Forest Research

A Comparison of Nature Based Solutions: Beaver Dams versus Timber Flood Storage Bunds at Cropton Forest, N Yorks.

Credit: Pete Richman

Huw Thomas

Hydrologist

Forest Research

May 2024

The Research Agency of the
Forestry Commission

Forest Research is the Research Agency of the Forestry Commission and is the leading UK organisation engaged in forestry and tree related research.

The Agency aims to support and enhance forestry and its role in sustainable development by providing innovative, high quality scientific research, data, technical support and consultancy services.

Introduction

The “Slowing the Flow” project at Pickering in North Yorkshire was designed to look at how changes in land use and land management can help to reduce flood risk through greater working with natural processes, as well as provide wider multiple benefits for local communities.

The project began in 2009 and succeeded by implementing a range of measures within the Pickering Beck catchment, including planting and restoring 18.5 ha of riparian woodland, constructing ~130 large woody debris (LWD) dams and installing >130 heather bale check dams.

A number of Natural Flood Management (NFM) measures were also implemented in the adjacent River Seven catchment, including the planting 23 ha of woodland and building 50 LWD dams. In addition, the catchment was the selected location for a novel trial of two timber bunds. These were constructed in August 2011 on Sutherland Beck, a tributary of the River Seven, to determine how these relatively cheap flood storage features would perform. The bunds span the full width of the floodplain at two central locations.

A family of beavers (*C. fiber*) was introduced to the Sutherland Beck catchment in a fenced enclosure in 2014 to see how they would interact with the established NFM measures and possibly replace these. Since their introduction, the number of beavers has grown, resulting in the formation of a number of large beaver-built dams and associated topographical changes.

A 2020 project carried out by Forest Research and repeated in 2023 involved an assessment of the integrity/strength of the man-made timber bunds, which concluded that both structures had degraded significantly and reaching the end of their effective life.

This study was undertaken to estimate the potential flood storage provided by the beaver dams during design flood events to compare with that of the man-made timber bunds in their current condition, to determine whether the beaver dams offer comparable storage volumes such that the eventual loss/failure of the timber bunds does not pose an increased risk of downstream flooding.

A 1-D mathematical/hydraulic model already existed for the Sutherland Beck, which was set up in 2014 and bounded by Keldy Bridge upstream and a concrete road bridge at the downstream limit. Since the dam building and pond formation by the beavers had changed the topography of the river channel, a new topographic survey was undertaken in April 2024 and the existing hydraulic model modified to account for the changes. Figure 1 shows a map of the study area displaying the location of the timber bunds, beaver dams and the new surveyed cross sections.

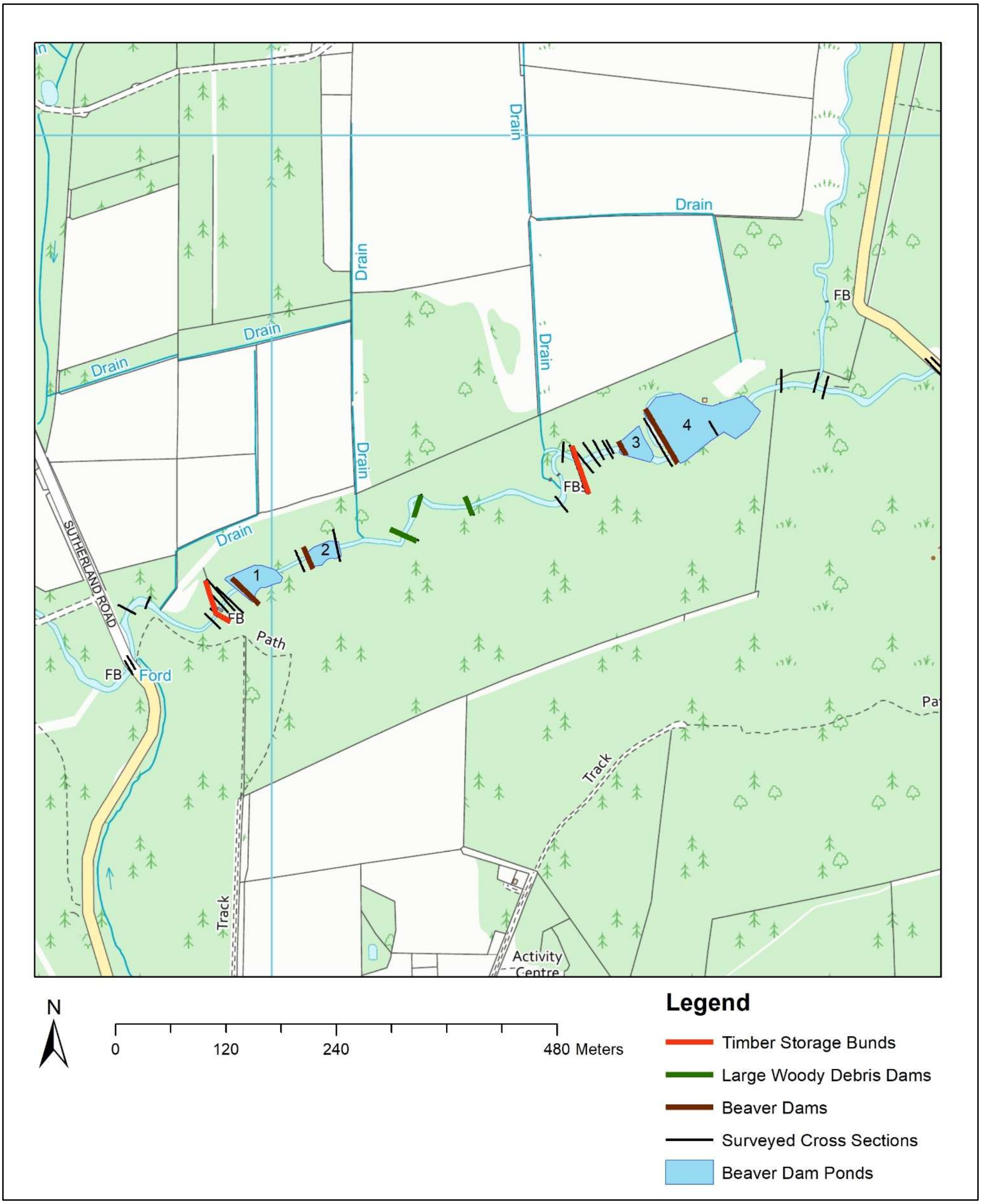

Figure 1 Site map showing location of surveyed cross sections, man-made NFM measures and beaver dams

Hydrological Processes and Beaver Dams

Beavers are ecosystem engineers, altering their surroundings through dam construction, micro-channel building and tree felling. The creation of dams has several ecological implications. Firstly, they create ponds and wetland habitats, promoting biodiversity by providing breeding grounds for amphibians, insects, and waterfowl. Additionally, the ponds act as nutrient sinks, trapping sediment and promoting nutrient cycling in aquatic ecosystems.

Several studies have highlighted the positive influence of beavers on ecosystem health. Hood and Larson (2014) conducted a study in the boreal forest of North America, demonstrating that beaver ponds increased riparian plant diversity and abundance. The creation of wetlands through dam construction also contributes to carbon sequestration, as wetlands are known to act as significant carbon sinks (Whiting and Chanton, 2001).

While beavers play a crucial role in shaping ecosystems, their dam-building activities can have profound hydrological effects, including alterations to streamflow, sediment transport, and flooding dynamics. The ability of beaver dams to slow down and store water is well-documented. Pollock et al. (2014) conducted a comprehensive analysis of beaver dam hydrology and found that beaver ponds significantly attenuate peak flows and reduce downstream flood risk by impounding water during storm events.

Beaver dams act as natural ‘sponges’, slowing the movement of water through river systems. The stored water in beaver ponds is gradually released downstream, reducing the intensity and duration of downstream floods. However, this positive hydrological effect varies depending on factors such as dam size, location, and local topography (Naiman et al., 1986).

Despite the potential benefits, conflicts arise when the hydrological effects of beaver dams meet with human infrastructure and land use. Beavers' propensity to build dams in culverts and under roads can lead to localised flooding and infrastructure damage, prompting concerns among landowners and communities about the future release of beavers into the wider environment, without enclosures.

Research suggests that, in certain contexts, beaver reintroductions can serve as effective tools for mitigating flooding. Wheaton et al. (2019) conducted a study in Utah, USA, where they actively reintroduced beavers to restore degraded streams. The results showed that the presence of beavers and their dams significantly reduced downstream flooding and erosion, showcasing the potential for beaver-assisted restoration efforts.

In terms of dam building, beavers typically choose a site along a watercourse where the water is slow-moving. They look for a location where they can create or enhance a pond by restricting or blocking the flow of water. They use a combination of materials to construct their dams, including logs, branches, mud, stones, and vegetation, usually starting by felling trees, then dragging the branches and logs to the dam site.

A foundation is built by laying down large logs and branches perpendicular to the flow of water, which helps to anchor the dam to the riverbed. Once the foundation is in place, beavers weave smaller branches, twigs, and vegetation between the larger logs. They tightly pack mud and stones into the structure to reinforce it and make it relatively watertight. As the dam takes shape, more layers of logs, branches, and mud are added, gradually increasing the height and length of the structure. They constantly assess and adjust the dam to maintain its integrity.

The creation of a permanent pond significantly reduces the scope to store flood water during a flood event, and it is only the available “freeboard” that contributes additional storage to reduce downstream flood risk. However, while this freeboard may form a relatively thin layer of surface water, depending on the leakiness and draw down in the water level prior to a flood event, the extended surface area of the pond can result in a significant volume of flood water stored. By spreading the flow, beaver dams also help to retard and thereby broaden the flood peak, further reducing the downstream flood peak.

Modelling approach

A new 1-D hydraulic model of Sutherland Beck was set up for the reach containing the man-made and beaver-built structures using the HEC-RAS software package (http://www.hec.usace.army.mil). HEC-RAS is a one-dimensional steady flow hydraulic model designed to aid hydraulic engineers in channel flow analysis and floodplain determination. Below is a summary of the methodology:

Data Collection

Compile topographic data from a cross section survey of the site, as well as 1m resolution LiDAR.

Acquire information on the location, size and characteristics of beaver dams and timber bunds within the river network.

Model design flows with given return periods using the Flood Estimation Handbook (FEH).

Geometric data input

Import the digital elevation model (DEM) and river cross-section data into HEC-RAS.

Define the river reach where the beaver dams, timber bunds and LWD are located and delineate the channel geometry, including cross-sections and flow paths.

Hydraulic properties assessment

Specify the hydraulic properties of the river channel and floodplain, including Manning's roughness coefficient.

Define the hydraulic characteristics of the beaver dams and man-made structures, including their height, length, and width.

Flow boundary conditions

Input the upstream and downstream boundary conditions for a range of inflows (e.g., river confluence and any outfall structures).

Hydraulic analysis

Conduct steady-state flow simulations using HEC-RAS to model the hydraulic behaviour of the river system.

Simulate various flow scenarios, including baseflow conditions, typical flow events, and design flood events, to assess how the beaver dams and man-made timber bunds affect flood storage capacity.

The modelled reach is 1.2km in length, with an average channel width of 4m in the upstream reach, up to 6m midstream and 4m in the downstream section (Figure 1).

The two bunds, three LWD dams within the beaver enclosure and four beaver dams were represented within the model by treating them (hydraulically) as bridges. This allowed the user to determine the exact proportion of the channel cross section to be blocked to simulate their effect on flows.

Flood Estimation Handbook (FEH) Analysis

A FEH analysis was carried out for Sutherland Beck to determine the return periods of the selected design flows used in the modelling exercise. The standard method of creating a pooling group from gauged donor catchments to create flood frequency curves for an ungauged catchment was used (Table 1).

Return Period (years)	Flow (m^3/s)
2	2.5
5	3.3
10	3.9
25	4.6
50	5.2
100	5.8

Table 1 FEH-generated flood flows and frequencies for the Sutherland Beck site.

Storage potential of the timber bunds

The 2014 modelling study predicted the potential storage volume of the two timber bunds along Sutherland Beck in Cropton Forest. The bunds differed in width; the downstream bund was 16.5m wide, while the larger upstream bund was 57.5m. They both had a maximum height of around 1.5 m, which decreased towards both ends. The bunds were formed by stacking horizontal logs against standing trees or timber posts to form a timber wall. Each extended approximately halfway into the channel frontal area to restrict high flows but not to impede normal and low flows; it is only when the river flow reaches the bottom of the timber bund that the bund starts to have a throttling effect. During high flows the timber bunds cause waters to back-up in the channel and eventually spill onto the surrounding floodplain.

The larger upstream bund contributed the majority of the storage potential, as well as being more effective at lower frequency flood events than the downstream bund, largely due to a smaller throttling effect. About 3,540m^3 of water was potentially stored during a 1 in 3-year flood, rising to 3,620m^3 during the more extreme 1 in 100-year flood at the upstream bund, while the downstream bund stored much smaller volumes of up to about 1,120m^3 when full. Combined, the 2 timber bunds stored up to 4,660m^3 when full.

Return Period (years)	**2**	**5**	**10**	**25**	**50**	**100**
Flow m^3/s	**2.5**	**3.3**	**3.9**	**4.6**	**5.2**	**5.8**
Downstream 2014	0	0	0	10	20	1120
Upstream 2014	0	3540	3550	3570	3580	3590
Combined 2014	0	3540	3550	3580	3600	4710
Downstream 2024	0	370	430	490	610	1330
Upstream 2024	0	360	410	440	530	590
Combined 2024	0	730	840	930	1140	1920

Table 2 Comparison between predicted storage volume (in m^3) of timber bunds in 2024 and 2014. Figures in red shows when bunds are full.

Table 2 shows that there has been a marked reduction in flood storage capacity for the two bunds compared to that in 2014. While severe degradation in the strength of the timber bunds has occurred over the years and thus weakened their ability to withstand a large flood (Forest Research, 2023), the reduction in their storage capacity is mainly due to channel erosion at the throttle point.

The 2024 model shows that the upstream bund now has a similar storage potential to the downstream one, with storage volumes of 360m^3 and 590m^3 for the 1 in 5 and 1 in 100-year floods, respectively, for the upstream bund, compared to 370m^3 and 1,330m^3 for the downstream bund (Table 3).

Return Period (years)	**2**	**5**	**10**	**25**	**50**	**100**
Flow m^3/s	**2.5**	**3.3**	**3.9**	**4.6**	**5.2**	**5.8**
Upstream Bund	0	360	410	440	530	590
Downstream Bund	0	370	430	490	610	1330

Table 3 Comparison of the storage potential (in m^3) of the upstream and downstream timber bunds in 2024.

An analysis of the topographical survey data between 2014 and 2024 shows a significant change to the profile of the river channel and immediate floodplain at both locations. While the downstream channel and floodplain area appears to have been subject to sediment deposition and a rise in ground levels immediately upstream of the timber bund, reducing the channel cross sectional area, the reverse is true for the channel at the upstream timber bund. The reduction in cross sectional area at the downstream timber bund will restrict flows more effectively and increase the bund’s storage potential, while erosion and an increase in cross sectional area at the upstream bund allows flows to pass under the timber bund unrestricted, essentially making the timber bund ineffective at lower flood flows.

Due to the change in the hydraulic behaviour of the two bunds, the way they store water has changed from 2014. The downstream bund now comes into effect at more frequent events, storing more water during lower flows than in 2014, while the upstream bunds is slower to fill, and arguably is more effective at storing water across a wider range of flows than in 2014.

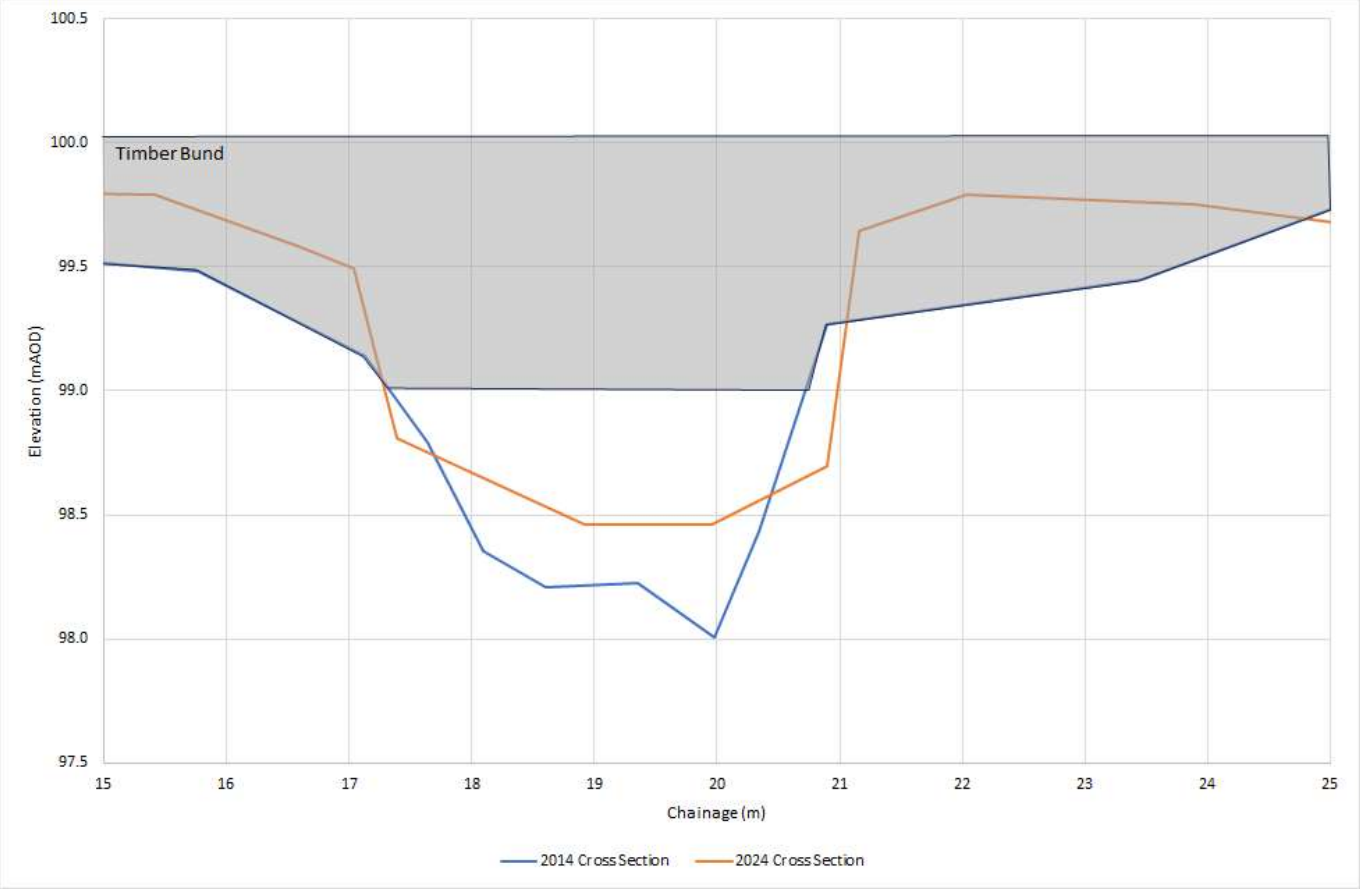

Figure 2 Change in channel cross section at the downstream timber bund (bund represented as grey shaded area) between 2014 and 2024.

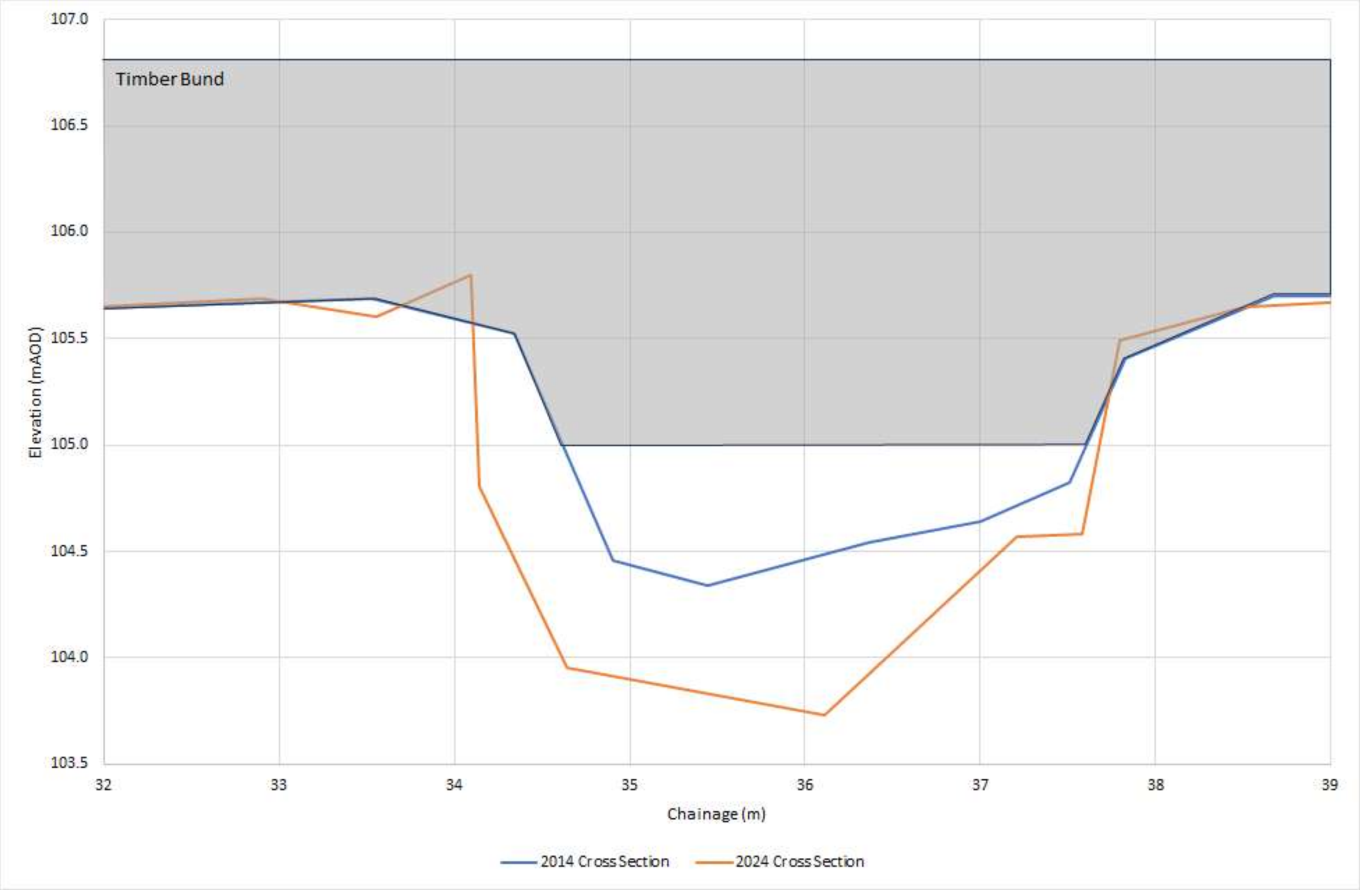

Figure 3 Change in channel cross section at the upstream timber bund (bund represented as grey shaded area) between 2014 and 2024.

Storage potential of the beaver dams

At the time of this study, four main beaver dams were present within the Cropton Forest enclosure, as shown in Figure 1. The approximate extent of the ponded areas when full have been delineated on the same map.

Dam number 1 is located at the downstream limit of the enclosure, and has an average height of 0.6m spanning 24.7m across the channel and floodplain. There is a permanent ponded area upstream of the dam with an estimated volume of 242m^3. A small amount of freeboard of approximately 0.2m is estimated as being available for rising water levels, as measured during the topographic survey in 2024.

Dam number 2 is located approximately 80m upstream of dam 1, spanning 16.1m across the channel and floodplain with an average height of 1.08m. Approximately 331m^3 of water is stored permanently in the ponded area upstream of the dam with approximately 0.4m of freeboard to store rising water levels during high flow events.

Dam 3 is the smallest of the beaver dams located 50m downstream of dam 4. With an average height of 0.6m spanning 14.7m across the channel and floodplain, the ponded area stores approximately 163m^3 of water with a freeboard of 0.2m.

The largest of the dams, number 4, is located towards the top end of the enclosure, and the result of the beavers building a dam across an existing pond. The dam has an average height of 1.07m and extends some 60m across the valley floor. Figures 4 and 5 show this dam from downstream of the structure and from above, including some of the ponded area. The dam holds a permanent body of water which has been estimated at 837m^3 using surveyed water levels and a combination of ground levels obtained from the topographic survey plus 1m resolution LiDAR data.

Figure 4 Photograph showing part of beaver dam number 4 looking upstream towards the ponded area. The main channel is located to the right of the dam.


Credit: Dr Alan Puttock

Figure 5 Drone image capturing the ponded area upstream of dam number 4. The dam is visible in the top right of the image.

Figure 6 displays the modelled storage potential of the beaver dams. All dams show a relatively minor enhancement of water storage as flood frequency decreases (i.e. flood magnitude increases). This is due to the limited amount of freeboard available behind each dam before it is overtopped, as well as the nature of the upstream topography and scope for the additional water to spread out across the floodplain. Dams 1, 2 and 3 create similar additional storage volumes of around 200m^3, whilst dam 4 has the greatest potential at 1,800m^3. In combination, it is estimated that the beaver dams store between 2,280m^3 and 2,542m^3 of additional flood water between a 1 in 2 and 1 in 100-year flood event, respectively.

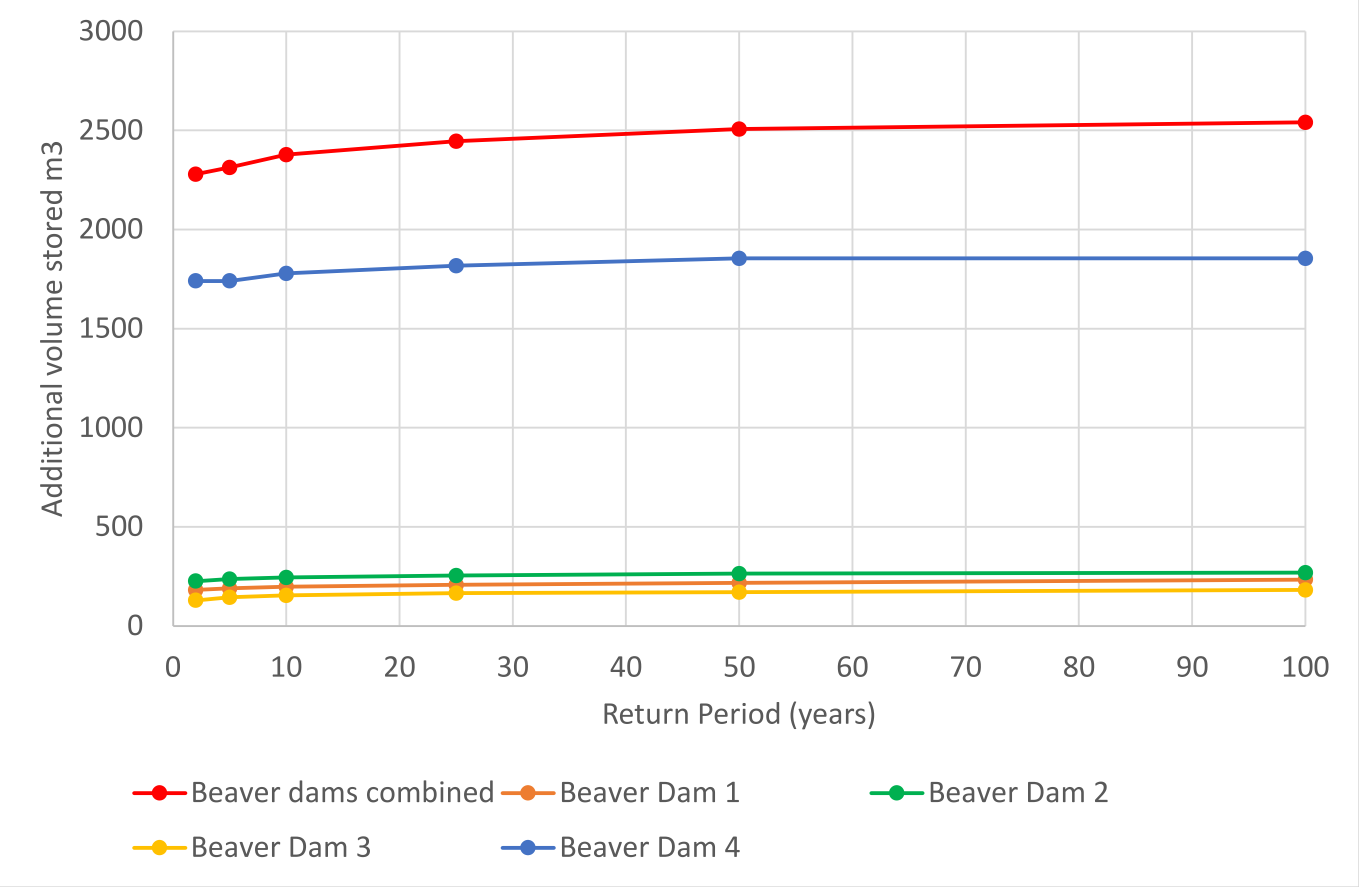

Figure 6 Modelled additional flood storage potential (in m^3) of the beaver dams at Cropton Forest for a range of flood frequencies

Comparison of the potential storage of man-made timber storage bunds verses beaver dams

Figure 7 compares the additional flood storage potential for a number of modelled scenarios. In their infancy, the two man-made timber storage bunds at Cropton Forest were able to store between 3,540m^3 and 4,710 m^3 once the flow reached approximately 3.3m^3/s, during the 1 in 5 and 1 in 100-year flood event respectively. Due to the degradation and decay of the timber structures and changes to the morphology of the channel, this storage potential has been drastically reduced to between 730m^3 and 1,920m^3 for the 1 in 5 and 1 in 100-year flood respectively (a 79 – 59% decrease respectively).

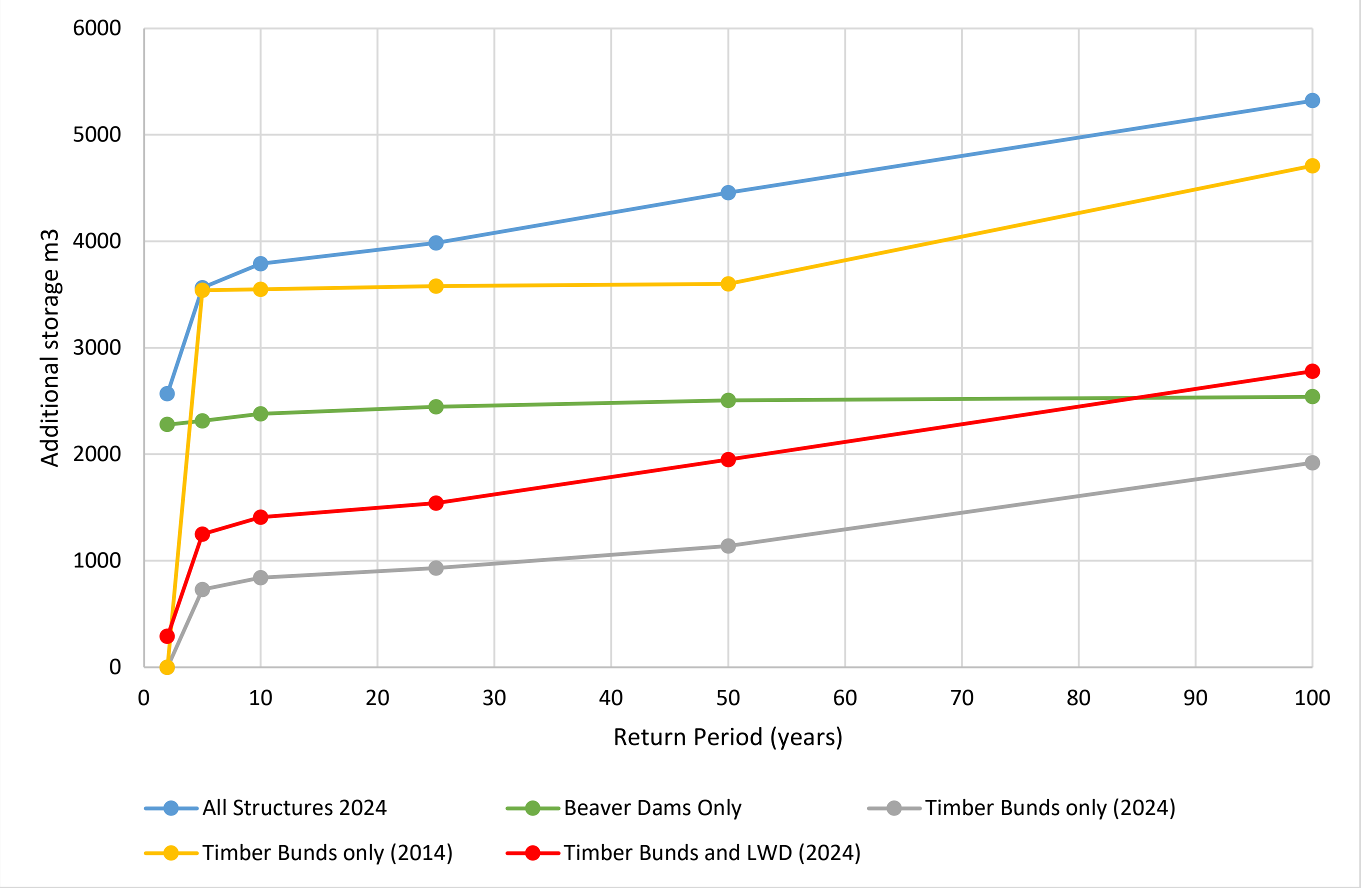

Figure 7 Comparison of the additional flood storage potential of man-made versus beaver-built dams

In addition to the man-made timber bunds, three LWD dams within the enclosure provide a small volume of extra storage of 290m^3 to 860m^3 between the 1 in 2 to 1 in 100-year floods respectively.

In combination, the four beaver dams provide significantly more additional storage potential than the timber bunds in their current condition, between 2,280m^3 and

2,542m^3 more between the 1 in 2 and 1 in 100-year floods. However, they fall short of providing the equivalent storage that the man-made structures provided when they were originally installed and designed appropriately.

The total volume of flood storage provided by the two timber bunds in their current condition, the three LWD and the four beaver dams exceeds that of the original timber bunds, across the range of modelled flood magnitudes (1 in 5 to 1 in 100-year floods). Table 4 shows a summary of the different volumes stored for each modelling scenario.

It is important to note that the river system within the beaver enclosure is constantly evolving. The beavers may build additional dams and thus create more flood storage, while the contribution of the existing bunds and LWD dams are also likely to change as they fall further into disrepair and/or the river channel throttle continues to erode or silt up.

Return Period (years)	**2**	**5**	**10**	**25**	**50**	**100**
Flow m^3/s	**2.5**	**3.3**	**3.9**	**4.6**	**5.2**	**5.8**
2014 Timber bunds	0	3540	3550	3580	3600	4710
2024 All structures	2570	3563	3789	3985	4458	5322
2024 Beaver dams only	2280	2313	2379	2445	2508	2542
2024 Timber bunds only	0	730	840	930	1140	1920
2024 LWD only	290	520	570	610	810	860

Table 4 Comparison of the flood storage potential (in m^3) of the timber bunds, LWD dams and beaver dams in 2024 vs 2014.

Conclusion

The hydrological impact of beavers is multifaceted, playing a crucial role in shaping aquatic ecosystems. Through their dam-building activities, beavers alter water flow dynamics, creating wetlands and ponds that serve as vital habitats for numerous species. These alterations also contribute to water storage, groundwater recharge, and sediment retention, thereby influencing water quality and availability downstream. While beavers can sometimes conflict with human interests, such as flooding infrastructure or altering landscapes in the wrong location, their overall contribution to ecosystem health and resilience cannot be understated.

The modelling study shows that while the Cropton Forest beaver dams alone could make a significant contribution to the potential additional flood storage at the site, the total volume stored fell short by an average of 35% across the 1 in 5 and 100-year flood magnitude of that of the man-made timber storage bunds in their original condition.

However the flood storage potential of the beaver dams far exceeds that of the man-made timber bunds in their current state and this difference is likely to further increase as the timber bunds continue to deteriorate and the beavers potentially build more dams.

This study has shown that the building of man-made timber structures for the purposes of Natural Flood Management cannot simply be a case of "build and forget". The morphological changes that have occurred to the channel at both the timber flood storage bunds highlights that the original designs should have considered some form of channel protection to reduce the effect of erosion at the upstream bund, as well as more routine maintenance to reduce or remove the volume of sediment build-up at the downstream bund. This would have helped maintain the hydraulic performance of both bunds and ensured that their original flood storage capacity would be maintained over time, notwithstanding the increased risk of failure and collapse due to timber decay. Plans need to be put in place for the continued maintenance and replacement of these structures for them to continue to function as designed.

References

Hood, G. A., & Larson, D. G. (2014). Effects of beaver dams on vegetation in boreal ecosystems. Ecoscience, 21(3-4), 310-318.

Naiman, R. J., Melillo, J. M., & Hobbie, J. E. (1986). Ecosystem alteration of boreal forest streams by beaver (Castor canadensis). Ecology, 67(5), 1254-1269.

Pollock, M. M., Beechie, T. J., Wheaton, J. M., & Jordan, C. E. (2012). Beaver-mediated restoration of incised stream ecosystems. Restoration Ecology, 20(4), 488-495.

Pollock, M. M., Beechie, T. J., Wheaton, J. M., & Jordan, C. E. (2014). Predicting the occurrence and persistence of beaver dams. Ecohydrology, 7(3), 581-592.

Pollock, M. M., Heim, M., Werner, B., & Olmstead, N. (2003). Hydrologic and geomorphic effects of beaver dams and their influence on fishes. American Fisheries Society Symposium, 37, 213-233.

Thomas, H & Nisbet, T. R. (2023) Assessing the Decay and Integrity of Timber Structures used for Natural Flood Management (NFM) on Sutherland Beck, Pickering, North Yorkshire. Report to Forestry England.

Wheaton, J. M., Bouwes, N., & Pollock, M. M. (2019). Ecohydrologically informed restoration of an incised river using dam-building species. BioScience, 69(6), 445-459.

Whiting, G. J., & Chanton, J. P. (2001). Methane production and consumption in temperate and subarctic peat soils: Response to temperature and pH. Soil Biology and Biochemistry, 33(3), 1823-1833.

Contact

Huw Thomas

Hydrologist

Forest Research

huw.thomas@forestresearch.gov.uk