Forest Research

Opportunities to use woodland measures for Natural Flood Management in Whinlatter Forest

Scoping Report

Huw Thomas

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1. Introduction

The Forest Design Plan for Whinlatter is currently under review and a new aspirations map has been produced. This includes a number of measures such as habitat creation, woodland planting and proposed extensions to the mountain bike trail network.

In addition to these proposals, other measures have been considered to support community flood risk alleviation, incorporating planting in appropriate areas to help reduce rapid runoff and alleviate flood flows in the Whit Beck and Newlands Beck catchments, as well as using soft engineering features such as leaky dams in the forest estate to store more water during periods of high flows.

In order to target the most effective locations and assess the potential scale of the Natural Flood Management (NFM) opportunities in the area, a desk-based GIS exercise was carried out by Forest Research.

2. Mapping locations to store water and slow the flow of surface water

2.1 Potential sites for the creation of Leaky Woody Dams

Leaky Woody Dams (LWD) alter the flow hydraulics in the river channel which enhances the river environment in a number of ways:

1. They increase the hydrological interactions between the river channel and the floodplain by holding back and thereby raising upstream water levels, creating increased opportunities for out of bank flows and flood storage.
2. They create spatial diversity in hydromorphology/flow regime providing habitat patches which support a range of organisms at different stages of their life cycle and an important refuge during high flows.
3. They enhance the storage and attenuate the transport of sediments, organic matter and solutes within the catchment. LWD accumulations retain important food resources for aquatic biota.
4. They affect the geomorphology of the river channel; resulting in greater variability in channel form (increased occurrence of riffle and pool sequences) and greater overall channel stability. Consequently the physical habitat diversity of woodland river channels is enhanced.

Past modelling (Thomas and Nisbet, 2012) has shown that LWD can have a marked effect on flood flows by reducing water velocities, increasing upstream water levels and the frequency of out of bank flooding, and delaying the travel time of the flood peak.

To be most effective, LWD should be constructed at points where they can hold water behind the obstruction for an extended distance in the stream channel and ideally can force water out onto the floodplain where it is widest. The volume of water held by the dam will depend on the gradient of the stream channel, the height of the dam and stream banks, and the connectivity between the stream channel and adjacent floodplain at high flow.

A digital terrain model (DTM) was created using 5m resolution elevation data that were available for the study area. The DTM provided source elevation data for delineating catchments for hydrological modelling. The Arc Hydro toolset was used to create a drainage network in the Whinlatter Forest and sub-catchments across this area were defined. The Arc Hydro tools define nested sub-catchments at each confluence of the modelled drainage network; for the assessment of NFM opportunities these were amended to create single sub-catchments for each tributary of the main channel. Opportunities for the installation of NFM measures were identified within each sub-catchment.

The slope of the individual line features of the DRN dataset was determined using the 5 m DTM. Stream reaches with slopes of <2° were highlighted as the most suitable potential sites for LWD construction (Thomas and Nisbet, 2012). Figure 1 maps the suitability of stream reaches across the study area.

Ease of access to sites for constructing LWD measures can affect build costs significantly and therefore reaches within 30 m of forest roads were prioritised for selection (Figure 2). It is recommended that LWD construction be timed to coincide with felling operations in order to make use of available machinery and local timber. Alternatively, appropriate lengths and amounts of timber should be left near suitable reaches for future use.

2.2 Identification of potential sites for Runoff Attenuation Features

The Working With Natural Processes (WWNP) project (Environment Agency, 2017) provides the evidence base summarising the effectiveness of WWNP measures from a flood risk reduction perspective, as well as the wider ecosystem services benefits they deliver. As part of the project, a mapping exercise was carried out to complement the evidence base to identify suitable areas for a selection of key WWNP measures.

Runoff Attenuation Features (RAFs) are one such WWNP measure that was mapped. These are areas of potential high run-off accumulation in the landscape where water can temporarily be held back to provide additional flood storage during storm events.

Examples of RAFs (Quinn et al., 2013) include:

1. Overland flow interception. This involves the creation of a low-level bund (constructed of soil, wood or a stone barrier) across a flow path to provide water storage. These features are designed to drain slowly by being built to be 'leaky' or have an outlet drainage pipe installed, or a combination of both.

2. Online ditch barriers. Barriers constructed from natural materials are placed within drainage ditches and minor streams to back-up water.

3. Offline ponds: Water is diverted from the stream network into a pond structure creating temporary storage. The pond is typically drained by an outflow structure in the form of a plastic pipe, which is designed to allow the feature to drain slowly.

A mapping layer was produced as part of the project to identify RAFs that would activate during a 3.3% Annual Exceedance Probability (AEP), or 1 in 30 year flood event and a 1% AEP (or 1 in 100 year flood event). Using this layer, the potential for RAFs in the Whinlatter area was assessed. Figure 3a provides an overview of the distribution of potential sites for RAF construction in the mapped catchments, while Figure 3b shows what they look like at the local level. The map is indicative only and opportunities shown require field assessment to determine their efficacy for flood risk management and their potential impact on existing features of high biodiversity value.

Opportunities for RAFs are much reduced on steeper ground and therefore the WWNP project classified such areas in terms of opportunities for gully blocking. A threshold of >6 degrees (10%) was used, based on the following criteria:

- Different typological classifications suggest slopes >5% are 'steep', have high energy and can cause braiding (Schumm and Khan 1972).

- Above 6 degrees (10%), restoring peatland vegetation by grip blocking becomes unviable (Evans et al. 2005) and gully blocking a preferred method for run-off attenuation.

Gullies naturally develop on steep slopes but are often associated with poor land management practices that increase runoff and erosion. Gully blocking can help to reduce erosion by slowing the flow and ponding back water, which can provide additional temporary flood storage (if the pools are able to drain down between each event). It can also help to split and divert flow paths during storm events, increasing the travel time of flood water further.

Figure 3a shows the areas where ponding is likely to occur during a 1 in 30 and 100 year storm event (Figure 3b zooms in on an area for illustration purposes) and where RAF measures and gully blocking on steeper ground may be appropriate.

2.3 Potential for Woodland Planting

Woodland creation is increasingly viewed as making an effective and sustainable contribution to NFM. Woodland can help alleviate flooding in three main ways: through the potentially high water use of trees increasing available soil water storage and reducing the generation and volume of flood water; by the typically high infiltration rates of woodland soils reducing direct surface runoff and delaying the passage of water to streams; and by the greater hydraulic roughness created by woodland vegetation, acting to increase above ground flood water storage and delay the downstream passage of flood flows (Nisbet et al., 2011a). These mechanisms are to varying degrees location dependent and considered to be greatest where there is most contact between water and woodland, such as along runoff pathways and on floodplains. A fourth, indirect mechanism whereby woodland creation can help to alleviate flooding is through trees protecting the soil and reducing sediment delivery to watercourses. This reduces downstream sedimentation in river channels, improving flood conveyance.

A number of new potential woodland creation sites have already been identified in the Whinlatter Forest area and included in the Aspirations Map for Whinlatter Forest. Broadleaf woodland and Scots pine planting is planned in the Lorton and Braithwaite catchments, both of which are expected to make a contribution to flood risk reduction.

The "Opportunity Mapping for woodland to Reduce Flooding in the River Derwent, Cumbria" report, 2010, identified priority woodland creation sites the wider catchment and riparian corridor to help reduce flooding. The sites identified for Whinlatter is shown in Figure 4.

3. Potential constraints and sensitivities to NFM measures

Existing woodland creation opportunity maps already consider key constraints to planting but a number of constraints also affect the construction of LWD and RAFs. These need to be considered as part of the planning process and include the following:

- Prior authorisation must be obtained from the Environment Agency or lead local flood authority before any works in or adjacent to watercourses that affect river flows, including any type of impoundment. Whinlatter Forest is outside of any main rivers. The consenting process will consider the risk of the construction increasing flooding downstream, for example as a result of failure and washout.
- The backing-up of water behind LWD and RAFs can affect neighbouring land, roads and tracks, and local properties, which needs to be minimised or avoided.
- The presence of local 'pinch-points' such as narrow culverts and undersized bridges in the river network can back-up flood waters and swamp NFM features, reducing their effectiveness. LWD and RAFs are best avoided close to road/track crossings to avoid flooding these or the potential for them to act as pinch points (Figure 5).
- LWD and RAFs will raise local water-tables, the duration of which will depend on the design of the structure. A prolonged rise in water-table can reduce tree growth and precipitate windblow, which needs to be carefully managed. The presence of trees within RAFs will also reduce the available flood storage, albeit only by a small margin. In most cases it will not be cost effective to intervene to fell trees to create larger open storage bunds until the stand is due for harvesting. Restock plans should consider opportunities to block forest drains and rewet naturally wet sites to create wet woodland and enhance flood water storage.

There are also a number environmental sensitivities that can limit the use of NFM measures. These include designated habitats and other features that could be adversely affected by local flooding. The UKFS Forest and water guidelines recommend that forest operations should generally avoid changes to the eco-hydrological conditions on designated sites.

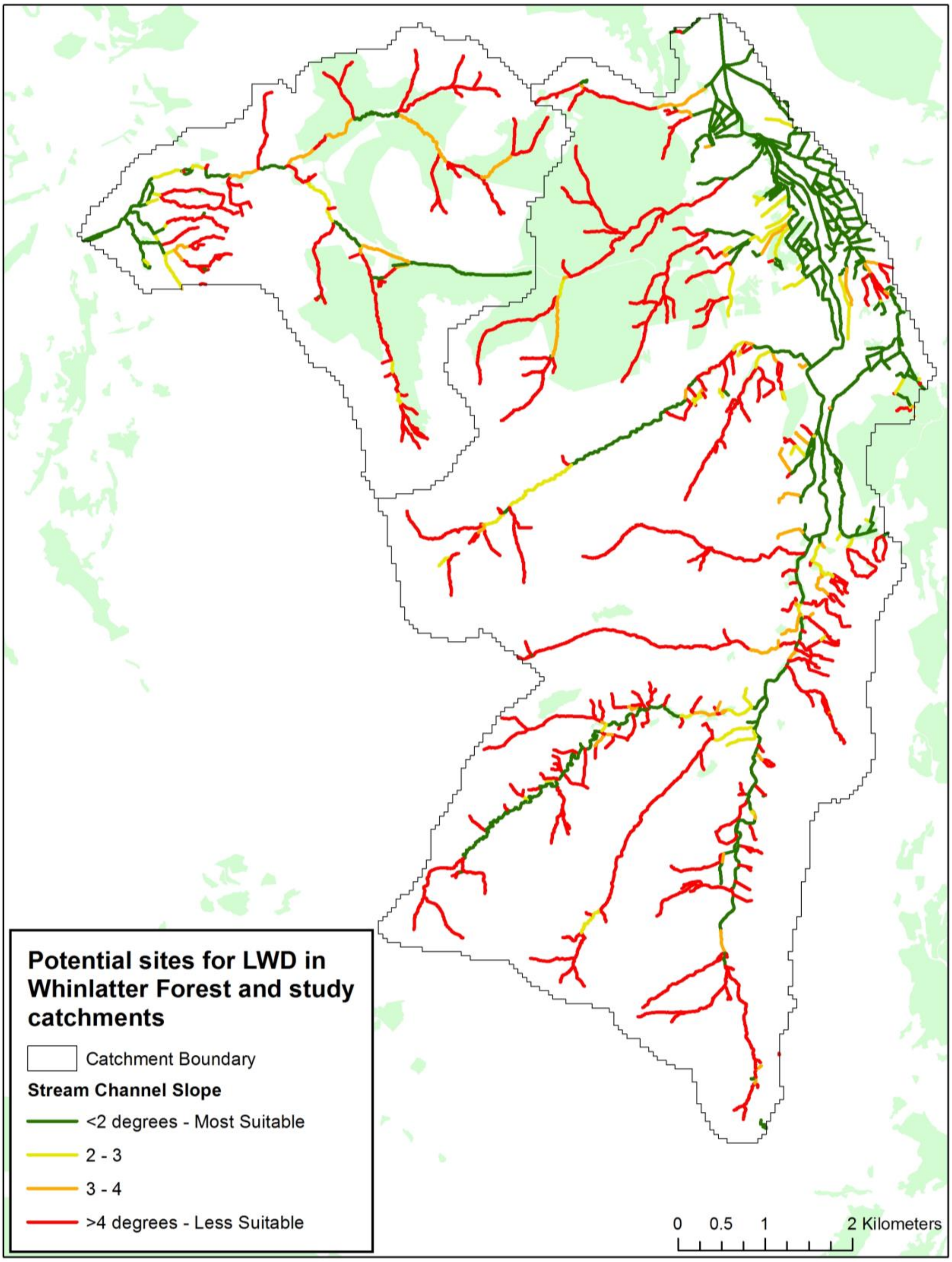

Figure 1 Modelled stream reaches considered to have suitable channel slope and width to be potential sites for the construction of LWD.

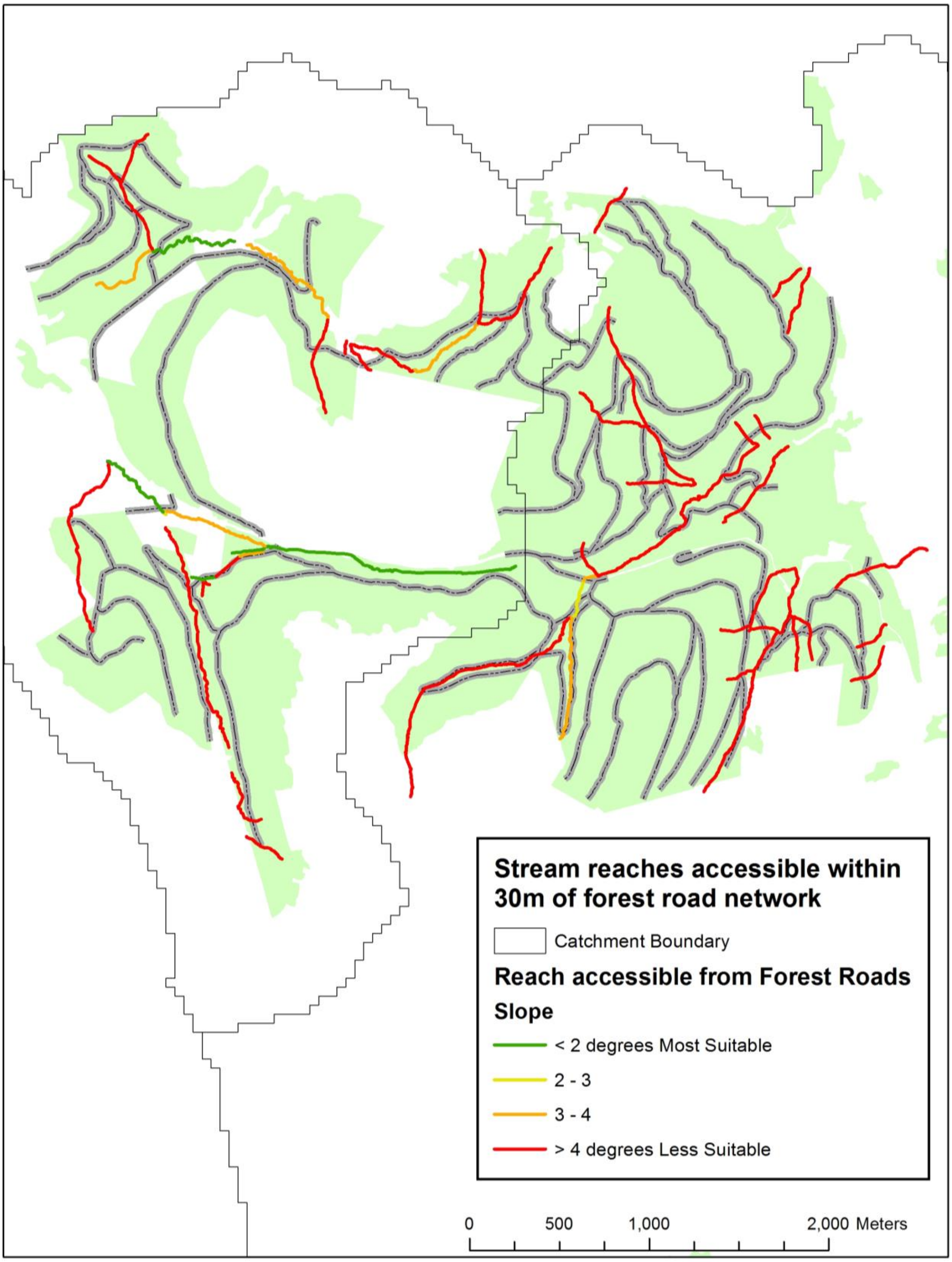

Figure 2 Modelled stream reaches considered to have suitable channel slope and width to be potential sites for the construction of LWD with easy access (<30 m) from existing forest roads.

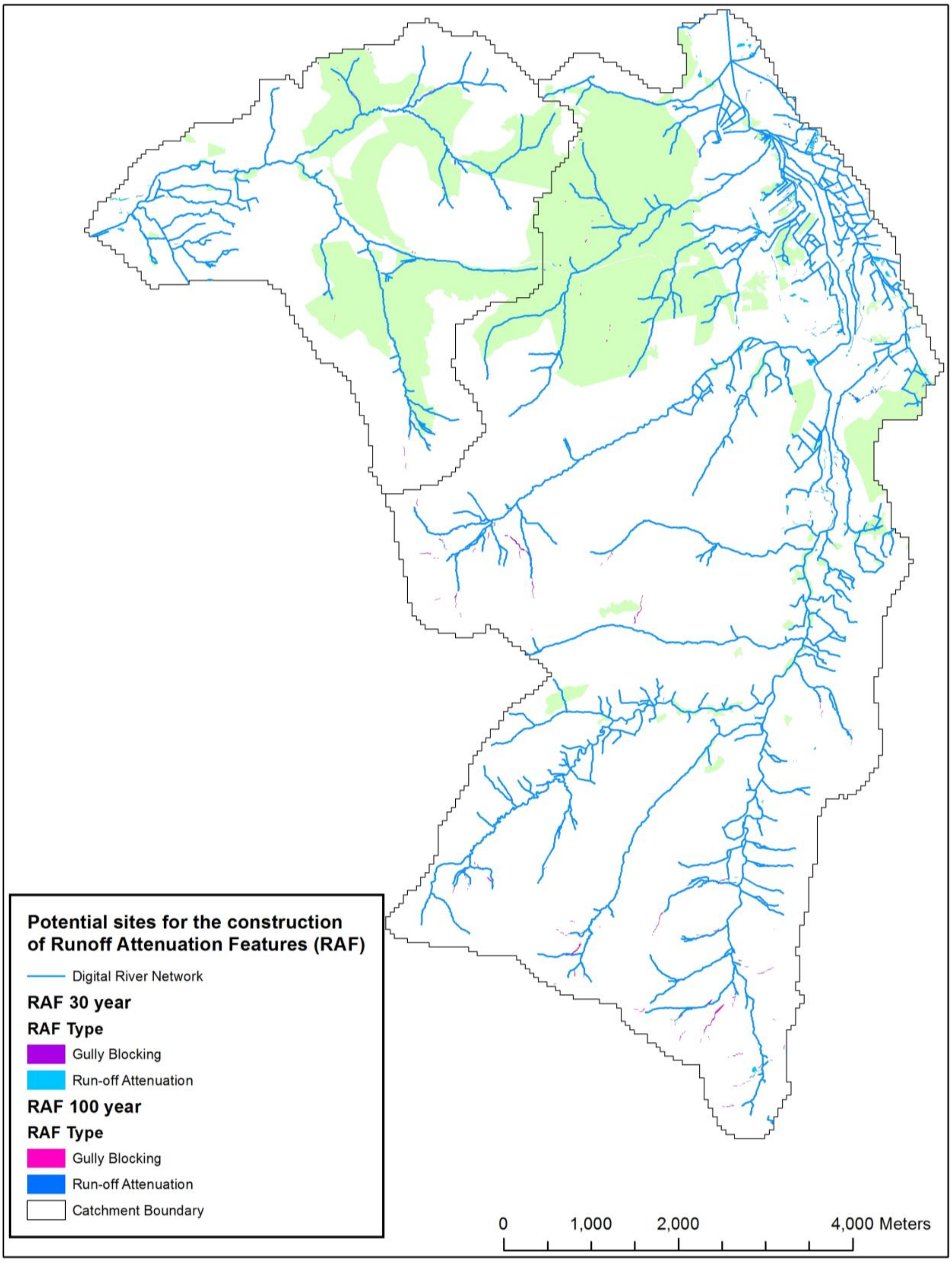

Figure 3a Opportunities to enhance out-of-bank flood storage through the construction of Runoff Attenuation Features (RAF) for 1 in 30 year and 1 in 100 year flood events.

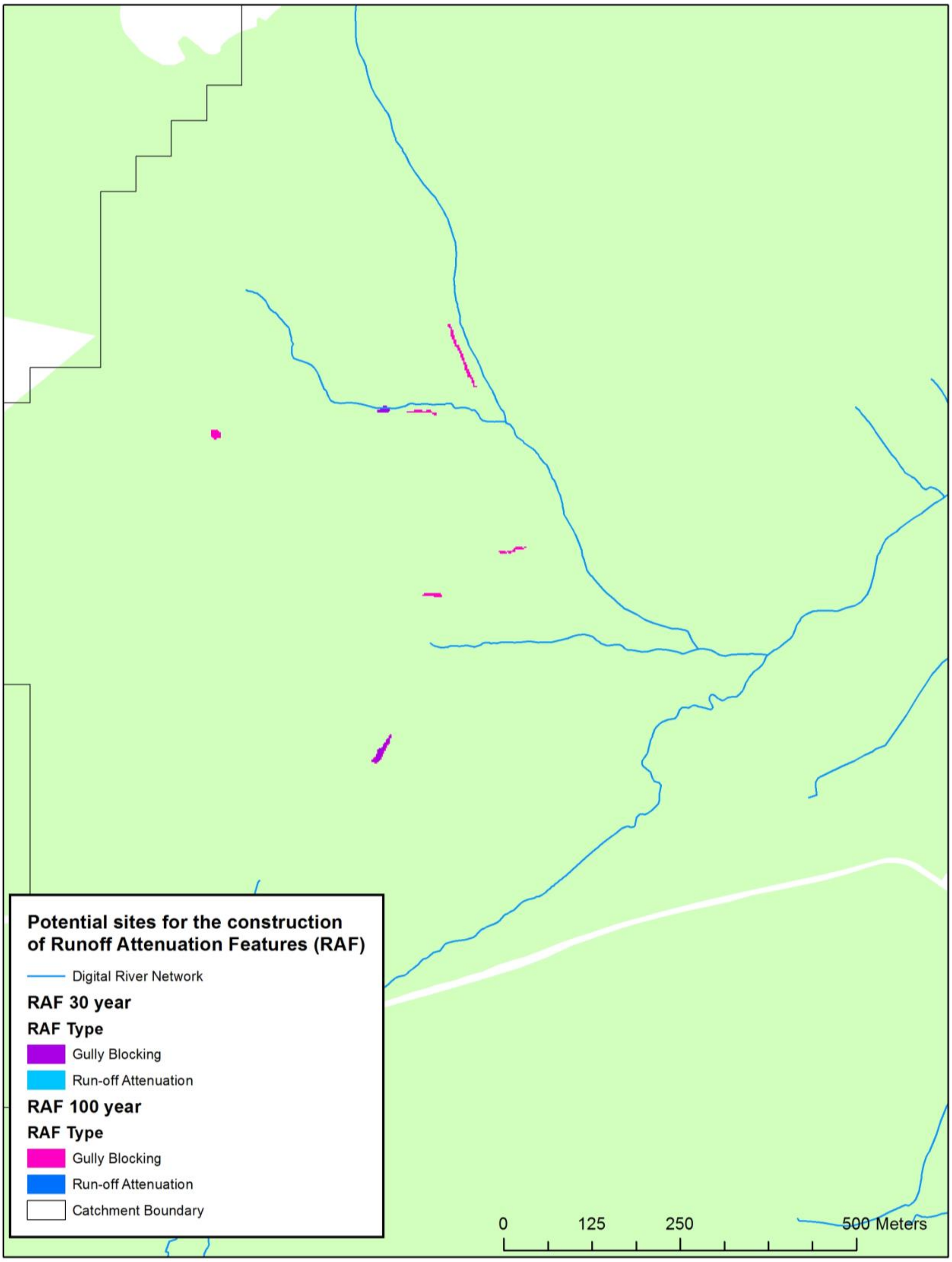

Figure 3b Higher resolution illustration of local opportunities to enhance out-of-bank flood storage through the construction of Runoff Attenuation Features (RAF) for 1 in 30 year and 1 in 100 year flood events.

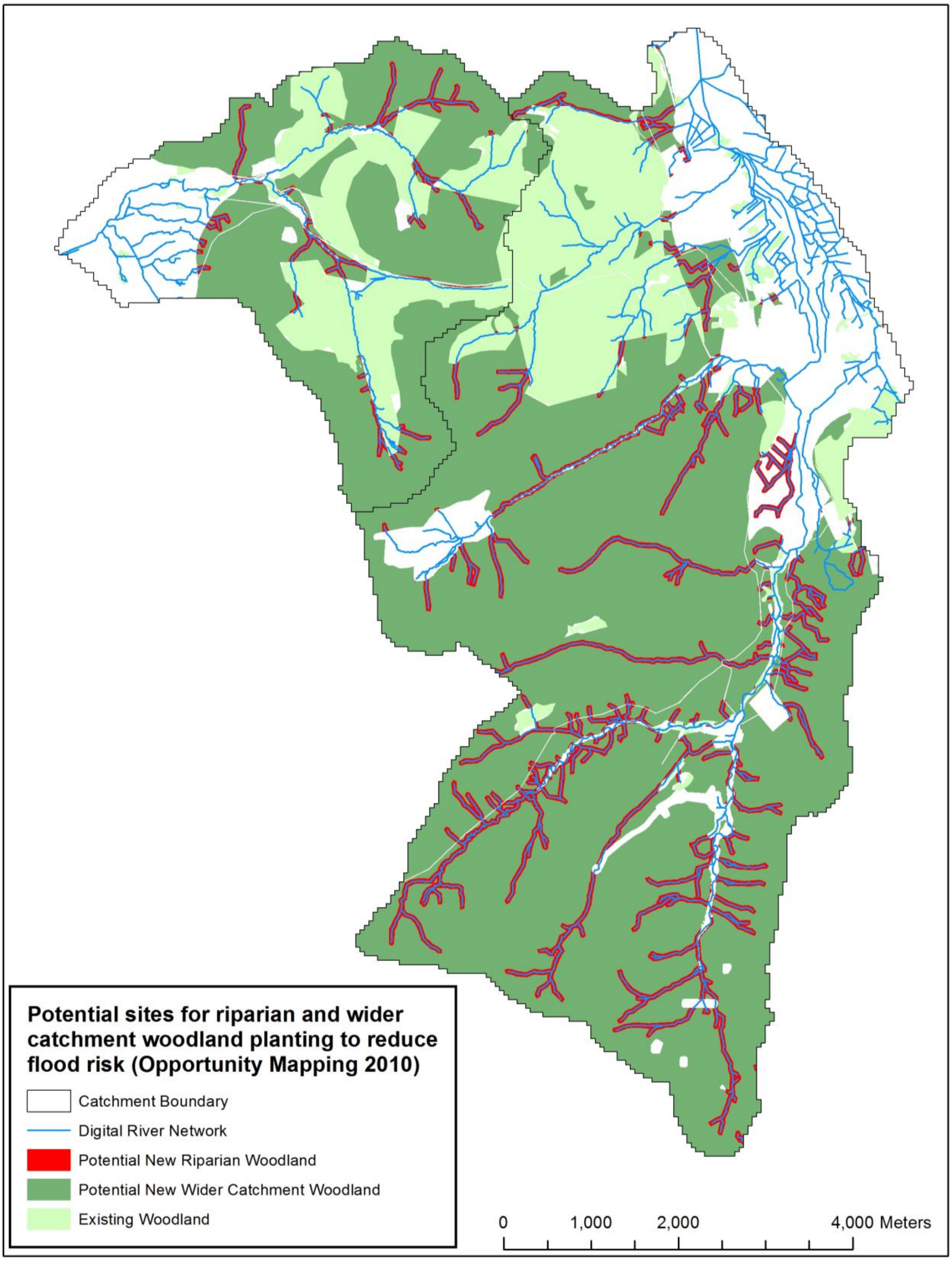

Figure 4 Potential new woodland creation opportunities in the wider catchment and riparian corridor to help reduce flood risk (Broadmeadow and Nisbet, 2010)

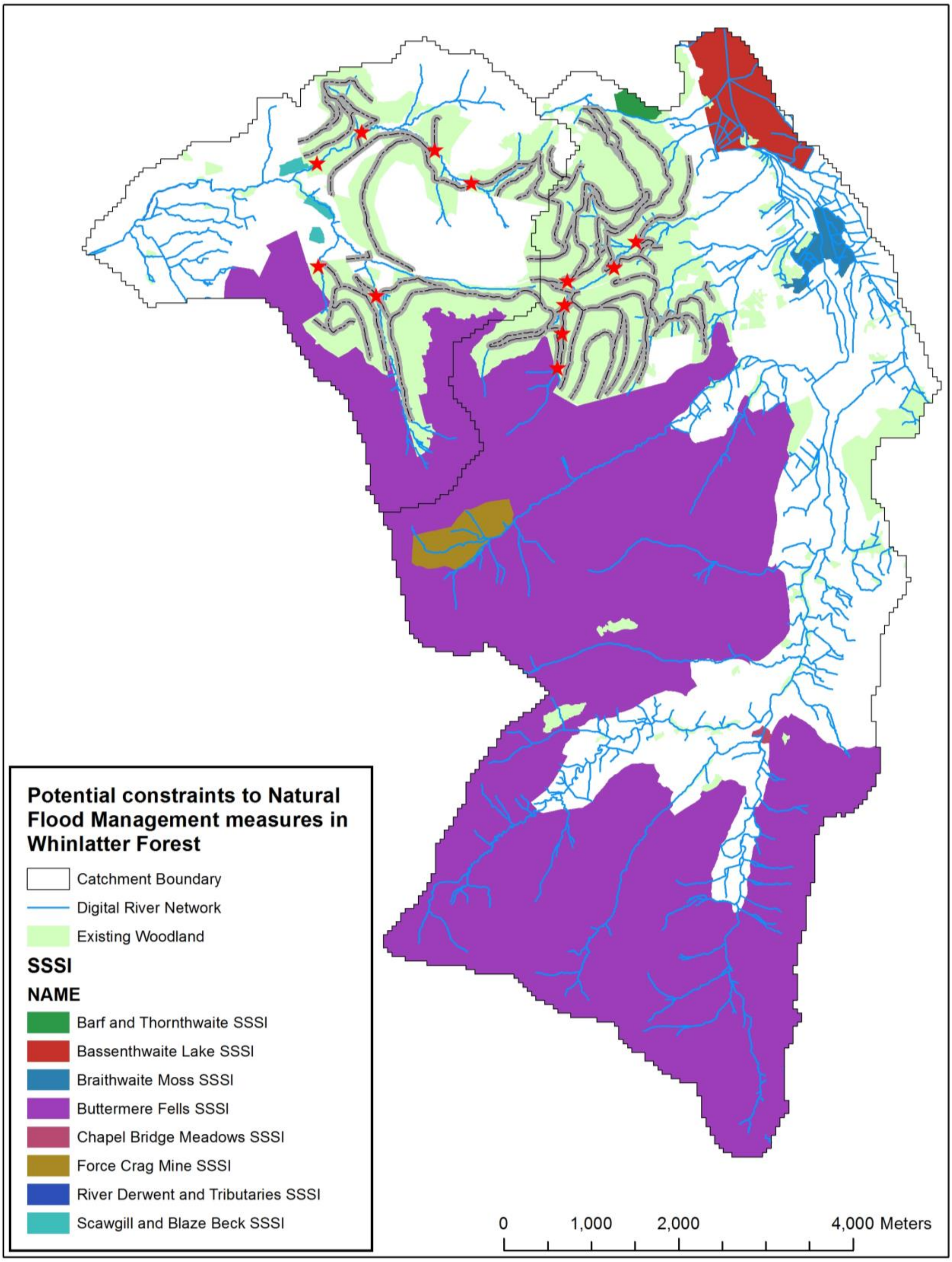

Figure 5 Potential constraints and sensitivities to the creation of NFM measures

4. Results

Table 1 shows the extent of opportunities for the creation of LWD in the Whinlatter Forest estate to enhance the volume of flood water storage within the stream channel system. The suitability of the streams for the creation of LWD is based on the gradient of each reach, with streams with an average slope of less the 2° being most suitable. Streams with gradients greater than 4° are less suitable for holding back water during storm events and subject to greater scour, but shouldn't be completely discounted.

The expected natural occurrence of a Leaky Woody Dams is approximately once every 10 channel widths along suitable reaches. Using this figure and an average channel width of 3m, a dam could be expected to occur naturally every 30m. The total number of potential dams has been estimated for each reach in the forest estate.

LWD can be designed to encourage out of bank flow and reconnect the stream channel to the adjacent flood plain, significantly enhancing the volume of water held and retained within the catchment. This can be further enhanced through the construction of timber bunds which increase the depth of water held on the floodplain. The potential additional storage was estimated, based on a number of assumptions and GIS measurements. The average floodplain width was taken from GIS measurements for shallower gradient streams and estimated for steeper reaches (30m on streams with a gradient under 2° to 50m on steeper reaches over 4°). And average depth of 1m was assumed and backwater effect reflecting the spacing of the dams and stream gradient (25m on slopes of 2° or less, 10m on steeper slopes over 4°).

Stream Slope (°)	Suitability	Length of stream channel (m)	Potential number of dams	Potential estimated storage volume (m^3)
< 2	Most suitable	7,848	262	196,200
2 - 3		3,014	100	30,140
3 - 4		4,212	140	21.060
> 4	Less suitable	24,054	802	40,090

Table 1 Extent of opportunities for the construction of LWD measures in the forest estate

When ease of access to the existing forest road network is considered in order to reduce construction costs, the number of potential sites in the forest area is reduced. Table 2 shows the length of stream reaches and estimated number of potential dams within 30 m of the forest road network.

Stream Slope (°)	Suitability	Length of stream channel (m)	Potential number of dams	Potential estimated storage volume (m³)
< 2	Most suitable	2,883	96	72,075
2 - 3		257	9	2,570
3 - 4		3,309	110	16,545
> 4	Less suitable	18,081	603	30,135

Table 2 Extent of opportunities for the construction of LWD measures in the forest estate within 30 m of the forest road network (i.e. within easy access)

Table 3 shows the type, number and total area of opportunities to create RAFs in the forest estate. Although the number of features is small in relation to LWD, the potential storage area and thus water volume stored is much greater. Storage volume was estimated using the assumption that each RAF would hold water to a depth of 0.5m.

Table 4 shows the number of RAFs within easy access to the forest road network and highlights the significant reduction in the number of these due to access restrictions.

	RAF 30 year			RAF 100 year		
RAF Type	Number of Features	Total potential storage area (m²)	Potential estimated storage volume (m³)	Number of Features	Total potential storage area (m²)	Potential estimated storage volume (m³)
Gully Blocking	20	4,966	49,660	42	8,013	168,273
Run-off Attenuation	38	17,112	325,128	34	13,713	233,121

Table 3 Extent of opportunities for the construction of Runoff Attenuation Features (RAFs) in the forest estate for a 1 in 30 and 100 year storm event.

	RAF 30 year			RAF 100 year		
RAF Type	Number of Features	Total potential storage area (m²)	Potential estimated storage volume (m³)	Number of Features	Total potential storage area (m²)	Potential estimated storage volume (m³)
Gully Blocking	6	996	2,987	17	2,829	24,045
Run-off Attenuation	1	336	168	3	691	1,037

Table 4 Extent of opportunities for the construction of Runoff Attenuation Features (RAFs) in the forest estate within 30 m of the forest road network (i.e. within easy access) for a 1 in 30 and 100 year storm event.

Despite being outside of the existing forest area, over 200km of potential new riparian woodland has been identified in the Whit Beck and Newlands Beck catchments with 65% of the catchments highlighted as potential areas for wider catchment planting to help reduce flood risk.

5. Conclusions

A desk-based GIS exercise was carried out by Forest Research for Forestry Commission England in order to identify the most effective locations and assess the potential scale of natural flood management opportunities in the Whinlatter Forest area which lies in the Whit Beck and Newlands Beck catchments.

Over 7.8 km of watercourse was identified as being most suitable (<2° average stream gradient) for the construction of LWD in the forest to help hold back and slow the passage of flood water. An estimated 262 LWD features could be built along these reaches, potentially storing 196,200 m^3 of water. Over 36% of the reaches are deemed easily accessible (within 30 m) from the existing forest road network.

Runoff Attenuation Features (RAFs) could contribute significant additional flood water storage within the forest. Fifty eight individual sites were identified for gully blocking and other RAFs, providing a total area of 2.2 ha for additional storage for the 1 in 30 year (3.3% AEP) storm, providing an estimated 374,788m^3 of storage. Seventy six individual areas were identified for the 1 in 100 (0.1% AEP) storm, also equating to 2.2 ha of additional water storage and an estimated 401,394m^3 of storage volume. Only 12% of 1 in 30 year and just over 26% of 1 in 100 year RAFs identified were deemed accessible within 30m of a forest road.

It is recommended that the results and maps of this exercise be used to ground-truth the identified sites for NFM measures to estimate their potential contribution to reducing downstream flood risk.

6. References

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