatest concerns as they may make embankments susceptible to a breach and land to flood which could have a significant financial impact on the farm businesses. This concern was greatest where embankments were at, or within close proximity (less than 5m) of, the river's edge. Burrowing into the riverbank was also a general point of concern for the farmers because most often the burrow entrances are underwater and therefore it is difficult to observe the extent (distance into bank, and sideways distance through the bank) of burrowing chambers and activity under the ground until there is failure of the burrow chamber or tunnel and either there is a visible hole in the bank or characteristic slumping. In summary, the following concerns were raised relating to beaver impacts and river processes:

- Collapse / failure of embankments due to beaver burrowing – valuable land flooded, crop income lost, costs and time associated with clear up and repair
- Loss of land and fences due to riverbank erosion/collapse exacerbated by beaver burrowing / tracks / canals
- Blocking of channels with beaver dams – causing flooding of valuable farmland, bank slumping and continuous removal costs/time
- Public liability – beaver burrows often not visible and concern for liability if walkers/anglers were to injure themselves.
- Felled trees (by beavers) that have fallen into the channel are a downstream flood risk liability
- Mid-channel island erosion due to tree loss from beaver activity
- Elevated fine sediment deposition in ditches due to tree removal by beavers and bank erosion

Figure 4. Examples of beaver impacts in the lower River Isla catchment observed during the visits in March 2022.

The effect of historic modifications on river processes

Rivers in the Isla catchment have been historically modified (e.g., embanked) and managed (e.g., dredged and vegetation managed) for agriculture and to protect land from flooding. As a result, river processes have been constrained, increasing erosion on the bed and banks so bank erosion protection measures, often using large boulders on the bank face and bank toe (e.g. rip-rap) have become more common. The following sections describe these channel modifications and the impacts on river processes, and how, when coupled alongside beaver activity, they can create concerns for landowners.

River straightening

Parts of the River Isla have been historically straightened evidenced in the historic maps (e.g., Roy Highlands Map (1747-52) and the OS maps (1850s – 1990s)) and topographic data (e.g., depressions of remnant channels visible in high resolution LIDAR data), from a previously meandering channel with mid-channel bars (Figure 5). This is likely to have occurred pre- or during very early embankment construction and has resulted in uniform river reaches (e.g., uniform in shape where all diversity in forms that provide habitats have been removed), with old paleo channels isolated from the main river (Figure 5). Straightening a meandering channel increases the bed slope (because of a reduction in channel length), and therefore water moves more quickly downstream. This results in an increase in river energy and therefore more potential for bed and bank erosion, which can lead to bank instability. The 2019 SEPA hydromorphological report highlighted that the River Isla catchment has shifted from a predominantly depositional catchment to an erosional catchment.

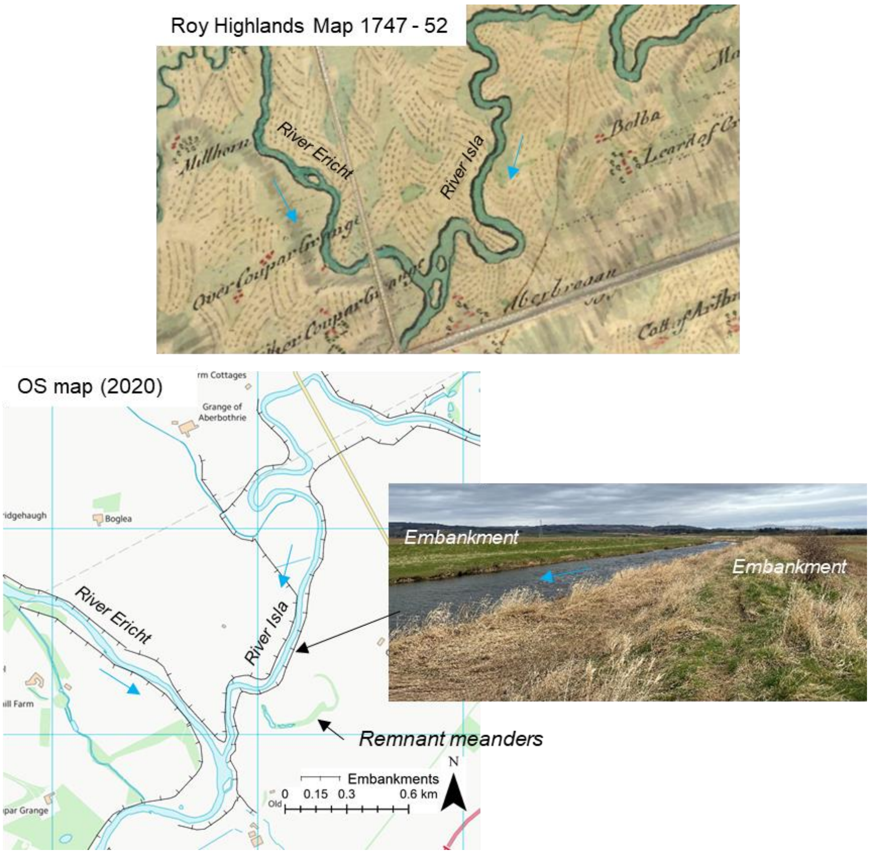


*Figure 5. Historic map (Roy Highlands Map 1747) compared to present OS map (*OS data © Crown Copyright and database right 2020) showing straightened *sections of the River Isla and River Ericht with setback embankments, remanent meander bends were observed in the floodplain.*

During the site visit landowners were concerned by bank erosion and associated loss of agricultural land and fence lines. Beaver activity can further contribute to bank erosion through the excavation of burrows and chambers in the bankside and via creation of beaver tracks and canals across the surface of the banks.

Flood embankments

Flood embankments were extensive along the channel banks in all the sites visited. Anecdotal reports suggest embanking dates to the Monks (*c.* 18th - 19th Century). At that time, embankments would have been built by hand and for this reason it is likely that they would have been far smaller and lower in height than their modern-day equivalent (now maintained and improved using large machinery). In the Tay catchment one of the earliest records of flood embankment construction is in a letter within the archives of the Atholl Estates in 1733 (Gilvear and Black, 1999). The letter states that one of the conditions of the mortgage of some land from the estate was that '12 ells of ground on the River Tay are to be fenced yearly with stones to prevent flood damage' (1 ell is equivalent to 1.14m).

Embankments affect natural river processes and can:

- Increase energy in the embanked channel area during floods (due to increased water depths) which can lead to increases in channel bank and bed erosion (which can subsequently cause the banks to be undermined and collapse).
- Constrain mobile rivers – rivers are restricted from moving laterally due to the presence of embankments, the River Isla historically would have laterally migrated across the floodplains, and therefore energy is concentrated on the channel bed which can lead to bed erosion and undercutting of channel banks.
- Disconnect floodplains – floodplains provide area for floodwater energy to be dissipated, therefore reducing energy in the channel and flows downstream. Over bank flows also provide water and nutrients for the land.

Flood embankment stability is influenced by multiple interacting factors including embankment design (angle, top width and height), construction materials (locally available or imported), embankment positioning (relative to the river), vegetation cover, water pressure, hydraulic processes, duration of flood peak and other factors. Embankment failure may occur due to:

- Erosion (embankment toe) due to a lack of distance (through river movement or poor embankment positioning) between the embankment and the riverbank, where riverbank erosion therefore equates to embankment erosion.
- Erosion (bank face) because of:
  - prolonged flood flows & high energy flows (eroding sediment particles on bank face)
  - saturation of the bank face leading to bank slump/collapse.
  - burrowing exposing bare soil/embankment material that is then scoured/eroded by flows
  - burrow or chamber collapse leading to bank slump/collapse
  - tree failure (wind-blown or floodwater) exposing bare soil/embankment material that is scoured
  - steepness of bank (e.g., too steep therefore leading to failure)
  - lack of cohesion of bank materials
  - lack of vegetation cover/root depth
  - emergency repairs
- Erosion (embankment crest) and reduction of embankment height due to overtopping flows.
- Erosion (landward face) due to flows overtopping the bank and scour on the landward face of the embankment.
- Seepage in the embankment which can lead to failure on either side of the embankment. Seepage can occur under the embankment and through the embankment face where the

increased height on the river side forces water through soil pores and fissures (including root voids and burrows).

- Slumping of the embankment face due to steepness of bank, lack of cohesion of bank materials, lack of vegetation cover/root depth.
- Animal burrowing or "honeycombing" weakening the bank structure – these burrows can be increased in size during floods

Gilvear et al., (1994) and Gilvear and Black (1999) investigated the causes of 228 embankment failures in the River Tay catchment over an 8-year period (1990 – 1997) and found:

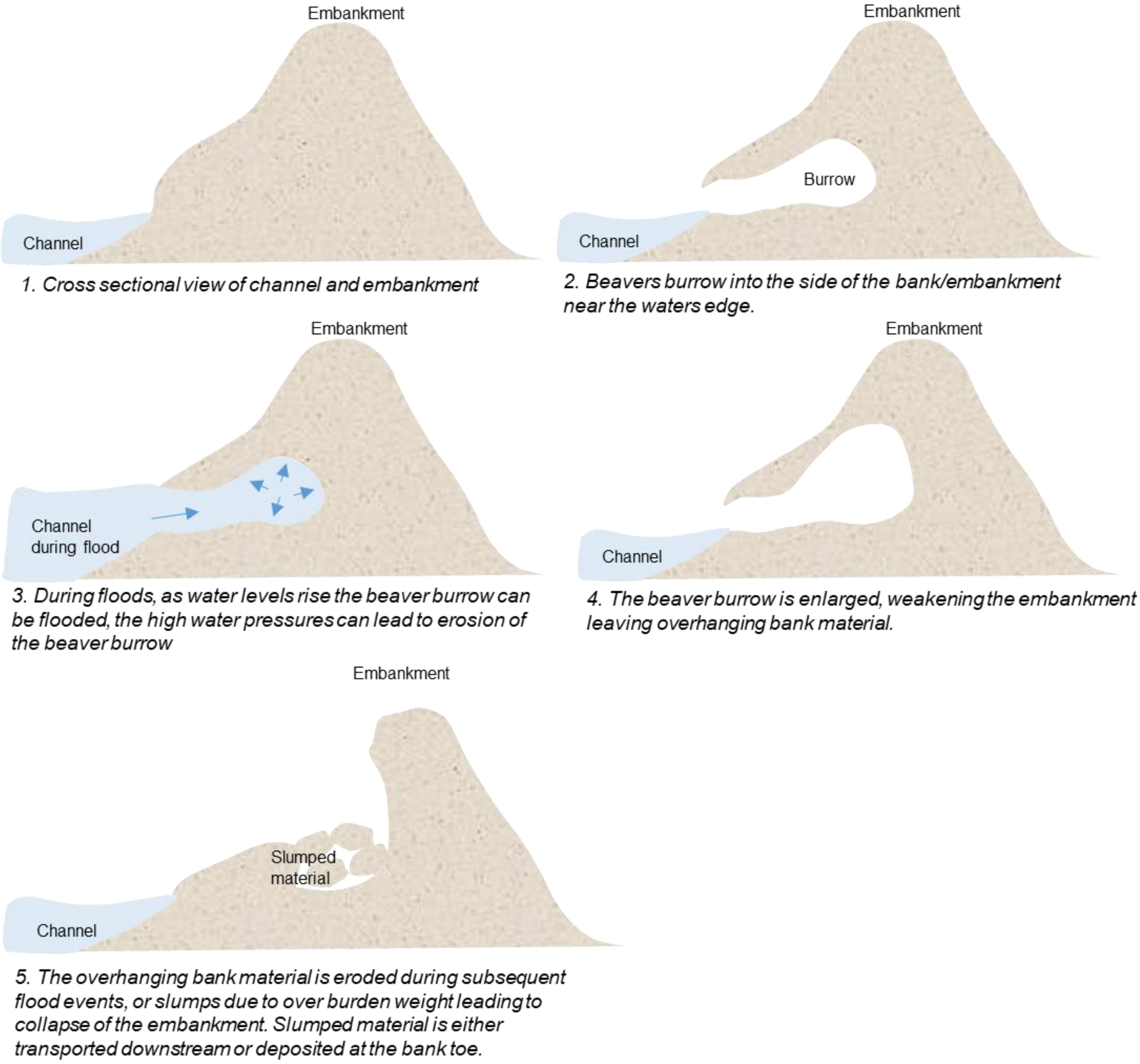
- The main cause of embankment failure (97% of 228 breaches investigated) was attributed to overtopping by floodwaters and floodplain basal scour evidenced by scour holes on the landward side of the river.
- Embankment failure tended to occur on the outside of meander bends and where embankments had been built on former river courses.
- Embankments were weakened due to animal burrowing.

Flood embankments in the River Isla catchment, were mostly observed on the bank top or set back a short distance (2-10m) from the water edge (Figure 6) and therefore there is little room for natural river processes and flood water energy dissipation. Embankments were often vegetated with grasses and regularly managed (cut and repaired) by landowners/managers. The embankments would have originally been constructed using dredged river sediments or other floodplain material. In the River Isla catchment, most embankment material would therefore comprise of mainly fine loamy silts and sands with little cohesivity or inherent strength and therefore are easily eroded. Embankment heights varied from just above field level (often tying into high ground), to up to 3.5 m high. Landowners have expressed concerns relating to the reduced stability of embankments in the River Isla catchment due to beaver burrowing activity.

Figure 6. Photos showing embankments on the River Isla taken in March 2022, blue arrows indicate flow direction. Embankments are commonly set back a short 2-10m distance from the water edge (top photo and bottom right photo) or located directly on the bank top (bottom left photo).

Figure 7. Example of embankment 'blow out' on the River Isla, this could have been caused by a combination of factors – embankment crest-overtopping by flood flows leading to scour on the landward side of the embankment and the weak bank materials used to construct the embankment. Beaver burrowing is less likely to have contributed to this embankment blow out due to the position of the embankment being set back from the river channel (>20m) and the shape of the scour hole on the embankment on the landward side.

Figure 8. Animal burrowing on eroding bank. This can contribute to localised bank erosion during flood events when water flows into the open burrow saturating and collapsing the roof, causing the bank surface to slump.



1. Cross sectional view of channel and embankment

2. Beavers burrow into the side of the bank/embankment near the waters edge.

3. During floods, as water levels rise the beaver burrow can be flooded, the high water pressures can lead to erosion of the beaver burrow

4. The beaver burrow is enlarged, weakening the embankment leaving overhanging bank material.

5. The overhanging bank material is eroded during subsequent flood events, or slumps due to over burden weight leading to collapse of the embankment. Slumped material is either transported downstream or deposited at the bank toe.

Figure 9. Conceptual diagram showing how burrowing into banks can lead to bank weakening (note burrowing into bank/embankments is one factor influencing stability, and there are often multiple interacting factors leading to bank/embankment collapse).

Bank and bed management

The River Isla has historically eroded, transported and deposited sediment to create its meandering course and floodplains (e.g., erosion on the outside of a meander bend is a natural process, and deposition occurs on the inside). Natural bank erosion fulfils several purposes it renews ecological habitats and is part of the natural sediment regime (Florsheim et al., 2008). However, channel modifications (embanking and straightening) in the lower River Isla catchment have exacerbated erosion on the bed and banks which has led to a loss of agricultural land and damage to fencing. In response to this, in places the channel banks have been reinforced and managed to try to reduce erosion. Certain types of bank reinforcement can exacerbate erosion issues further downstream, for example, hard bank protection (such as riprap/pitched stone) prevents water energy dissipation, and instead increases energy (due to the smooth stone/boulder surface) moving the problem immediately downstream, therefore where bank protection ends, further erosion is likely.

Landowners expressed concerns over bank erosion and loss of fences. These locations were often on the outside of meander bends (where velocities are highest, and erosion is the dominant process) or in straightened reaches (where energy is increased due to straightening and/or deepening/dredging).

Landowners were also concerned about beaver burrowing activity weakening bank stability and leading to increased likelihood of riverbank collapse or erosion.


Figure 10. Left - river bank erosion on outside of a meander bend, fence line is on the top of the bank and has been undermined. Right – example of bank toe reinforcement using large boulders 'rip-rap', this does not stop erosion but leads to excess bank erosion downstream where banks are not protected.

Bank materials in the River Isla catchment were composed of fine loamy sand and silts which lacked cohesivity, there was also a lack of mature bankside vegetation. Tree roots can physically bind sediment particles together, roots and vegetation can act to armour and protect the bank face sediments from fluvial entrainment, as well as increasing soil shear strength. In some situations, mature riparian vegetation was removed by landowners due to concerns over liability related to trees falling into the channel and contributing to flood risk or damage to properties downstream. In other locations, the riverbanks were often kept 'tidy' and over-managed through regular cutting and management and therefore only had one or two vegetation species (predominantly grasses which have a shallow root structure). On some sites visited, despite no livestock grazing pressure there was very limited riparian tree cover which could have arisen from other pressures such as vehicle (car, tractor etc) access, recreational access by fishing users, public access including horses and embankment repairs and reprofiling. Beaver burrow collapses were often observed where there were no, or isolated scattered trees, where there was little riparian bankside vegetation cover.

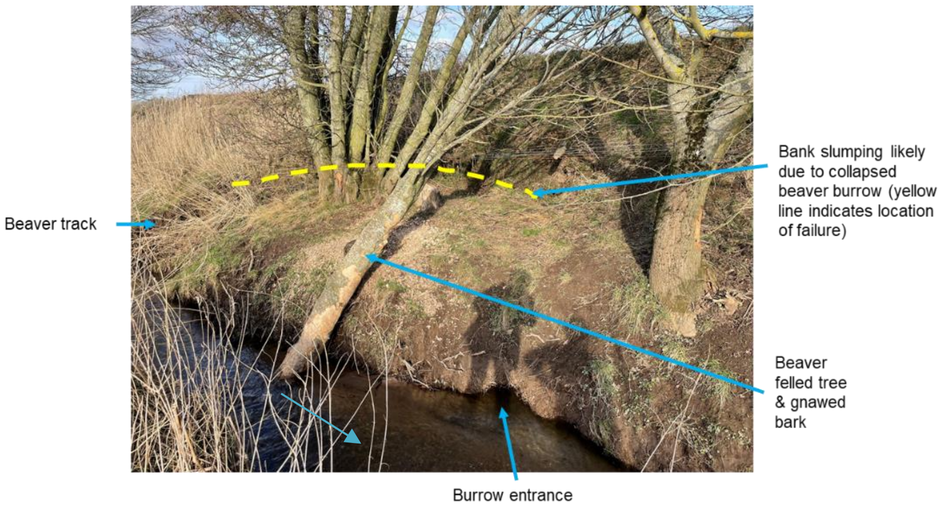


Figure 11. Example of the impact of beaver activity on bank erosion / stability in the River Isla catchment.

Channel maintenance (dredging, vegetation clearance)

Given the highly productive nature of the prime agricultural land there were well established regimes for channel and ditch management to ensure unimpeded drainage of fields, this included silt dredging, vegetation removal, riparian vegetation management. Dredging is commonly carried out to reduce the perceived loss of channel capacity due to deposition; however, rivers actively erode, transport and deposit sediment and therefore the area where sediment has been dredged will infill rapidly to maintain a natural sediment balance.

Living alongside beavers - mitigating the impact of beavers on agricultural land

This section outlines options for mitigating the impact of beavers to address the concerns of landowners/managers visited. Many of the mitigation options below involve working with natural river processes (rather than constraining them) to make rivers more resilient, move the beaver burrowing pressure away from critical infrastructure and support wider catchment benefits.

Reducing the risk of embankment breaches: creating space for river processes & beavers

Rivers in the Isla catchment are dynamic and have actively eroded and deposited sediment (evidenced by the historic maps and remnant meander scars in the floodplains). The erodible bank materials and lack of vegetation binding the bank materials together, means the banks are susceptible to erosion via fluvial processes with beaver burrowing contributing to further localised bank instability. Coupled with the modifications such as embankments and bank reinforcements restricting natural processes, the behaviour of the river has been altered and therefore there is a need to create space for natural processes and beavers along the river network.

In Bavaria, 90% of beaver conflicts with society occurred within 10 m of the water's edge (Campbell-Palmer et al., 2016). Where flood embankments are set back from the main channel by a distance greater than 30m the impacts of burrowing are insignificant (Campbell-Palmer et al., 2016). Conflicts further away from this have been observed, however, this is often rare and usually associated with an attractive food source (Campbell-Palmer et al., 2016). Creating space for natural processes and beavers could involve removing or setting back embankments (at least 20-30m from the channel. e.g. Figure 12), if setting back embankments various aspects of design and construction should be considered:

- Embankments built too high are often more susceptible to overtopping and crest failure.
- Re-construct embankments during spring-summer months so they re-vegetate quickly and are less likely to be washed out during winter floods.

If embankments cannot be set back, they can be retrofitted with hidden sheet piling or a heavy-duty wire mesh inserted into the embankment to deter beaver burrowing deep into the embankment (Figure 13). If embankments are set back far enough (greater than 30m), this additional reinforcement is unlikely to be needed. It is important to note that sheet piling will help reduce the likelihood of complete failure, and piling or wire mesh will prevent beaver burrowing activity to an extent, however, the embankment will still be under pressure on the river side from river processes, burrowing and flood flows requiring further maintenance and full repair if partially damaged.

Benefits of set-back embankments	Wider Environmental Benefits

• Reduced risk of beaver burrowing and associated failure
• Reduced risk of undercutting and erosion of the embankment by river processes
  ○ Velocities and shear stress acting on the embankment will be reduced as it is further from the channel
• Reduced risk of flooding of agricultural land:
  ○ Greater capacity for flood water to stay within the channel plus 20-30m before the embankment
  ○ The height required for an embankment reduces incrementally the further it is set back, as more water can be conveyed between the embankments.
	• Allowing space for natural river processes
	• Reduced flood risk downstream and climate change adaptation.

Figure 12. Example where the flood embankment is set back up to 60m from the riverbank allowing space for natural river processes and flood conveyance and avoiding any beaver burrowing activity due to the distance from the river bank. The grassed area could be improved by encouraging mixed vegetation growth.

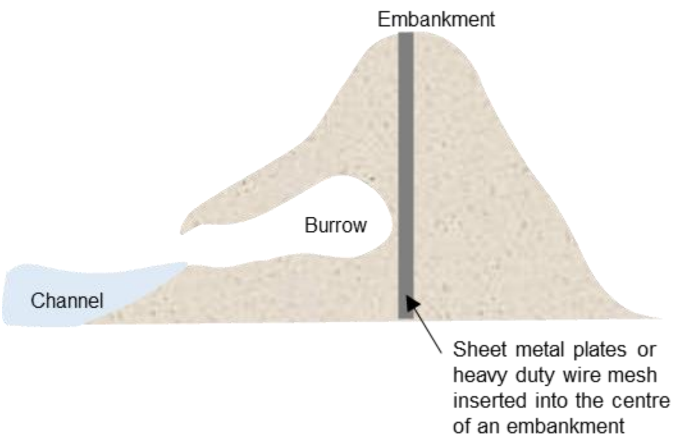


Figure 13. Cross section through embankment. Sheet metal plates or heavy-duty wire mesh can be inserted into the centre of an embankment to deter beavers burrowing too far into the embankment (modified from Campbell-Palmer et al., 2016)

Vegetated riparian corridor

At many locations there was a lack of, or lack of depth to the river margin, bank and bank top vegetation (often just a single line of mature trees perched on the bank edge). If a tree is eroded/undercut/felled by a beaver it leaves a 'gap' in the riparian zone and can affect the stability of vertical banks (due to the erodible bank materials), with no other well developed/well rooted trees behind it. Planting the riparian zone with native trees and shrubs (e.g., wet woodland by taking cuttings from existing riparian vegetation such as willows) will help to encourage natural vegetation regeneration. The vegetation growth will help to bind the erodible bank materials together and resist erosion. Also, creating a riparian vegetation buffer zone close to the water's edge will mean beavers do not need to move further into the floodplain/agricultural areas to find food.

If 20m+ riparian buffers already exist, but the vegetation is managed (e.g. regularly cut or is one type such as grass) these areas could be allowed to naturalise by allowing scrub and other vegetation to grow and become wooded over time or could be planted with native trees and shrubs.

Benefits of a vegetated riparian corridor	Wider Environmental Benefits
• Increased bank stability	• Direct ecosystem benefits associated with the creation of new riparian habitats and improvements to biodiversity

Further information on vegetation planting can be found in these resources:

- Restoring and Managing Riparian Woodlands (Scottish Native Woods) - www.environmentdata.org/archive/ast:64/OBJ/x050-restoring-and-managing-riparian-woodlands.pdf
- Riparian Vegetation Management (SEPA) - www.sepa.org.uk/media/151010/wat_sg_44.pdf
- Trees for Life – www.treesforlife.org.uk/into-the-forest/habitats-and-ecology/habitats/riparian-woodland/

Working with natural processes and restoring natural forms

The historic maps show the River Isla to be an actively eroding and depositing system. In the topographic LIDAR data and during the site visits old remnant meanders were observed in the floodplains. Some of these have been artificially cut off resulting in a local increase in channel slope, whereas others look to have naturally been cut off by meander bend migration and neck narrowing. Where remanent meanders have been cut off artificially, investigations could be made to reconnect these floodplain features, this will increase the channel length, and therefore reduce the channel slope, helping to dissipate some of the energy of the system. In locations where remnant channels cannot be fully reconnected banks can be lowered so that they can be inundated during flood events to help store floodwaters and slow the flow downstream.

Benefits	Environmental Benefits
• Reduced bank erosion • Reduced flood risk	• Resilient rivers • Natural flood management - slowing flow

Beaver management – restricting access / capture / control

To date, removal of beavers through either trapping for relocation or lethal control are the last resort options to prevent serious damage to agricultural interests when there are no suitable alternatives. Both lethal control and trapping for relocation are time consuming and will result in vacant territories which in time will likely be colonised again as young adult beavers disperse to find new territories.

Beaver exclusion is a management option that is currently being investigated in Scotland, particularly in relation to conflicts occurring in Prime Agricultural Land. One potential solution is “water gates” whereby an exclusion area is created through the installation of in-stream metal grilles/fencing and associated wing fencing is installed to prevent beaver access. In some situations, such as continual damming of agricultural ditches where flow devices are not an option could be resolved by beaver exclusion. The process for beaver exclusion takes time as it requires numerous checks for eligibility and consents. The first such trial example of water gates is planned for summer 2022.

Funding / policy

In Scotland, the current funding streams available to deliver the kinds of natural process restoration and riparian planting opportunities mentioned above are the Agri- Environment Climate Scheme (AECS), Forestry Grant Scheme (FGS) and potentially discrete challenge funds such as the Nature Restoration Fund. The agri-environment and forestry schemes have evolved from previous iterations to the present day over decades and as a result there is no specific reference to beavers. As a result of EU exit and other policy drivers such as the need for clearer demonstration of the outcomes delivered it is expected that there will be significant changes to the way these schemes are run in future. However, the current schemes will be in place more or less unchanged until at least 2024 while a National Test Programme is rolled out, similar to work ongoing in England. Meanwhile there are opportunities as set out in the NatureScot guidance to apply the current funding to beaver mitigation. For beaver mitigation the Water Environment Fund is not included as advised by SEPA. The green finance sector is also a potential area of opportunity which has not yet been tested in relation to beaver mitigation, although the packaging of measures would have to be carefully considered.

Summary of mitigation options

Long-term beaver management is best focused where practical on setting back embankments creating space for beavers and natural processes and through the establishment or regeneration of riparian buffer zones with native vegetation along the rivers, streams and ditches (Campbell-Palmer et al., 2016).

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