Oifig na nOibreacha Poiblí
The Office of Public Works

Lower Lee (Cork City) Flood Relief Scheme
(Drainage Scheme)

Supplementary Report on Option of Natural Flood Management

230436-00
December 2017

ARUP

Office of Public Works

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Supplementary Report – Option of Natural Flood Management

230436

Issue to website | 5 December 2017

Job number 230436-00

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Executive Summary

The Lower Lee Flood Relief Scheme (LLFRS) was commissioned by the Office of Public Works (OPW) with the objective of delivering a flood relief scheme for Cork City and environs to provide protection against the 1 in 100 year fluvial/1 in 200 year tidal flood events.

The proposed scheme – a combination of a flood forecasting system, optimised dam operating procedures and direct defences – was brought to Statutory Exhibition stage through the Arterial Drainage Act (as amended) in late 2016/early 2017.

During the exhibition stage, members of the public were invited and encouraged to submit their views in relation to the preferred Scheme. Several submissions received suggested that Natural Flood Management (NFM) measures should have been assessed in further detail as part of the scheme options assessment.

This report was produced in response to the above submissions and presents the findings of an NFM opportunity mapping exercise combined with high-level modelling to demonstrate the potential impact of NFM measures on the River Lee Catchment to Cork.

NFM is the alteration, restoration or use of small scale localised landscape features to reduce flood risk. NFM takes an ‘engineered’ approach to deliver many small landscape interventions that intercept and attenuate hydrological flow pathways to emulate natural processes and provide multiple benefits, including flood management and improving water quality. Put simply, the design philosophy is to create features that ‘slow, store and filter’ runoff and peak flow in the landscape.

NFM has limitations that should be understood by risk management authorities. Choosing locations for features, developing land owner engagement and providing maintenance of numerous assets is rarely straightforward. As a result, NFM is generally considered as a wider catchment-based approach to work alongside traditional forms of flood defence, rather than in isolation.

The detailed assessment of the Lee Catchment concluded that almost 5000 potential interventions combined would still only reduce the 1 in 100 year flow at Cork by between 0.5 - 4.5%. This would have negligible effects on defence heights in the city and in fact, it identified that there was a risk that NFM measures could give rise to a potential for delayed peak flows on the Shournagh which could actually increase flood risk in Cork.

Furthermore, the scale of intervention studied here is between 10 and 100 times larger than any other such scheme that has successfully been implemented in the UK. Such a project could involve several hundred landowners and several different management authorities. This also assumes that all landowners are amenable to the proposed features, which would require extensive change of use of large tracts of private lands. This would be very difficult to achieve logistically, both for construction and how the scheme could be reliably monitored and maintained in the long term.

Therefore, it is evident that a Natural Flood Management solution is not technically viable as an alternative to the proposed scheme or even in combination with other measures.

1 Introduction and Background

1.1 Overview

The Lower Lee Flood Relief Scheme (LLFRS) was commissioned by the Office of Public Works (OPW) with the objective of delivering a flood relief scheme for Cork City and environs to provide protection against the 1 in 100 year fluvial/1 in 200 year tidal flood events.

The project followed on from the pilot Lee CFRAM Study which identified the preferred scheme as being a combination of a flood forecasting system, optimised dam operating procedures and direct defences.

Following extensive study and assessment, a proposed scheme was developed which consisted of a modified version of the above measures together with a flow control structure on the south channel to rebalance flows between the north and south channels.

The proposed scheme was subsequently brought to Statutory Exhibition stage through the Arterial Drainage Act (as amended) in late 2016/early 2017.

Details of the scheme were available for inspection to members of the public between 12 December 2016 and 20 January 2017 at four locations around Cork City. The Scheme has also been available to view online on the project website www.lowerleefrs.ie. Submissions were invited up to the 7 April 2017.

During the exhibition stage, members of the public were invited and encouraged to submit their views in relation to the preferred Scheme. Several submissions received suggested that Natural Flood Management (NFM) measures should have been assessed in further detail as part of the scheme options assessment.

This report was produced in response to the above submissions and presents the findings of an NFM opportunity mapping exercise combined with high-level modelling to represent the impact of NFM for the River Lee Catchment to Cork. Note that while the project brief assumed that flood mitigation measures would be contained within the Lower Lee catchment (i.e. downstream of Inniscarra dam), this analysis has also assessed potential measures in the Upper Lee catchment.

This report should be read in conjunction with the main Lower Lee Exhibition Report and Lower Lee Hydrology Report.

The report is divided into the following chapters:

1. Introduction;
2. Methodology - including the desk study, mapping of features, technical modelling, refinement to prioritised features and sensitivity analysis;
3. Results;
4. Costs and assumptions;
5. Qualitative land use assessment;
6. Identification of potential scheme delivery routes in Ireland;

7. Responses to key questions raised through statutory exhibition process;
8. Discussion.

1.2 Context

Man-made influences such as agriculture, urbanisation etc. have altered natural hydrology of catchment systems. In many catchments, there is anecdotal evidence that these artificial influences have led to increased flood peaks and higher rates of sediment delivery to catchment outlets. Modern tillage practices, including the removal of hedgerows to enlarge the size of fields, constructing under-drainage and ditching works, increased stocking densities and intense cultivation, alter the storage potential and connectivity of the landscape[1].

Research investigating stream water quality in a study catchment in Devon, UK, found clear evidence of increased erosion rates since 1950[2]. The changes were thought to reflect post-1945 intensification of agriculture, which include the modern tillage practices. The Heathwaite and Burt (1991) study also suggested that reductions in water quality could be attributed to an increase in stocking density from less than four livestock per hectare between 1905 and 1950 to over fifteen livestock per hectare in 1965 (in their study catchments). A particular issue is associated with changing the timing of tillage operations leading to 'muddy' floods[3], which are more damaging to properties and drainage systems due to the large volumes of particulate matter being deposited by the floodwater. These changes in land use reduce natural attenuation of water within the catchment[4].

The floods that have affected the UK in recent years have reinforced growing concern that changes to agricultural practice may have increased the risk of flooding[5], and there is good reason to believe that the same mechanisms are at work in Ireland. It is thought that agricultural intensification may cause higher flood peaks in streams and rivers due to its impact on runoff processes.

For example, degradation of soil structure can lead to reduction in infiltration rates and available storage capacities, increasing rapid runoff in the form of overland flow[6,7].

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[1] O'Connell P, Ewen J, O'Donnell G and Quinn P (2007). Is there a link between land-use management and flooding? Hydrology & Earth Systems Sciences, 11, 96–107

[2] Heathwaite A and Burt T (1991). Predicting the effect of land use on stream water quality in the UK in Peters N and Walling D eds Sediment and stream water quality in a changing environment IAHS Publication 203. IAHS, Wallingford 209–19

[3] Boardman J (1995). Damage to property by runoff from agricultural land, South Downs, southern England, 1976–93. The Geographical Journal, 161, 177–91

[4] Boardman J, Ligneau L, de Roo A and Vandaele K 1994 Flooding of property by runoff from agricultural land in northwestern. Europe Geomorphology, 10, 183–96

[5] Wheater, H. (2006). Flood hazard and management: a UK perspective. Phil. Trans. R. Soc. Lond. A., 365, 2135-2145.

[6] Heathwaite, A. L., Burt, T. P., & Trudgill, S. T. (1990). Land-use controls on sediment production in a lowland catchment, south-west England. In J. Boardman, I. D. Foster, & J. A. Dearing, Soil Erosion on Agricultural Land. John Wiley and Sons Ltd.

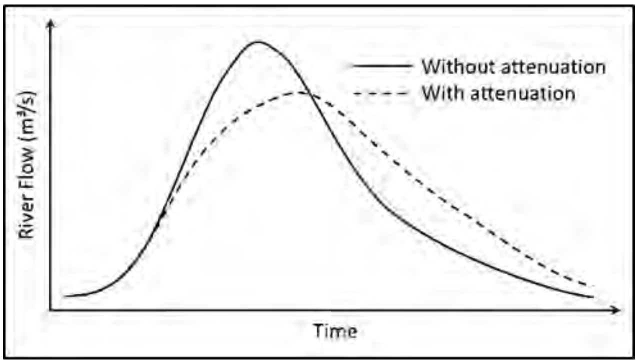
[7] Bronstert, A., Niehoff, D., & Burger, G. (2002). Effects of climate and land-use change on storm runoff generation: present knowledge and modelling capabilities. Hydrological Processes, 16, 509-529.

Although flood hazard is greater in lower lying regions (i.e. areas where population is usually higher), the management of headwaters, with their generally higher precipitation rates and flashier response, is of particular interest for flood runoff generation[8].

NFM is the alteration, restoration or use of landscape features to reduce flood risk[9]. There are arguments that support the restoration of catchments through 'Rewilding,' allowing natural processes and native species to reclaim their position in large areas of land.

NFM takes a more 'engineered' approach to deliver many small landscape interventions that intercept and attenuate hydrological flow pathways to emulate natural processes and provide multiple benefits, including flood management and improving water quality. Put simply, the design philosophy is to create features that 'slow, store and filter' runoff and peak flow in the landscape[10]. The key approach is to link these hydrological processes (as well as the requirements of landowners and downstream receptors) and take a holistic approach to their management. Figure 1 shows an idealised storm hydrograph, which has had its shape altered through attenuation from NFM.

Figure 1: Attenuating flow in a hydrograph



NFM has limitations that should be understood by risk management authorities. Choosing locations for features, developing land owner engagement and providing maintenance of numerous assets is not always straightforward.
As a result, NFM should be considered as a wider catchment-based approach to work alongside traditional forms of flood defence.

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[8] Wheater, H., Reynolds, B., Mcintyre, N., Marshall, M., Jackson, B., Frogbrook, Z., Soloway, I., Francis, O. & Chell, J. (2008). Impacts of upland land management on flood risk: Multi-scale modelling methodology and results from the pontbren experiment. FRMRC Research Report UR 16.

[9] POST, 2011. Natural Flood Management POSTNOTE 396, London, UK: Parliamentary Offices of Science and Technology.

[10] Nicholson, A. R., Wilkinson, M. E., O'Donnell, G. M. & Quinn, P. F., 2012. Runoff Attenuation Features: A sustainable flood mitigation strategy in the Belford Catchment, UK. Area, 44(4), pp. 463-469.

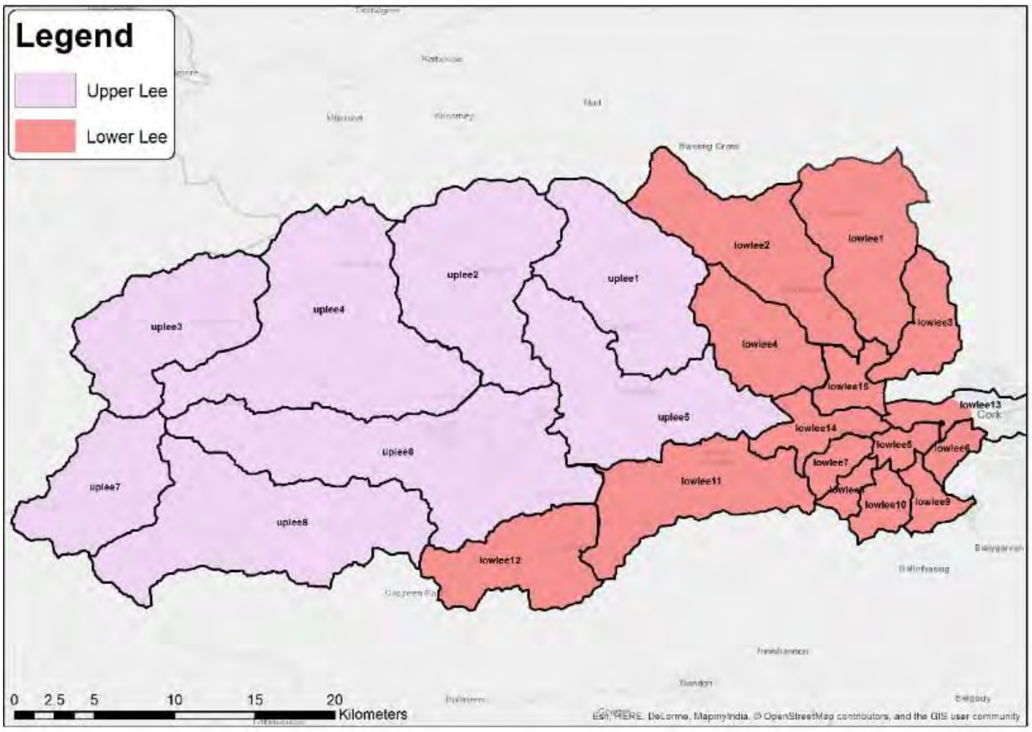
NFM has the potential to increase resilience of existing flood defence schemes by attenuating flood flow, capturing sediment before it enters the watercourse[11], creating habitat and, in some cases, providing sources of energy through the implementation of short rotation coppice crops for biomass.

Examples include better land use management and catchment-wide water storage (for example, the runoff attenuation approach in Belford, Northumberland, UK[12]).

1.3 Description of the River Lee Catchment

The River Lee Catchment covers an area of approximately 1,200km^2 to the point of interest in Cork City Centre. The whole catchment (approximately 2,000km^2) forms one of the largest River Catchments in southwest Ireland. For this study, the area being considered is the River Lee Catchment draining to Waterworks Weir and immediately downstream, where the Curragheen and Glasheen rivers join the River Lee (Figure 2). The underlying hydrology for this study is taken from the Lee CFRAMS project[13], in addition to the work carried out as part of the Lower Lee FRS hydrology study.

Figure 2: Upper and Lower Lee Catchment areas considered by this study



[11] Barber, N. J., & Quinn, P. F. (2012). Mitigating diffuse water pollution from agriculture using soft-engineered runoff attenuation features. Area, 44(4), 454-462.
[12] Quinn, P. et al. (2013). Potential use of Runoff Attenuation Features in small rural catchments for flood mitigation: Evidence from Belford, Powburn and Hepscott, s.l.: Joint Newcastle University, Royal Haskoning and Environment Agency Report.
[13] Halcrow (2009). Lee Catchment Flood Risk Assessment and Management Study (CFRAMS): Hydrology Report. Halcrow Group Ireland Ltd. February 2009.

1.3.1 Upper Lee Catchment

The Upper Lee Catchment covers an area of approximately 790km^2 and extends from the Shehy mountains eastwards to the outlet of Inniscarra reservoir. The catchment boundary is along the Derrynasaggart Mountains and Boggeragh Mountains to the north, and the Bandon River Valley to the south.

The main rivers of the catchment include the Lee, Sullane, Foherish, Laney and Dripsey. The Seasonal Annual Average Rainfall (SAAR) for the catchment is 1,450mm.

The catchment uplands extend around the north and west perimeter of the catchment and consist primarily of exposed rock and sandstone till subsoils. The majority of the catchment is overlain with deep, well-drained mineral soils with areas of peaty topsoil and blanket bogs in the uplands. Agriculture in the uplands is largely grazing and forestry. Forest cover is predominantly coniferous trees with areas of transitional woodland. The lower more undulating ground in the east of the catchment allows for small areas of arable land in the predominantly pastoral landscape. The subsoils in the lower catchment are predominantly sandstone till with pockets of sandstone sands and gravels and alluvium gravels. The difference in elevation in the Upper Lee is 649mAOD at Mullaghanish in the west, to 50mAOD at Inniscarra Reservoir in the east.

1.3.2 Lower Lee Catchment

The Lower Lee Catchment (to Waterworks Weir) covers an area of approximately 410km2, extending from Inniscarra Reservoir outfall to Waterworks Weir. The SAAR for the catchment is 1,100mm.

The land in the Lower Lee Catchment is generally undulating with steeper sloping valleys located in the north of the catchment (draining through the Shournagh River Catchment) from the slopes of the Boggeragh Mountains. To the south of the catchment, both the River Lee and Bride River have wide, flat floodplains. The geology of the catchment is predominantly sandstone till overlain by a cover of relatively fertile and well-drained acid brown soils. The topography and geology of the catchment result in a lower runoff potential than the Upper Lee Catchment.

Urban areas cover approximately 6% of the land in the catchment. Cork City extends approximately 8km from Waterworks Weir, and suburban areas of Cork City make up a significant proportion of the Curragheen and Glasheen Catchments.

2 Methodology

2.1 Overview

The size of the catchment under assessment is far larger than would typically be encountered in an NFM study (by a factor of approximately 10 - 100 times). As a result, it was not considered practical to assess each sub-catchment to the level of individual NFM measures/sites. Therefore, a bespoke methodology was developed in order to identify the potential for NFM and prioritise at a catchment scale. The methodology developed is as follows:

1. Desk study and analysis of mapping layers to generate runoff pathways, stream network and slope values for the entire River Lee Catchment to Cork City;
2. Characterise the Lee catchment by analysing slope values, runoff pathway lengths, stream networks and areas of existing reservoir storage within a 'search grid';
3. Select statistically heterogeneous sample areas of the 'search grid' to perform manual NFM mapping;
4. Apply findings of the sample NFM mapping to other non-mapped areas of the search grid to estimate potential catchment-wide storage/attenuation of water through NFM;
5. Determine the total storage/attenuation volumes in each sub-catchment (based on the analysis in points 2 - 4);
6. Undertake a general assessment of flood risk throughout the Lee catchment to see which areas may benefit from NFM (on the way down to Cork City);
7. Simulate this storage/attenuation in a hydrological model by allocating storage areas at sub-catchment outfalls within the model;
8. Prioritise NFM interventions based on their potential to reduce peak flow, their location within the whole catchment, and the location of potentially vulnerable communities on the way down to Cork City that may also benefit from NFM.

2.2 Assumptions

Several assumptions have been made to undertake a feasibility assessment of NFM features in a catchment area of this scale. These include:

- It is assumed that the IFSAR data is suitable in accuracy for the assessment of runoff pathways, which impact the location of NFM features.
- It is assumed that NFM mapping across the whole catchment area can be based on assessing the feasibility of features in categorised grid squares and applying the same mapped storage across statistically similar grid squares (see explanation below).

- Some potential site specific constraints have not been taken into consideration in the detailed mapping of selected grid squares (including access, utilities, designated areas) - though mapping of features in analysed grid squares has taken OS mapping, satellite imagery and existing land cover into consideration. The generalisation of NFM storage from analysed grid square to non-analysed grid square takes no site specific issues into account (apart from average slope).
- The volume of NFM features has been based on the typical dimensions of a feature and the slope of the ground in the area it has been proposed (see explanation below). In reality, opportunistic locations for NFM features may allow for greater levels of storage, allowing for cheaper construction and better mitigation of flows.
- It is assumed that land owners are amenable to the proposed features.
- It is assumed the soil conditions at each site will be suitable for constructing small barriers to flow.

2.3 Data Collection

A series of contemporary maps, topographic information, property data, flood mapping outlines and other useful spatial data have been requested to undertake the opportunity mapping and feasibility study for NFM in the River Lee Catchment. The following data have been obtained for use in the study:

- Background mapping (1k, 5k, 50k scale) (OPW).
- IFSAR data (5m x 5m grid) (OPW).
- CORINE[14] land use data (open-source).
- Satellite imagery (Bing Maps Hybrid © 2010 Microsoft Corporation and its data suppliers).
- Lee CFRAM study outputs.
- Lower Lee hydrology study outputs.
- Flood mapping data from PFRA study and CFRAMS[15] (OPW).

Analysis of the spatial (mapping) datasets in conjunction with a hydrological representation of the River Lee Catchment will enable the understanding of available locations for NFM features and the potential impact that a network of NFM features will have upon river flow downstream in Cork City.

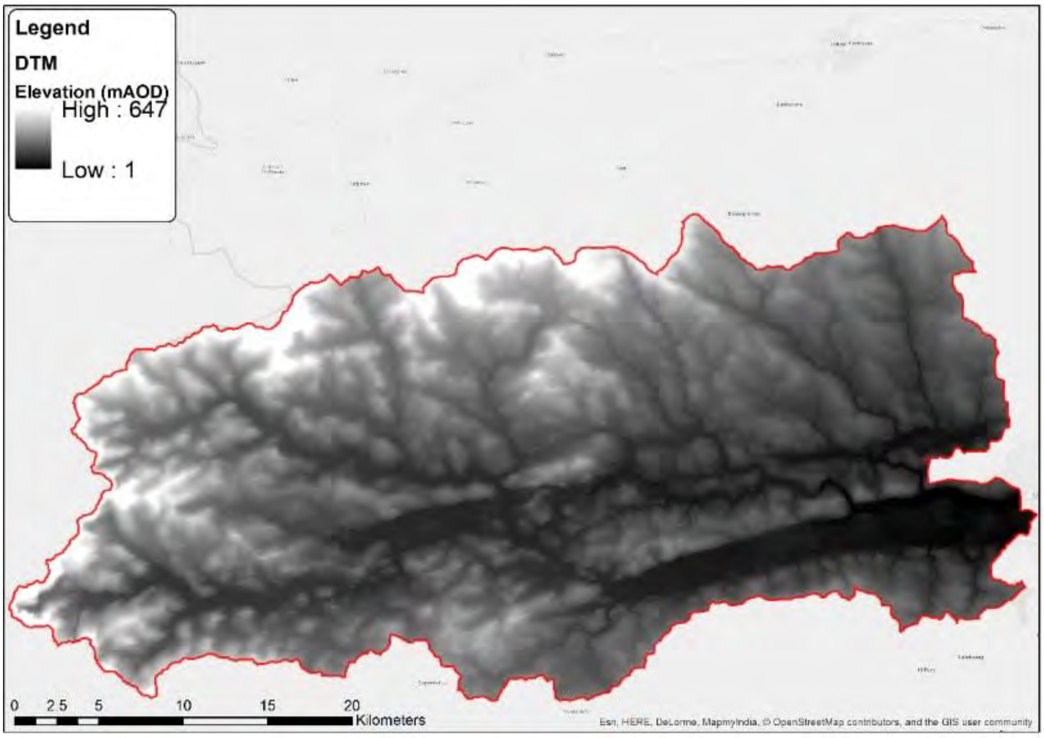
[14] CORINE land cover data. Available at [http://land.copernicus.eu/pan-european/corine-land-cover]
[15] Catchment Flood Risk Management Plans. Available at [http://maps.opw.ie/floodplans/]

2.4 Initial Catchment Schematisation

A desk study of contemporary maps, existing asset information and GIS data was carried out to attain an initial understanding of the catchment system. The catchment area to Waterworks Weir was split into 17 distinct sub-catchment areas as per the Lee CFRAMS catchment schematisation.

A digital terrain model based on IFSAR[16] data was obtained for the full catchment area (Figure 3). A GIS analysis of the IFSAR topographic data identified and mapped the spatial variation of potential surface runoff generation. A package called 'Hydro-Tools' within the ArcGIS toolkit was used. This analysed the topographic data to determine flow direction and areas of possible water accumulation within the catchments. The process of analysing the catchment is described below.

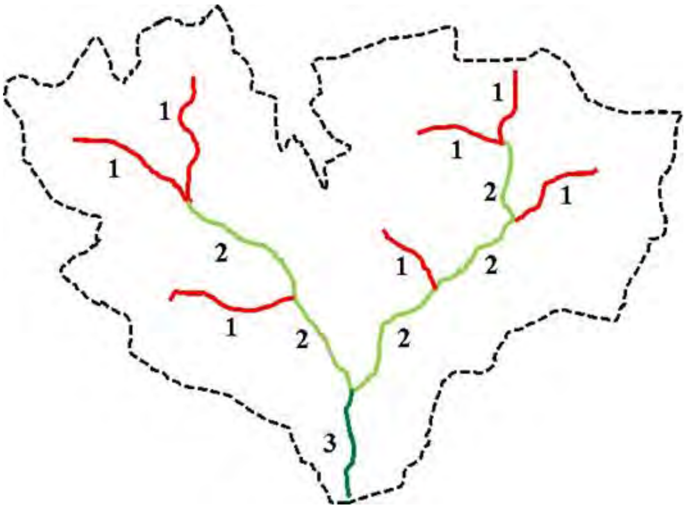
Figure 3: IFSAR data (5 m x 5 m), mosaicked and clipped for the River Lee Catchment at Waterworks Weir in Cork (identified by the red boundary)



A threshold was set for first order streams, such that $0.5km^2$ (50ha) of contributing drainage area is required before the streams are drawn. This is an arbitrary scale chosen based on experience of NFM mapping. All other streams are generated using the Horton-Strahler stream ordering method (Figure 4).

[16] Interferometric Synthetic Aperture Radar

Figure 4: Horton-Strahler ordering of a catchment river channel network

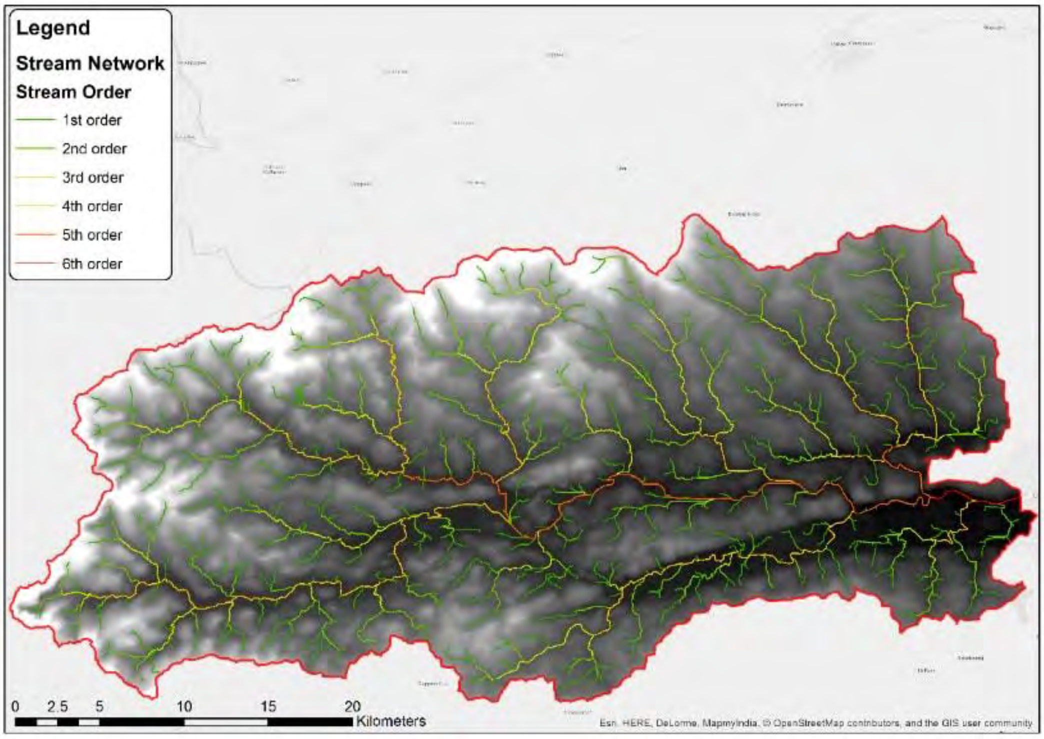


Ordering the stream network is a useful element of identifying feasibility of NFM given the scale of the catchment being investigated.

Ordering the stream network in this way is important for identifying prioritised opportunities for NFM in the 1,200km^2 catchment – focussing on the 1st and 2nd order streams, which form smaller 'headwater' catchments.

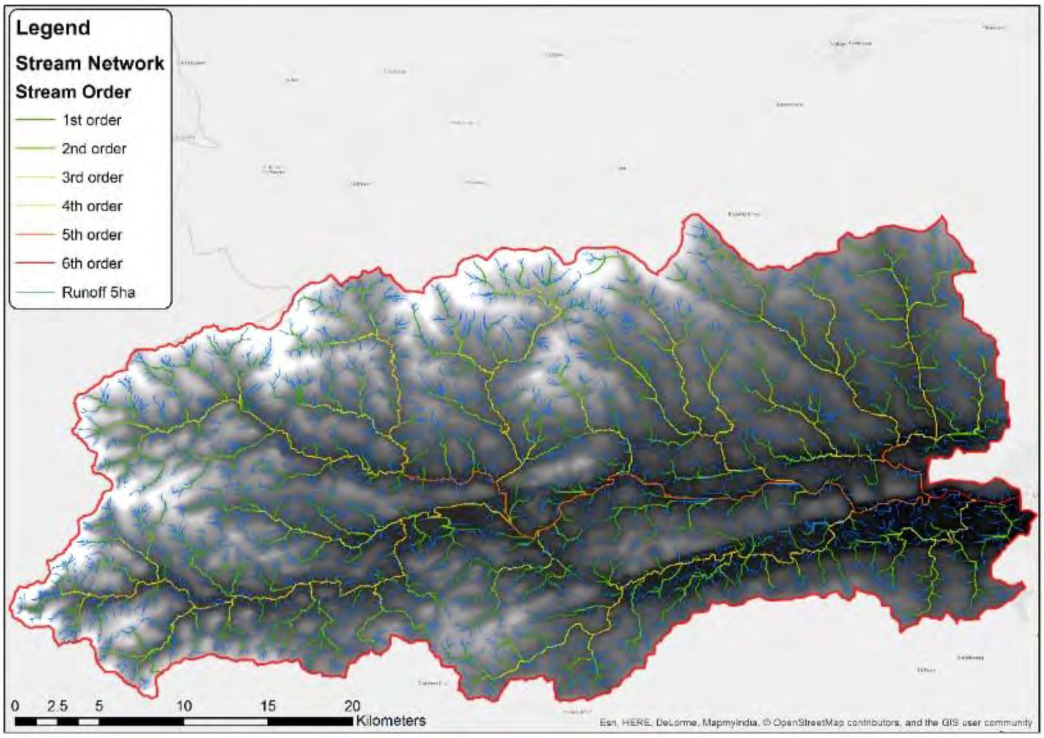
The IFSAR data has been used to calculate this stream ordering for the River Lee Catchment (Figure 5).

Figure 5: Strahler stream order for the River Lee Catchment (with a 0.5km^2/50ha threshold for first order streams)



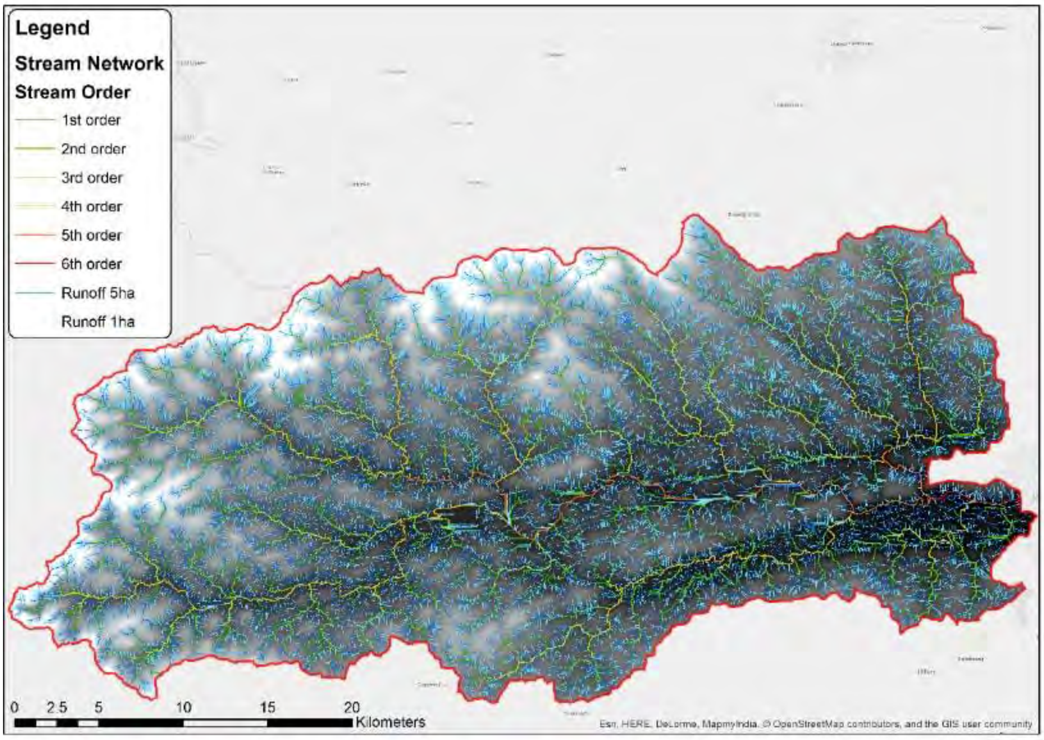
Another threshold was set to assess primary runoff routes in the catchment (Figure 6). The threshold was set to consider runoff between 5ha and 50ha ($0.5km^2$) of contributing drainage area. These runoff routes are assumed to be active in low to medium magnitude storm events, and are therefore more established runoff routes.

Figure 6: Runoff generated between 5ha and 50ha of contributing drainage area



A final threshold was set to assess secondary runoff routes in the catchment (Figure 7). The threshold was set to consider runoff between 1ha and 5ha of contributing drainage area.

Figure 7: Runoff generated between 1ha and 5ha of contributing drainage area



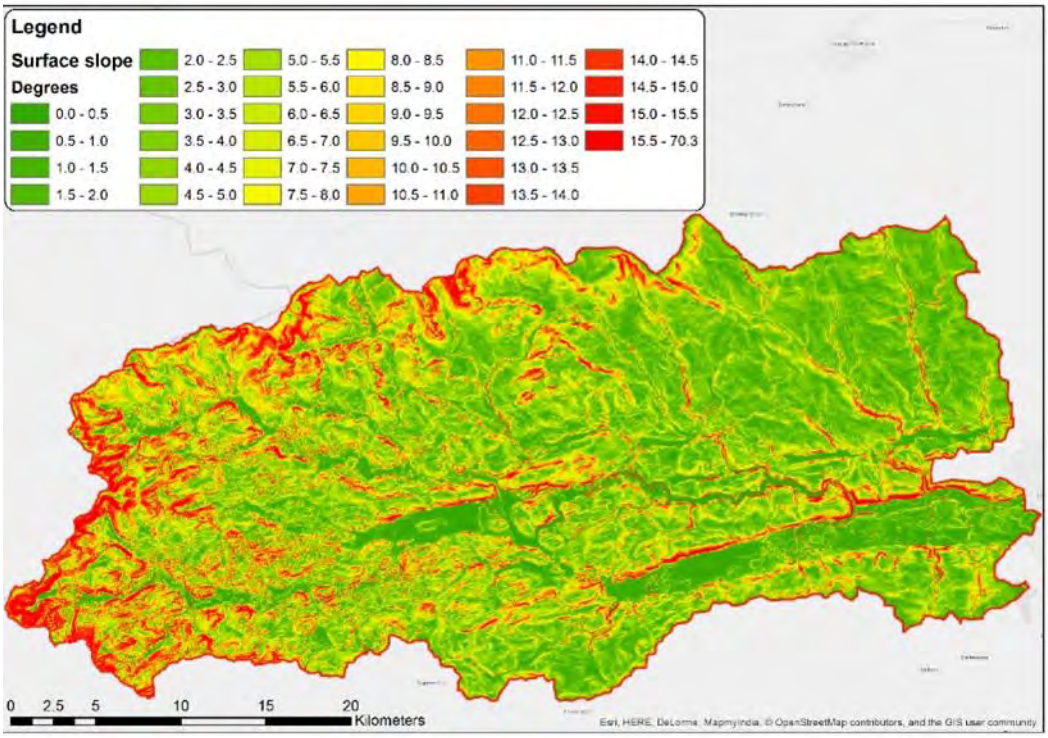
The additional threshold for runoff is set to consider surface water runoff routes that may take longer generate during rainfall events. Intercepting water from these sources is more likely to 'target' peak flow in high magnitude rainfall events.

The purpose of mapping these stream orders and runoff routes is to use them, in combination with other mapping layers, to determine more productive locations for NFM. The output from the ArcGIS analysis was combined with background mapping, fluvial flood risk layers, land use data, and satellite imagery to determine feasible locations for NFM interventions. The NFM features considered in the mapping process are shown in Section A1– Glossary of NFM Features considered in analysis.

2.5 Further Catchment Characterisation and Selection of Test Squares

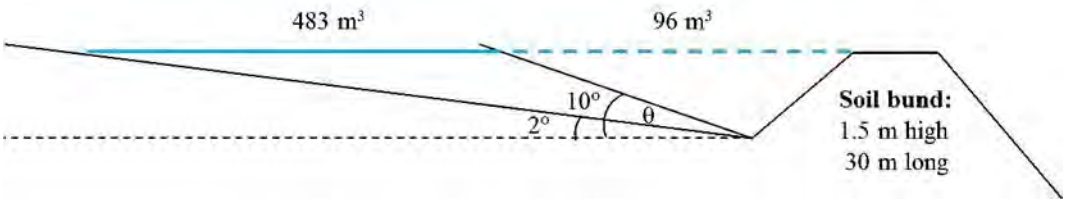
Due to the catchment size (1,200km^2), a targeted approach to NFM opportunity mapping was adopted through statistical analysis. The IFSAR data was analysed to produce a raster image of slope throughout the entire catchment area. Slope is an important component to consider as it not only dictates where runoff will occur in the catchment, but where higher levels of storage can be positioned to capture that runoff. The slope magnitudes for the entire catchment are shown in Figure 8.

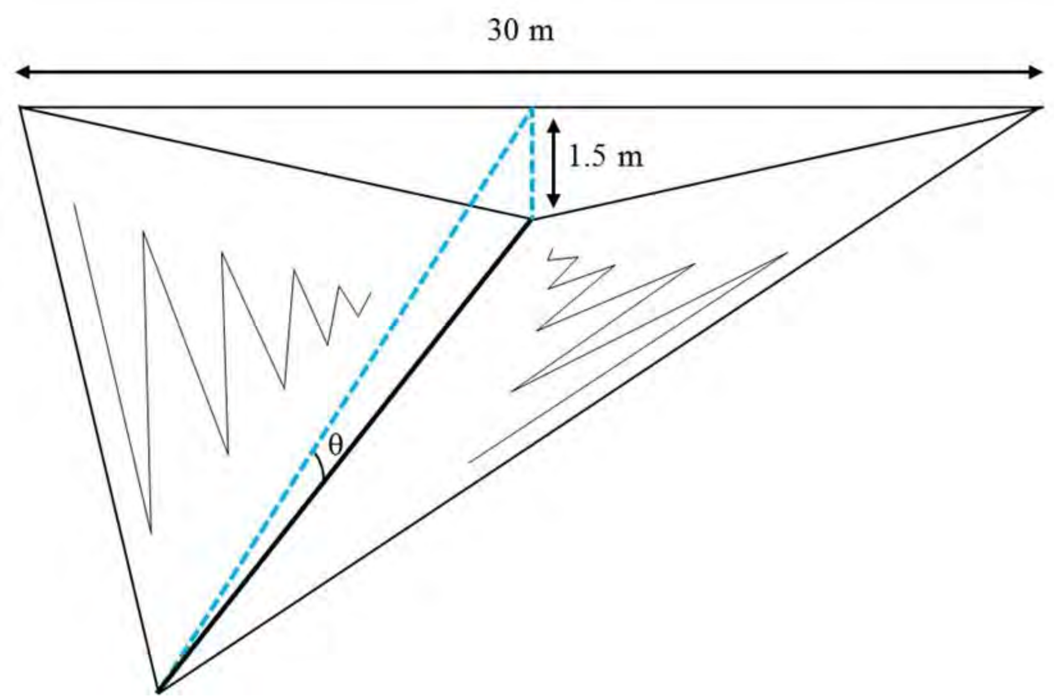
Figure 8: Attenuation in some sites was underestimated by the initial analysis



Slopes in the range 0º - 15.5º are considered suitable for NFM interventions. Consider a barrier to runoff or floodplain flow that is one and a half metres high and thirty metres long. The remaining characteristic controlling the storage volume of a NFM feature is the slope of the land of which it is situated (Figure 9).

Figure 9: Example cross section (top) and elevation (bottom) of a physical barrier installed on a slope





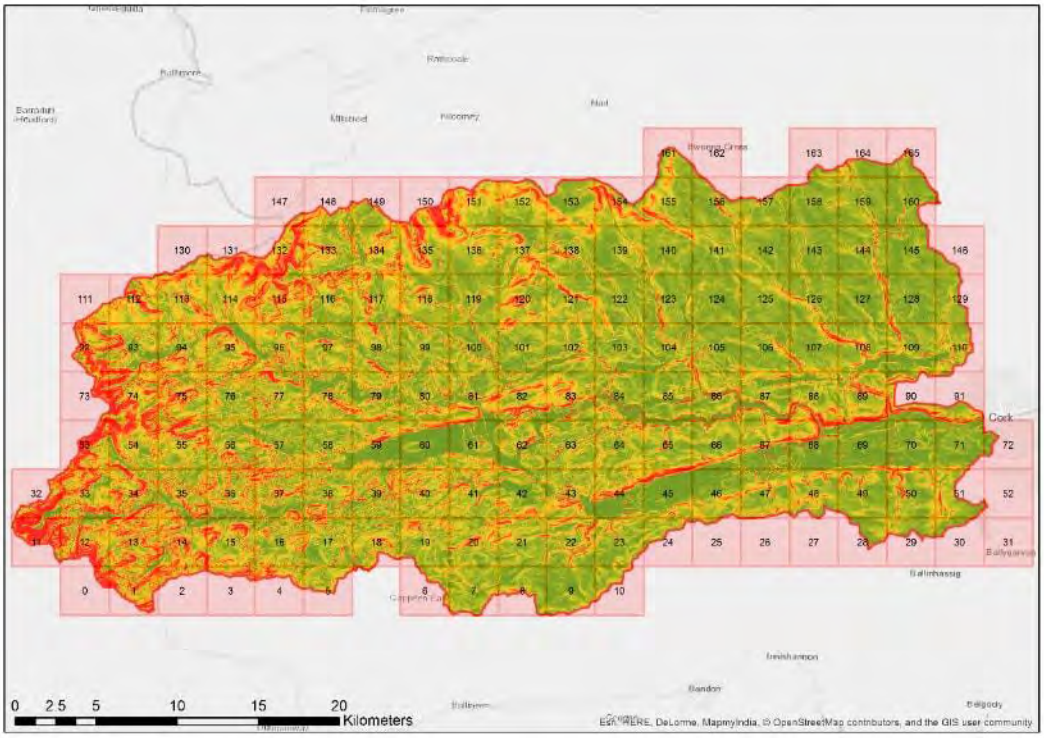
A summary of potential storage magnitudes for a typical NFM feature (1.5m high and 30m long) is shown in Table 1. The table shows how potential storage quickly diminishes as the slope magnitude increases.

Table 1: Example storage volumes for each slope (based on a 1.5m high, 30m long soil bund)

Slope (°)	Typical volume (m^3)
0.5	1,934
1	967
2	483
3	322
4	241
5	193
6	161
7	137
8	120
9	107
10	96
11	87
12	79
13	73
14	68
15	63
16	59

Surface slope is used as a metric to categorise the catchment using a 'Fishnet' grid system, which has been applied to the entire catchment (Figure 10). The grid squares of the fishnet are 3km x 3km (9km^2). The River Lee Catchment is represented using 166 of these grid squares (though many of the parimeter grid squares only contain a small area of the catchment).

Figure 10: Fishnet applied to the catchment area (numbers in each grid square is the grid square reference number)



Applying the grid has enabled statistical grouping of average slope magnitudes from each grid square. For example, the average slope throughout grid square 74 is 11.6º and the average slope throughout grid square 124 is 3.0º. It was decided to create the following statistical groups to categorise the grid squares from the catchment: 2 - 4º, 4 - 6º, 6 - 8º, 8 - 10º and >10º. The grid squares in each group were qualitatively assessed to ensure that a mix of headwater catchment and lower lying areas, as well as areas of large waterbodies and changing land use, were included in a detailed mapping exercise (see Figure 12 after land cover).

Land cover data for the River Lee catchment has been obtained from the Copernicus Land Monitoring Service's Corine[17] dataset.

The data consists of 100 x 100m grid squares, where each grid square is coloured based on the dominant land cover 'class.' For the River Lee catchment to Waterworks Weir, specifically, there are eighteen land cover classes.

[17] Copernicus land monitoring service: http://land.copernicus.eu/pan-european/corine-land-cover/view [Accessed August 2017]

Figure 11: Corine land use data for the River Lee catchment

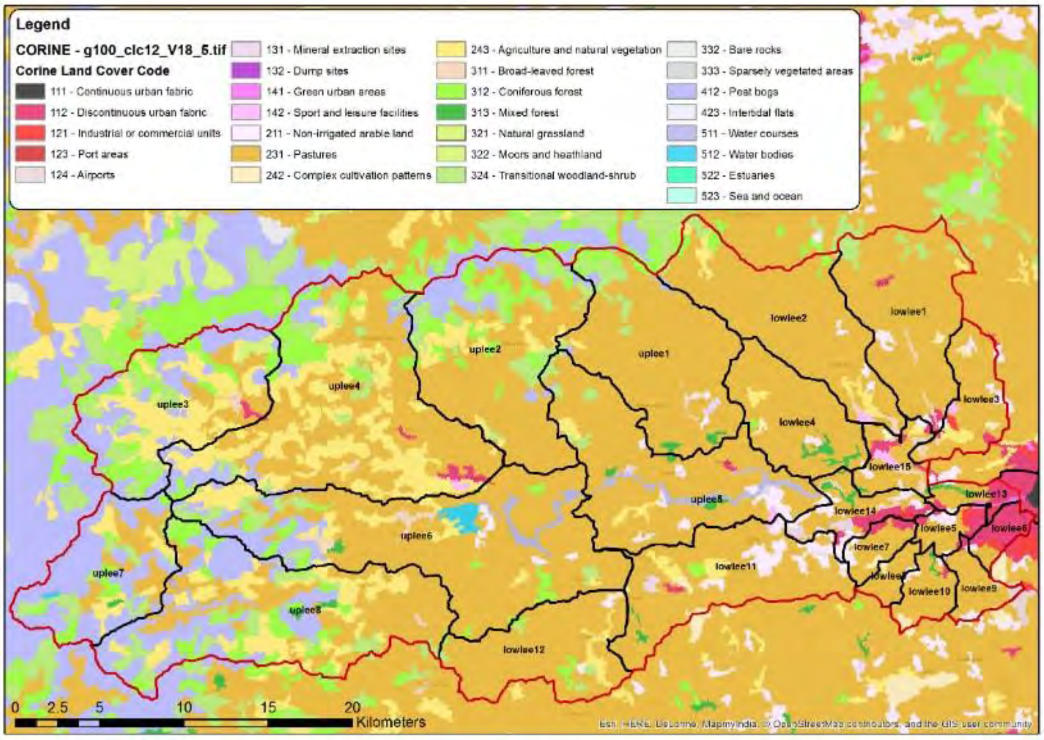


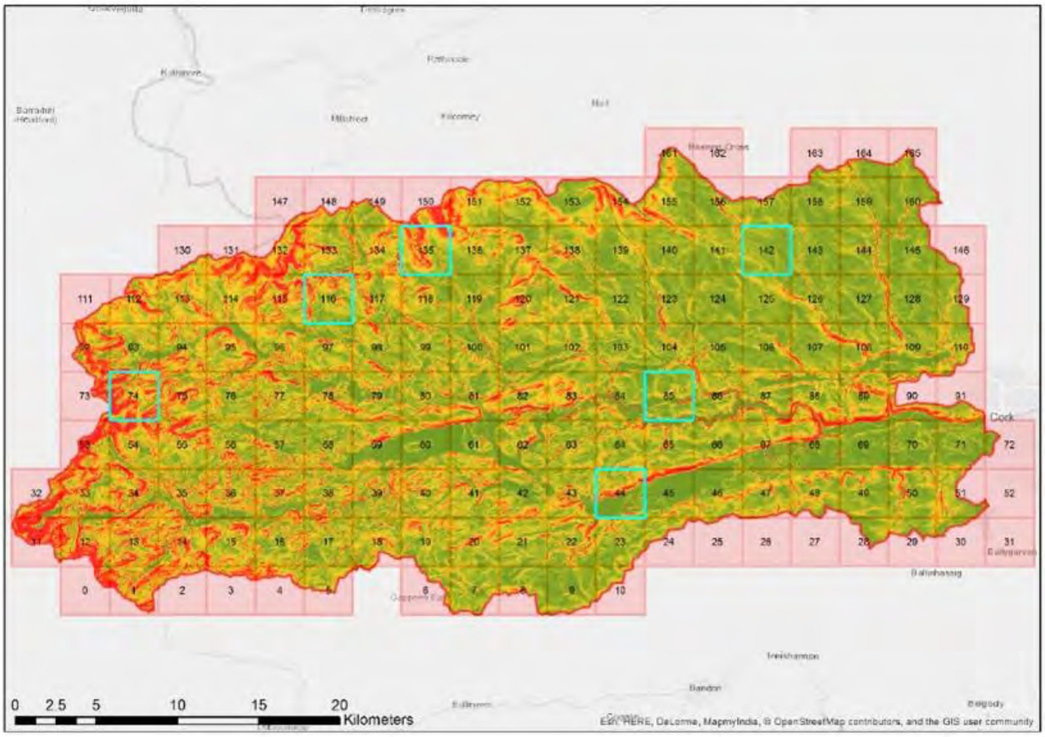
Table 2 shows the percentage of land cover classes for each sub-catchment of the River Lee Catchment to Waterworks Weir. The sub-catchments in the table have been colour-coded to identify an approximate grouping, based on the combination of land cover. The dominant land use for most of the catchment is pasture (indicated by orange groupings). Woodland, peatbog and moorland areas are more prevalent in the higher elevation areas of the Upper Lee (indicated by green groupings). Large areas of urban cover only begin to dominate the landscape near Cork (indicated by red groupings).

Table 2: Corine land use data as percentage for each sub-catchment of the River Lee Catchment (approximately grouped based on qualitative assessment)

CLC-CODE	112	121	124	131	141	142	211	231	242	243	311	312	313	321	324	412	511	512
Description >> Sub-catchment	Urban	Industrial	Airports	Mineral extraction	Green urban areas	Sport and leisure	Non-irrigated agriculture	Pasture	Complex cultivation	Agriculture and natural vegetation	Broad-leaved forest	Coniferou s forest	Mixed forest	Natural Grassland	Transitional woodland	Peat bogs	Watercourses	Water bodies
uplee1	0.0	0.0	0.0	0.6	0.0	0.0	0.8	85.7	0.0	0.6	0.4	3.4	1.2	0.0	5.6	1.5	0.0	0.0
uplee2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	55.8	0.0	8.4	0.0	11.7	0.0	0.0	11.6	12.5	0.0	0.0
uplee3	0.8	0.0	0.0	0.0	0.0	0.0	0.0	11.8	0.0	30.3	1.0	14.4	0.0	2.5	11.5	27.8	0.0	0.0
uplee4	1.3	0.0	0.0	0.0	0.0	0.4	0.0	47.5	0.0	30.7	0.2	7.1	0.0	0.0	4.9	8.0	0.0	0.0
uplee5	0.4	0.0	0.0	0.6	0.0	0.4	5.0	81.1	0.0	2.6	0.0	0.0	1.2	0.0	2.8	0.3	5.7	0.0
uplee6	0.1	0.0	0.0	0.0	0.0	0.0	1.2	67.4	0.0	7.7	1.7	4.2	0.3	0.0	4.7	8.1	2.7	1.9
uplee7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	19.7	0.0	9.7	0.0	6.9	0.5	0.0	10.8	51.8	0.0	0.5
uplee8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	34.9	0.0	18.2	0.2	10.5	0.6	0.0	9.0	25.1	1.4	0.0
lowlee1	1.5	0.0	0.0	0.0	0.0	0.1	2.0	88.5	0.5	0.6	1.3	0.0	0.0	0.0	5.4	0.0	0.0	0.0
lowlee2	0.0	0.0	0.0	0.0	0.0	0.7	1.3	86.9	0.1	5.0	1.4	2.7	0.0	0.0	1.8	0.3	0.0	0.0
lowlee3	2.7	1.6	0.0	0.0	0.0	1.7	5.3	77.9	2.6	5.7	2.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0
lowlee4	0.1	0.0	0.0	0.0	0.0	0.0	1.3	91.1	0.9	2.0	0.0	0.6	4.1	0.0	0.0	0.0	0.0	0.0
lowlee5	18.8	10.3	0.0	0.0	3.1	0.0	12.6	55.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
lowlee6	69.6	8.9	0.0	0.0	0.1	0.0	2.4	17.5	1.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
lowlee7	13.8	0.3	0.0	0.0	0.0	0.0	10.4	71.4	4.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
lowlee8	0.0	0.0	0.0	0.0	0.0	0.0	2.9	93.0	4.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
lowlee9	4.3	0.1	4.6	0.0	0.0	0.0	6.3	81.2	3.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
lowlee10	2.1	0.0	0.0	0.0	0.0	0.0	5.1	85.9	4.5	0.0	0.0	0.0	2.3	0.0	0.0	0.0	0.0	0.0
lowlee11	0.8	0.0	0.0	1.1	0.0	0.4	11.8	77.6	1.7	4.9	0.0	1.1	0.7	0.0	0.0	0.0	0.0	0.0
lowlee12	0.0	0.0	0.0	0.0	0.0	0.0	1.3	87.8	0.6	5.1	0.0	2.8	0.0	0.0	2.5	0.0	0.0	0.0
lowlee13	32.5	2.5	0.0	0.0	6.4	0.0	5.3	44.4	0.0	0.0	0.0	0.0	8.8	0.0	0.0	0.0	0.0	0.0
lowlee14	15.4	1.8	0.0	7.0	0.0	0.0	19.2	47.1	0.0	0.0	5.1	0.0	4.3	0.0	0.0	0.0	0.0	0.0
lowlee15	10.2	0.0	0.0	0.0	0.0	5.7	5.2	63.0	1.8	2.7	9.9	0.0	1.4	0.0	0.0	0.0	0.0	0.0

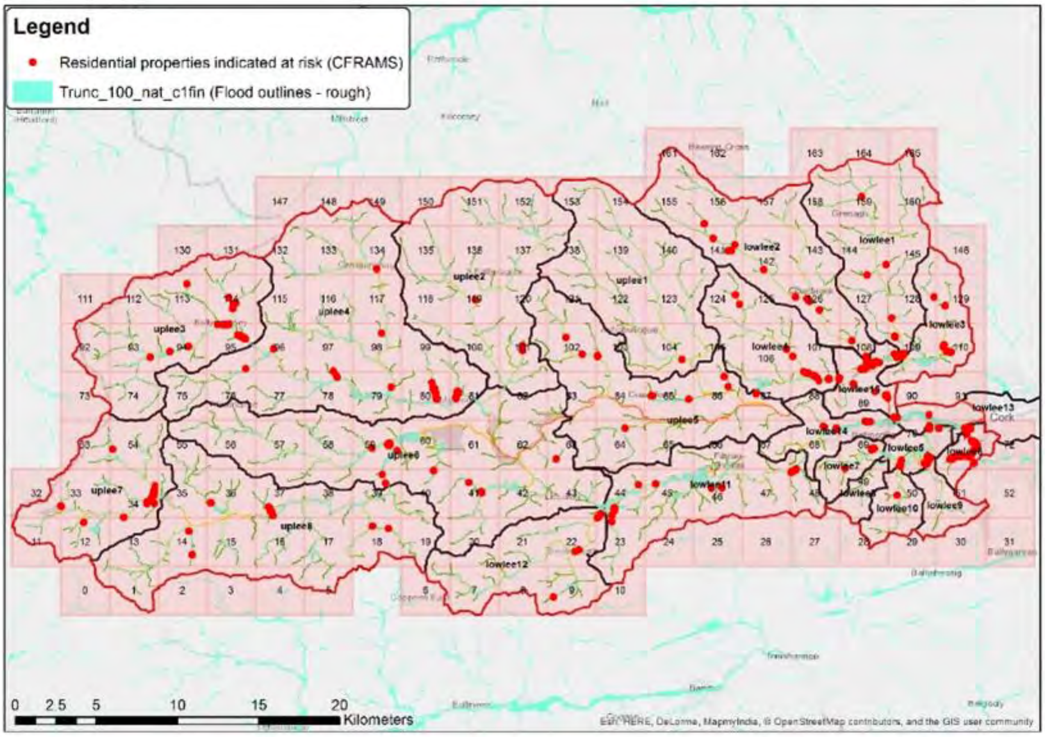
The presence of large areas of woodland, peat bog and surface water bodies has qualitatively influenced the decision to select certain grid squares in the analysis. Figure 12 shows the grid squares that have been chosen (44, 74, 85, 116, 135 and 142), each of which represents a slope group category. Grid square 85 shares slope group category with 142, but also contains a significant area of Inniscarra Reservoir. It was selected for this reason, due to the fact that less land may be available for NFM features.

Figure 12: Grid squares chosen for the analysis of slope and land use (squares 44, 74, 85, 116, 135 and 142)



Finally, the presence of potentially vulnerable areas (PVAs) has also been used as a proxy for determining locations for detailed NFM opportunity mapping. PVAs that exist throughout the catchment have the potential to benefit from NFM interventions installed upstream of them (i.e. it is not only the city of Cork that can benefit). Figure 13 shows all the 'Residential' properties that lie within the flood extents identified in the PFRA study. Although the PFRA study is considered unsuitable for detailed assessments of flood extent, it is assumed that it can be used as a metric of flood risk in the catchment. It identifies areas in the Upper Lee (Uplee3, 4 and 7) and properties on the Shournagh (Lowlee1, 2, 3, 4 and 15), the River Bride (Lowlee12 and 11), the Curragheen (Lowlee7 and 5) and the Glasheen (Lowlee6). This information should be taken into account when prioritising upstream areas for NFM opportunities.

Figure 13: Residential properties that lie within the high-level flood outlines from the PFRA study



The results of the analysis identify over 1000 properties within the PFRA flood outlines in the River Lee Catchment (Table 3). Approximately half of these are within the urban and suburban areas of Cork City (in the Curragheen and Glasheen River Catchments). This analysis identifies the role that NFM or catchment management could play for reducing flow on the way to Cork City, as several properties could benefit on the way to Cork.

Table 3: Residential properties identified within the PFRA flood outlines for each sub-catchment (Total = 1021 properties)

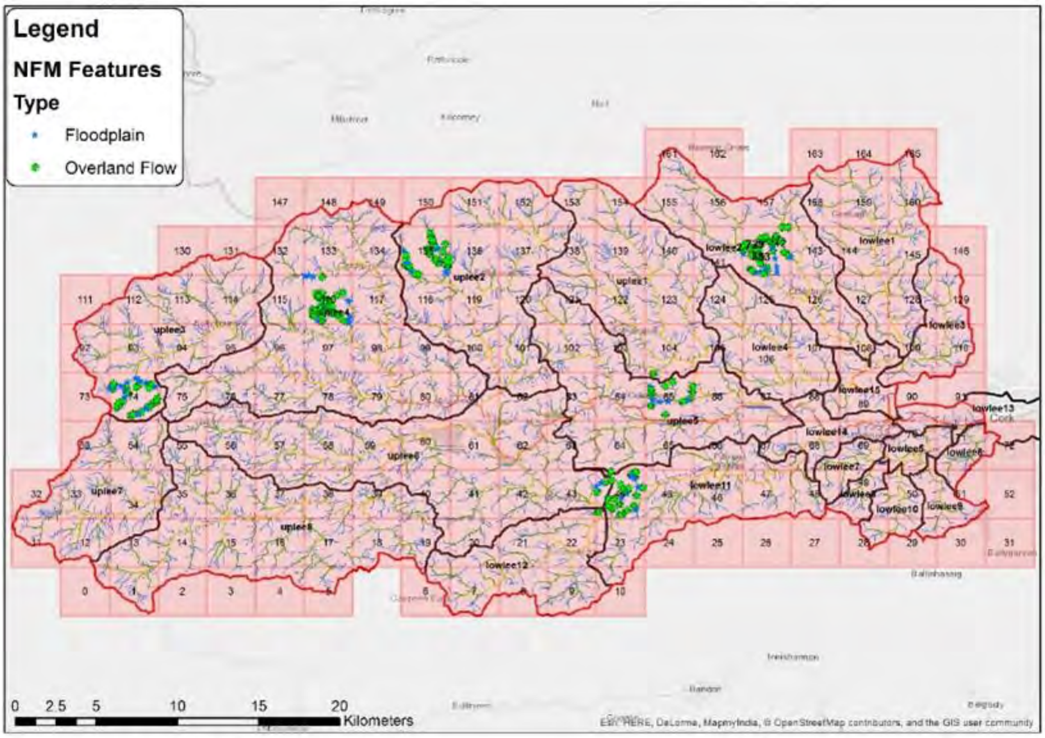
Sub-catchment	Properties identified within flood outline
Uplee1	1
Uplee2	3
Uplee3	46
Uplee4	79
Uplee5	16
Uplee6	19
Uplee7	32
Uplee8	17
Lowlee1	27
Lowlee2	14
Lowlee3	12

Sub-catchment	Properties identified within flood outline
Lowlee4	28
Lowlee5	59
Lowlee6	294
Lowlee7	23
Lowlee8	0
Lowlee9	124
Lowlee10	10
Lowlee11	27
Lowlee12	11
Lowlee13	3
Lowlee14	12
Lowlee15	164

2.6 NFM Feature Mapping within Test Squares

Section 3.3 described how the 166 grid squares of the River Lee Catchment have been grouped based on the average slope in each of the grid squares. Each category has had a grid square selected for manually mapping potential opportunities for NFM features. As discussed previously, an extra square (square 85) was selected and manually mapped for the 2 - 4º category due to a large proportion of lake area (from Inniscarra) compared to the grid square area. The mapping has considered land use, aerial imagery and OS mapping alongside the calculated runoff routes and flow paths expected from the topographic data in order to map a realistic number of features in each grid square. NFM measures, including floodplain storage and overland flow storage ponds were mapped throughout the Lower Lee catchment. Quantification of these measures is based on the addition of 'New' storage within each sub-catchment of the River Lee Catchment and is only based on the specific measures that are capable of adding physical storage to the catchment.

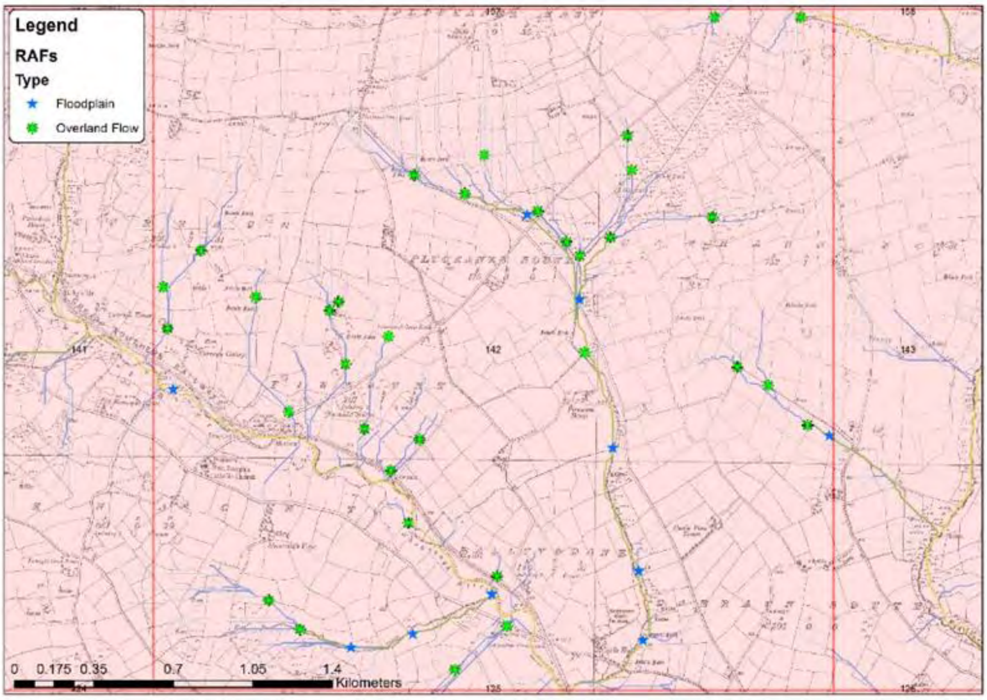
Figure 14: Mapped features in selected grid squares



Using all these different layers and datasets makes it possible to position NFM features in the landscape. ‘Overland flow’ features are intended to capture runoff pathways and ‘Floodplain’ features are intended to either reconnect areas of floodplain currently disconnected from the watercourse, or maximise the depth of storage being stored on floodplains that are known to flood already (see Section A1 – Glossary). In all cases, these NFM features use some kind of leaky structure (timber or soil bund) to temporarily store a depth of water during an intense rainfall event.

Practical implementation must be considered when positioning NFM features in the catchment. NFM features situated in any area must consider land use. For agricultural land it is best practice to consider corners of fields (or field boundaries) rather than the middle of a field. This is particularly relevant on arable fields. Fields used for pasture and livestock are less critical, but fields are often rotated between land uses after periods of time. For this reason, it is beneficial to always position overland flow ponds at field boundaries or corners. Floodplain features must also consider land ownership, ensuring that features are kept in individual fields until more is known about specific sites. Examples of positioning NFM are shown in Figure 15.

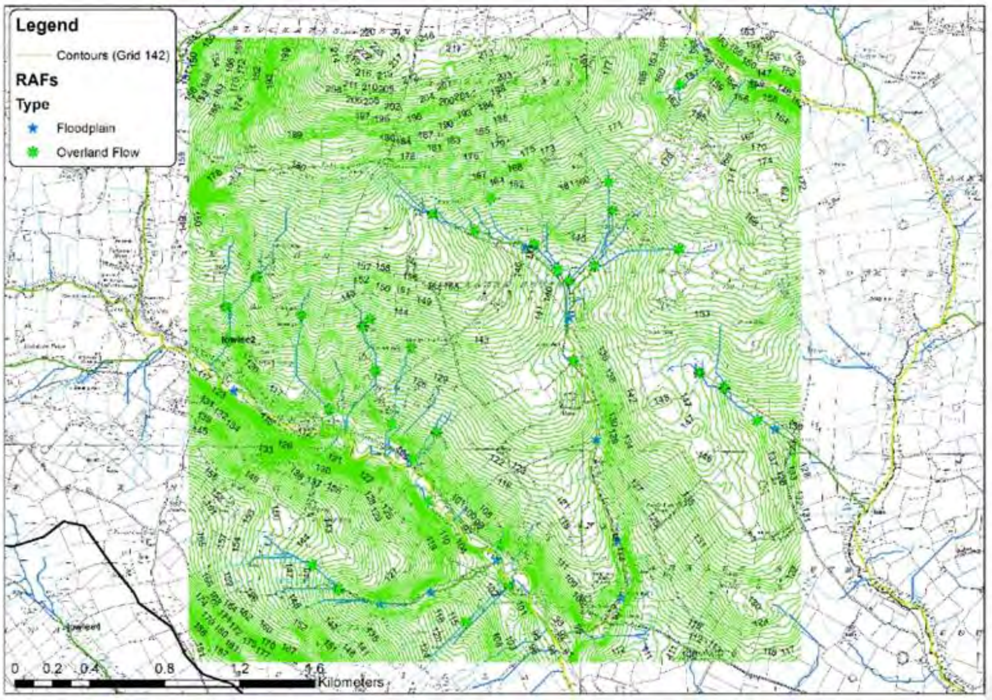
Figure 15: NFM opportunity mapping in grid square 142 (see Appendix C1 for output maps of all mapped grid squares)



The mapping methodology uses the tools described above and expert judgement from extensive knowledge in the field of NFM to locate interventions in feasible locations. NFM options are considered throughout the wider catchment area to capture sources of overland flow and slow delivery of storm water in lower order streams in the catchment headwaters.

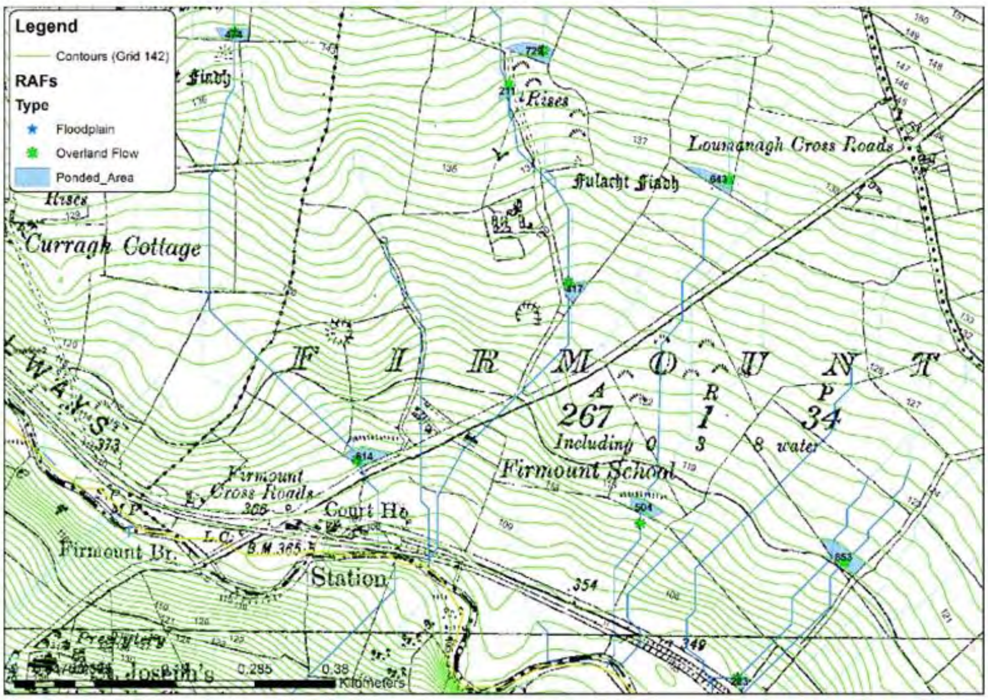
The storage of each NFM feature is estimated based on the slope calculation and methodology described in Section 3.3. To demonstrate the accuracy of this methodology, a test square has been selected to measure the ponded area of a selection of features. Grid square 142 was used to cut a section of IFSAR data and generate a contour map with 1m spacing (Figure 16).

Figure 16: Contour map of grid square 142 (generated using the 5m IFSAR data)



A 1.5m high barrier to flow situated over a stream line at a contour will generate a 'tail' of water up to the next contour. Figure 17 shows the ponded areas of a selection of features in the 142 grid square.

Figure 17: Ponded areas for a selection of features in grid square 142



The areas range from 211 - 853m^2. Assuming an average depth of 0.5m over the whole area yields storage volumes ranging from 105 - 426m^3 for the features shown in Figure 17.

Table 4 shows the comparison of storage volumes between the average slope method and the ponded area measured between contours. For the majority of measurements, the average slope method estimates less storage than the measured ponded area between contours. Therefore, it is assumed the average slope method is conservative for the River Lee catchment.

Table 4: Comparison of storage volumes estimated using different methods

NFM ID	Slope estimated volume (m^3)	Contour measured volume (m^3)
8	171	237
9	286	209
10	171	307
11	171	112
21	215	322
22	245	365
123	286	427
124	171	252
132	245	106

2.7 Catchment-wide Storage Estimation

The results of the NFM mapping in the test squares was then applied to other non-mapped areas of the search grid to estimate potential total catchment-wide storage of water through NFM. Figure 14 shows a map of all 166 grid squares. Of these squares, 66 of them are only partially filled with catchment area from the River Lee Catchment. This meant that a proportion of the potential NFM storage had to be applied to these partial grid squares, based on the slope group they were categorised under.

Table 5 shows the potential storage, following the statistical method described in the previous section, available in the River Lee Catchment – assuming a 1.5m high, 30m long barrier to flow.

These dimensions have been chosen as they are deemed practical to construct on farmland, based on past experience of constructing NFM interventions e.g. Belford, Northumberland, UK[18]. However sensitivity analysis has been carried out to demonstrate the potential storage achieved by different sizes of barrier (Tables 4 and 5). These shows that the height of a barrier is more likely to have a greater impact on potential storage than its length.

The breakdown of storage and number of features per sub-catchment is shown in Section 4.

[18] Nicholson, A. R., Wilkinson, M. E., O’Donnell, G. M. & Quinn, P. F., 2012. Runoff Attenuation Features: A sustainable flood mitigation strategy in the Belford Catchment, UK. Area. 44(4) 463-469.

Table 5: Summary of storage potential in River Lee Catchment (assuming a 1.5m high, 30m long barrier to flow)

Slope Group	Test Square	Square total (m^3)	Full group total (for full grid squares) (m^3)	Full group total (for partial grid squares) (m^3)
2-4°	142	19,736	434,188	196,268
4-6°	44	18,468	590,991	212,776
6-8°	116	13,813	303,882	44,682
8-10°	135	12,081	96,652	38,442
> 10°	74	13,861	13,861	89,238
Grids with lakes	85	12,177	97,415	
		TOTAL (m^3)	**1,536,989**	**581,406**
		GRAND TOTAL (m^3)	**2,118,395**	

Table 6: Summary of storage potential in River Lee Catchment (assuming a 1.5m high, 40m long barrier to flow)

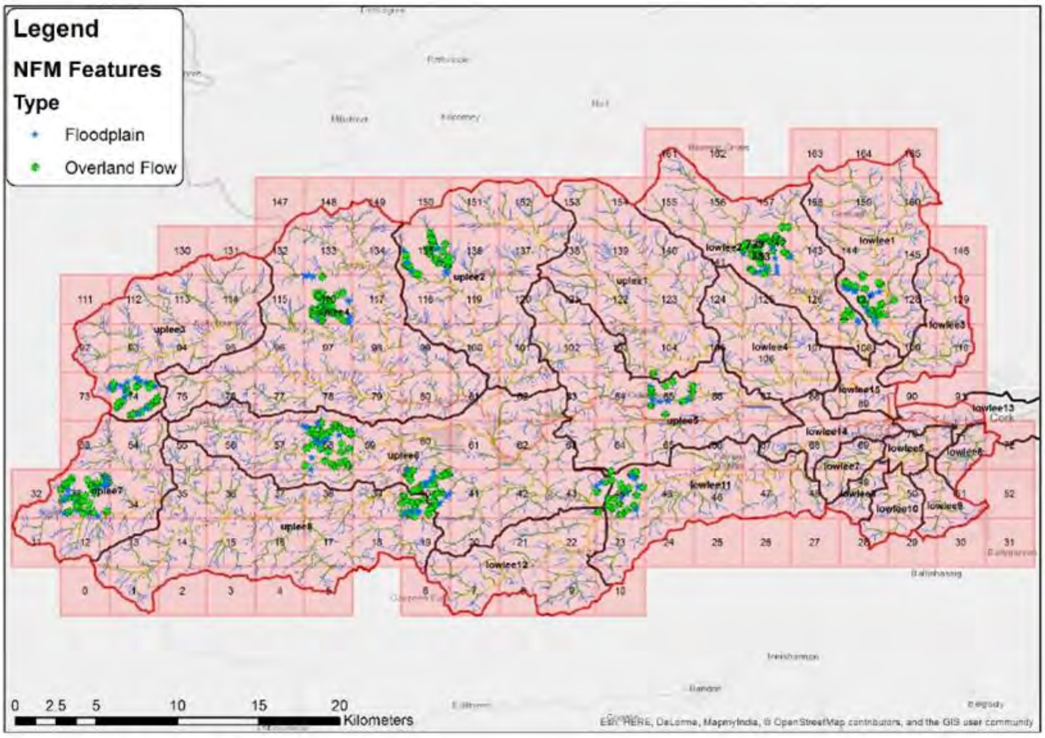
Slope Group	Test Square	Square total (m^3)	Full group total (for full grid squares) (m^3)	Full group total (for partial grid squares) (m^3)
2-4°	142	26,314	578,918	261,691
4-6°	44	24,625	787,987	283,701
6-8°	116	18,417	405,176	59,576
8-10°	135	16,109	128,869	51,256
> 10°	74	18,481	18,481	118,984
Grids with lakes	85	16,236	129,886	
		TOTAL (m^3)	**2,049,318**	**775,209**
		GRAND TOTAL (m^3)	**2,824,527**	

Table 7: Summary of storage potential in River Lee Catchment (assuming a 2m high, 30m long barrier to flow)

Slope Group	Test Square	Square total (m^3)	Full group total (for full grid squares) (m^3)	Full group total (for partial grid squares) (m^3)
2-4°	142	44,406	976,924	441,604
4-6°	44	41,554	1,329,729	478,746
6-8°	116	31,079	683,735	100,535
8-10°	135	27,183	217,466	86,495
> 10°	74	31,187	31,187	200,785
Grids with lakes	85	27,398	219,183	
		TOTAL (m^3)	**3,458,224**	**1,308,165**
		GRAND TOTAL (m^3)	**4,766,389**	

A validation exercise was undertaken to test the methodology described in Section 3.3, by manually mapping a further 4 grid squares. The additional grid squares fall into average slope groups 2 - 4º, 4 - 6º, 6 - 8º and 8 - 10º. Slope group 10º+ was excluded as it only contained 1 full-sized grid square. Figure 18 shows all the manually mapped grid squares.

Figure 18: Additional opportunity mapping (performed as a check on grid squares 33, 40, 58 and 127)



The results of the additional mapping identified a greater number of NFM features and greater storage potential for each slope group (see Table 8). It has been decided to adopt the original mapping findings to achieve a more conservative result (given wider assumptions).

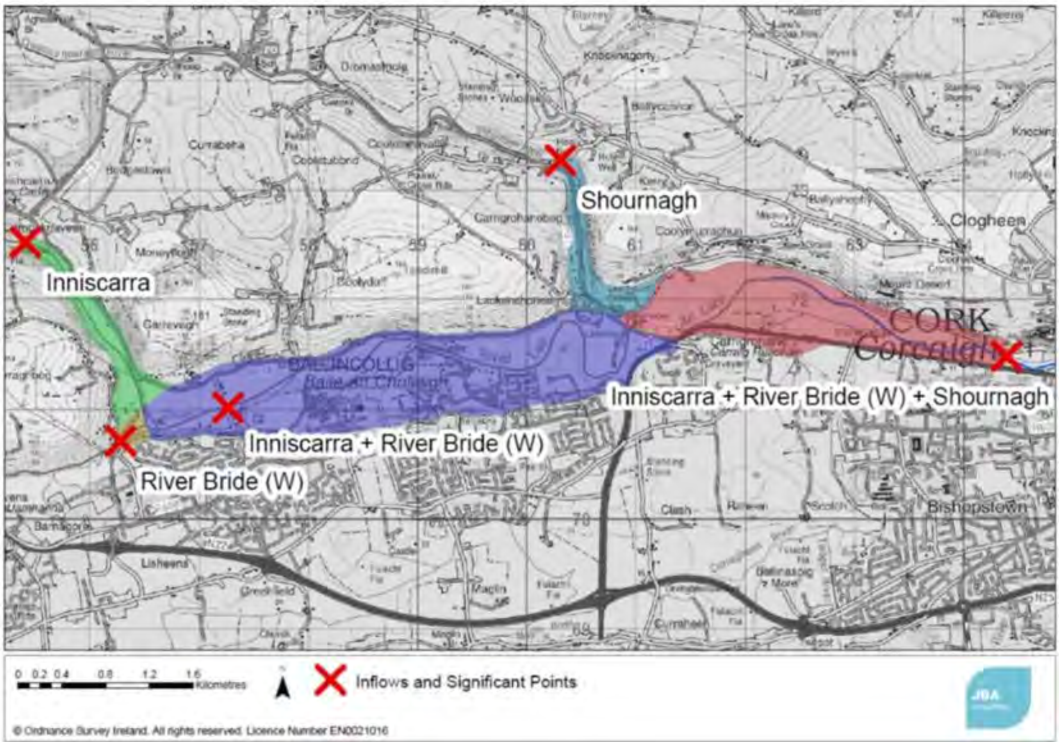
Table 8: Check using further opportunity mapping on statistically similar grid squares

Slope Group	Test Square	Square total (m^3)	Test Square	Square total (m^3)
2-4°	142	19,736	127	22,719
4-6°	44	18,468	58	26,491
6-8°	116	13,813	40	20,409
8-10°	135	12,081	33	16,332
> 10°	74	13,861	n/a	n/a
Grids with lakes	85	12,177	n/a	n/a

2.8 Hydrological Modelling of NFM Storage

Prior to undertaking NFM modelling, an understanding of the hydrological modelling framework was required so an assessment of which sub-catchment areas would be delivering flow downstream to Cork. As part of the Lower Lee FRS hydrology study, continuous flow simulations were created at several locations upstream of the Waterworks Weir in Cork. A screenshot from the Final Hydrology report shows the locations of these flow simulations (Figure 18).

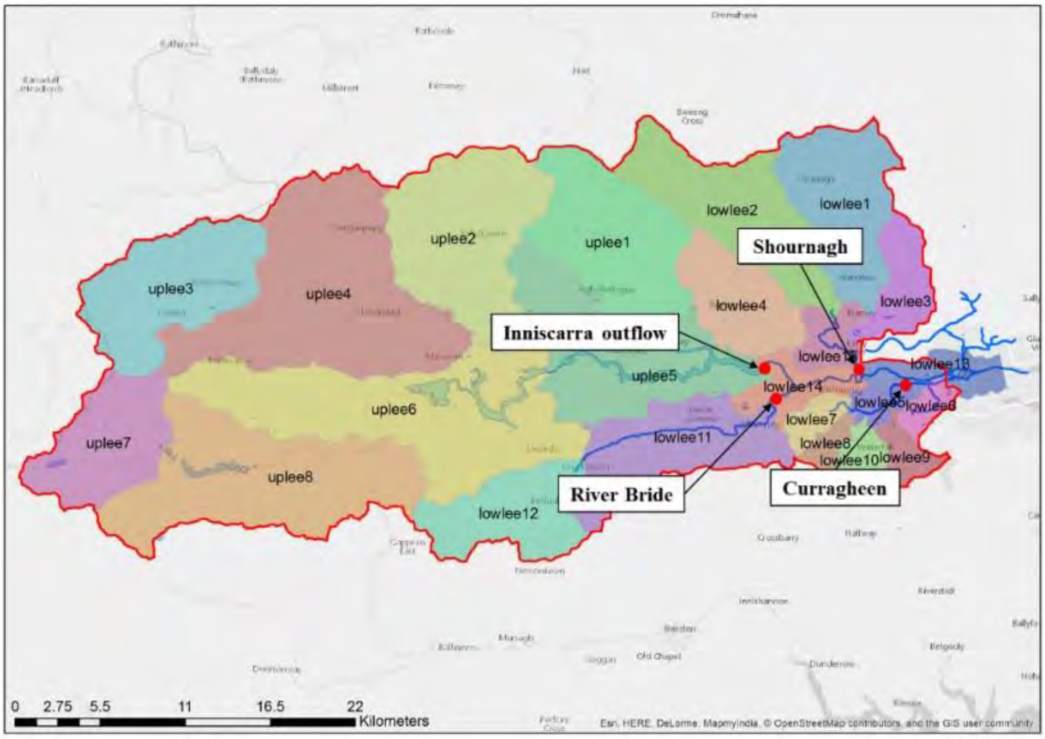
Figure 19: Continuous flow locations[19]



To analyse the impact of the mapped storage in reducing flood flows, it is necessary to ascertain design flows up to the point of interest, Waterworks Weir in Cork. The continuous flow hydrographs generated for the Lower Lee FRS study are the most up to date and realistic flows that can be used for the catchment. However, the routing effect of NFM storage can only be tested by delineating the catchment into smaller areas. The Lee CFRAMS hydrology assessment of the catchment has already developed this representation, albeit in a high-level way. Lee CFRAMS shapefiles of the sub-catchments of the River Lee were provided for the study area. Figure 20 shows the CFRAMs hydrological catchments with the calibration locations from the detailed continuous flow modelling superimposed on the map.

[19] Lower Lee Flood Relief Scheme, Hydraulic Modelling Report, April 2017. Arup and JBA Consulting

Figure 20: Lee CFRAMS hydrological catchments with calibration locations from the continuous flow simulations overlain



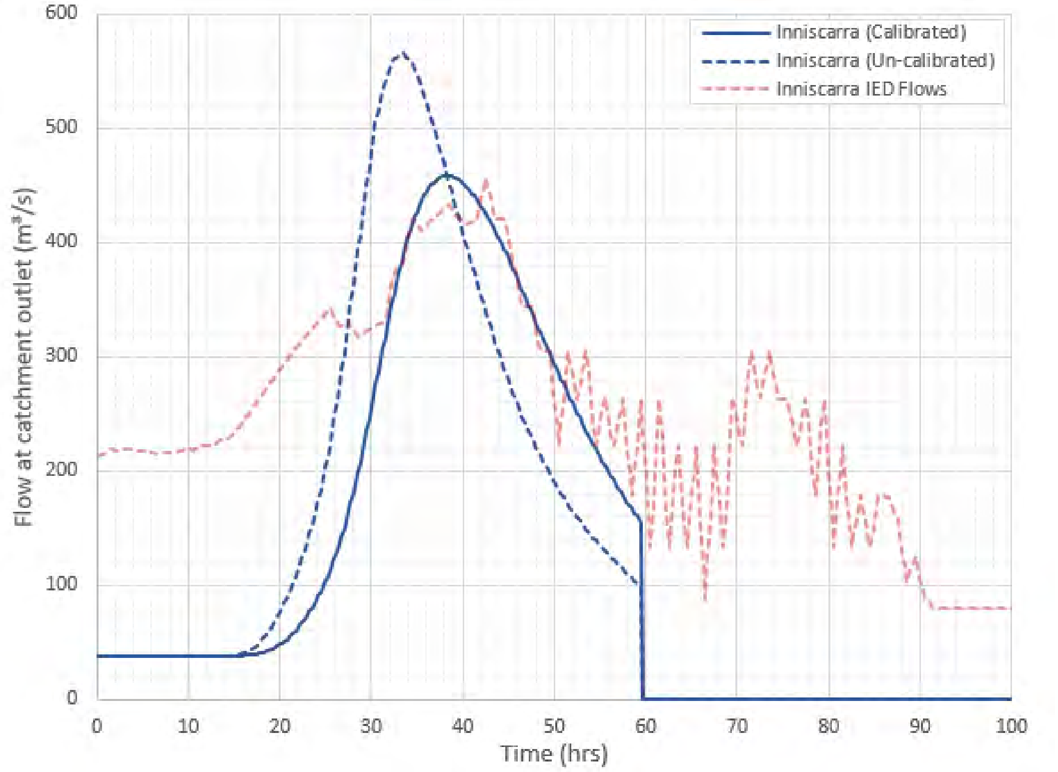
The flows from the continuous simulations (for various return periods) have been used as calibration points when using the Lee CFRAMS hydrology data.

2.8.1 Calibration

For the calibration and subsequent optioneering of NFM interventions, the design event being simulated is limited to the 1 in 100 year return period.

The Lee CFRAMS hydrology data consists of regularly-shaped design hydrographs for each sub-catchment of the wider River Lee catchment area. The continuous flow hydrographs (IED), however, have greater irregularity to simulate flow in a design event preceded and followed by smaller rainfall events. Each of the Lee CFRAMS hydrographs has a duration of 44 hours, compared to the continuous flow simulations, which have a duration of 409 hours. Calibrating the Lee CFRAMS hydrographs has primarily focussed on achieving the same peak flows as the corresponding continuous flow hydrograph, when combining hydrographs for sub-catchments.

Figure 21: Inniscarra flow comparison (calibrated Lee CFRAMS Vs continuous hydrograph IED)

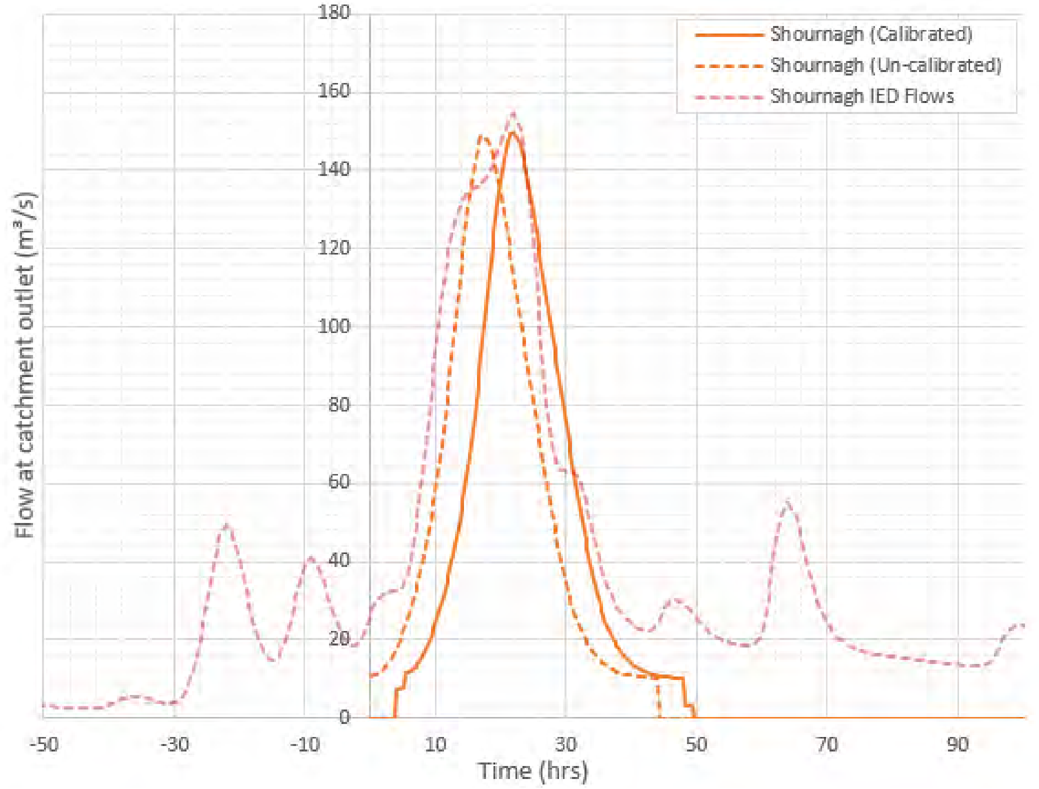


Characteristics of the Carrigadrohid and Inniscarra reservoirs, including the planform area and simplified outlet conditions were represented in the NFM optioneering tool using equations for Level Pool Routing[20]. Flow was routed through the model and calibrated by comparing with baseline flows from the IED hydrographs. The flows from the Upper Lee Catchment, upstream of the reservoir, are adequately represented using the Lee CFRAMS hydrology. However, due to the lack of flow representation for the rising and falling limb, it will be necessary to import additional flows to show the impact downstream at Waterworks Weir.

NFM storage is a function of the timing of when it becomes active and the limit of when the storage is exceeded. The rising limb of Inniscarra in particular will have significant influence on the function of an NFM scheme. For this reason, the rising limb of the Inniscarra IED flow, up to hour 30 in the simulation, is accounted for using an additional inflow (adding the difference between the level-pool routed Lee CFRAMS flow and continuous flow hydrographs for the first 30 hours of the simulation, and again from hour 50 in the simulation).

[20] Chow, V. T., Maidment, D. R. & Mays, L.W. (1988). Applied Hydrology. McGraw-Hill, Singapore.

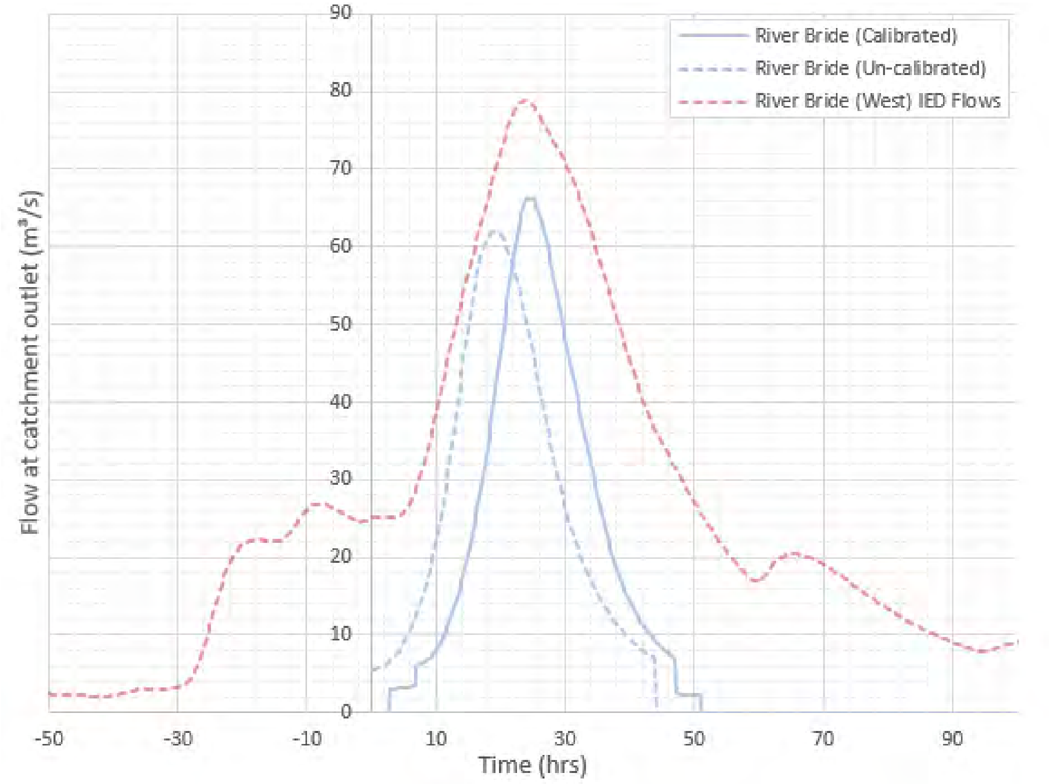
Figure 22: Shournagh flow comparison (calibrated Lee CFRAMS Vs continuous hydrograph IED)



The timing and peak flow for the Shournagh are also adequate (Figure 22). Again, some additional flow to represent the rising and falling limb of the continuous flow hydrograph is necessary to represent the magnitude of flows at Waterworks Weir.

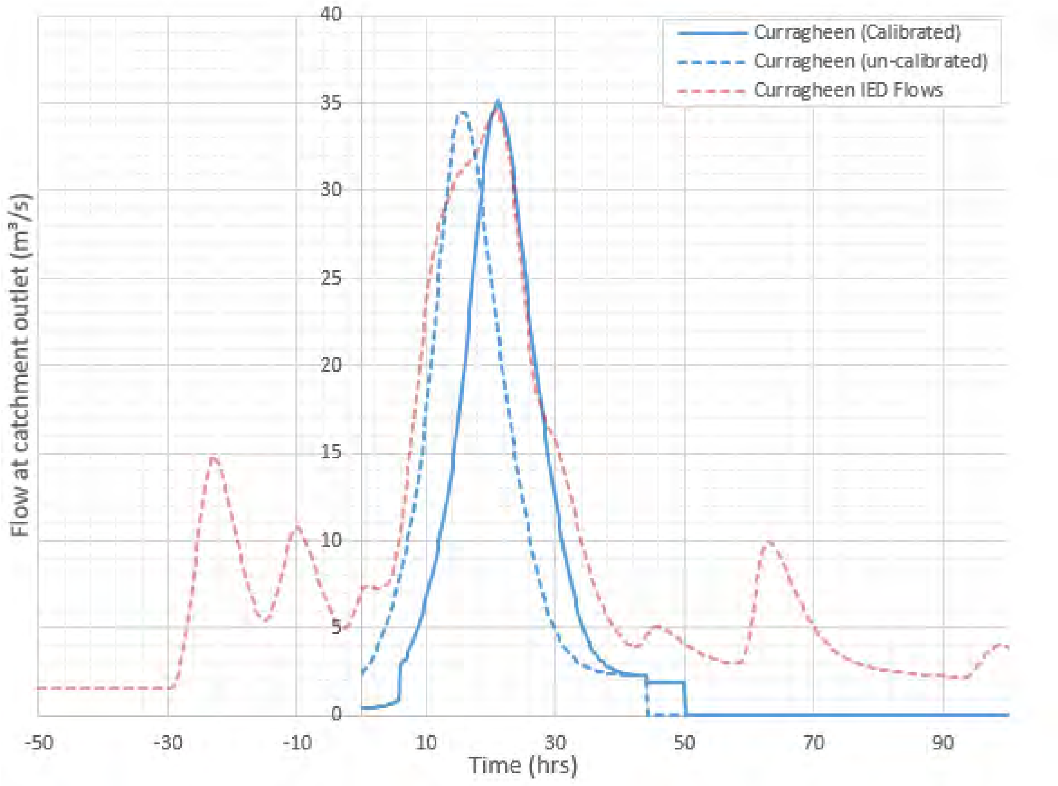
The flow magnitude and hydrograph volume for the River Bride are significantly under estimated using the Lee CFRAMS hydrographs for Lowlee12 and Lowlee11 (Figure 23). This could be due to the continuous flow IED representing a slightly larger catchment area than this. In addition the 1:100 year flow for the larger catchment area (of the River Bride) may be made up of different combinations of flows from the sub-catchment areas. As a result, another import of additional flow will be required to represent flows at Waterworks Weir.

Figure 23: River Bride flow comparison (calibrated Lee CFRAMS Vs continuous hydrograph IED)



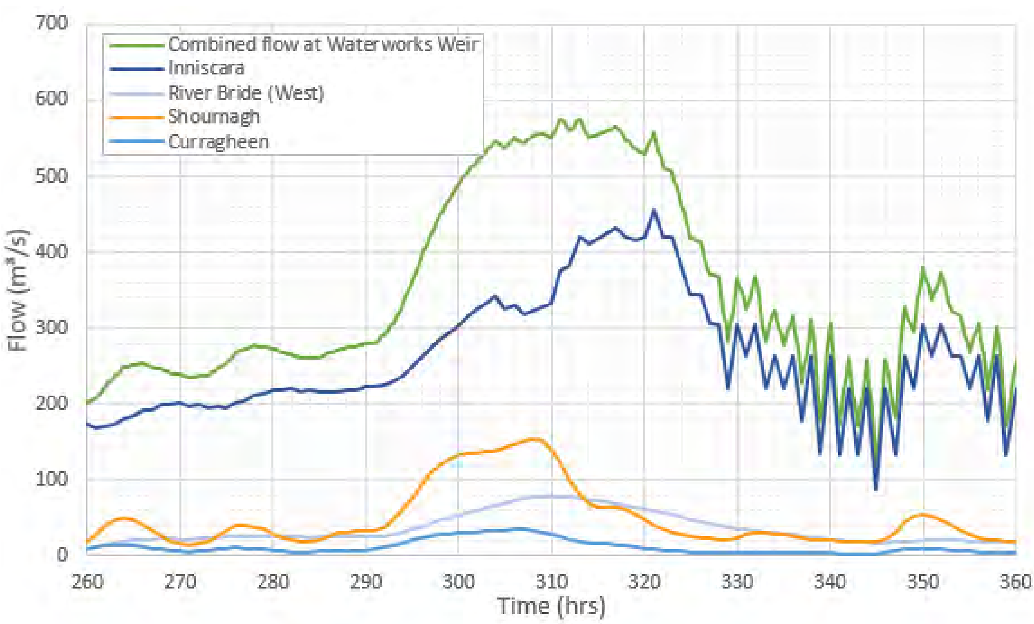
Although the Curragheen joins the Lee downstream of Waterworks Weir, it was decided to represent the flows in the hydrology. There have been opportunities mapped for the Curragheen, and it may benefit the scheme if flows into the South Channel of the River Lee are reduced. Similar issues are evident for the comparison of Lee CFRAMS with the continuous IED. However, as the flows do not add to the magnitude at Waterworks Weir, no additional flows have been imported into the hydrological model.

Figure 24: Curragheen flow comparison (calibrated CFRAMS Vs continuous hydrograph IED)



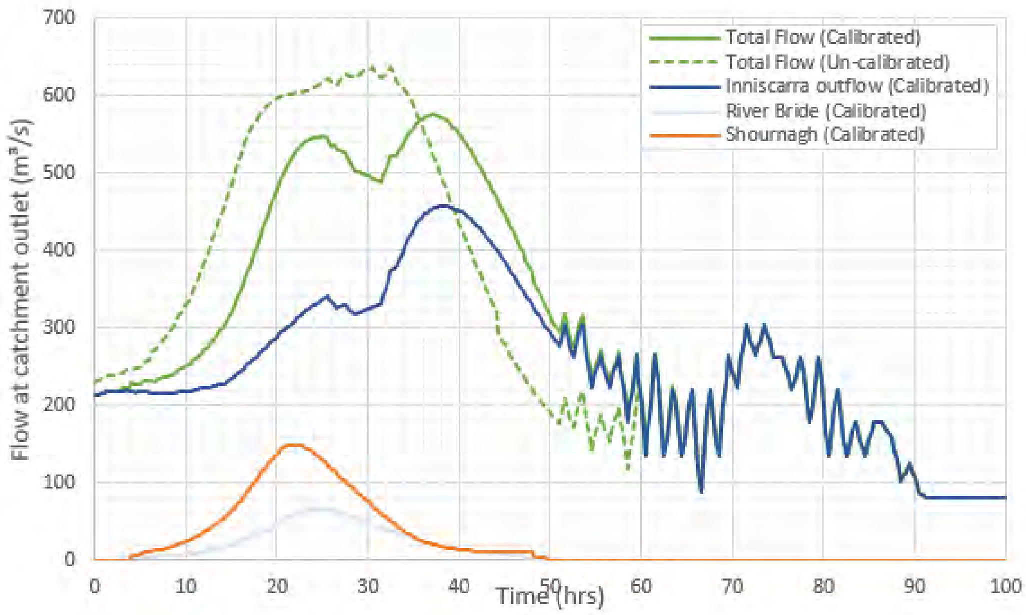
The continuous flow hydrographs for the catchment produce a combined flow of 575m^3/s at Waterworks Weir (Figure 25). The hydraulically routed flows at Waterworks Weir are 568m^3/s.

Figure 25: Continuous flow hydrographs from 100 year IED file for Inniscarra, Shournagh, River Bride (West) and Curragheen, and the un-routed combined flows for Waterworks Weir



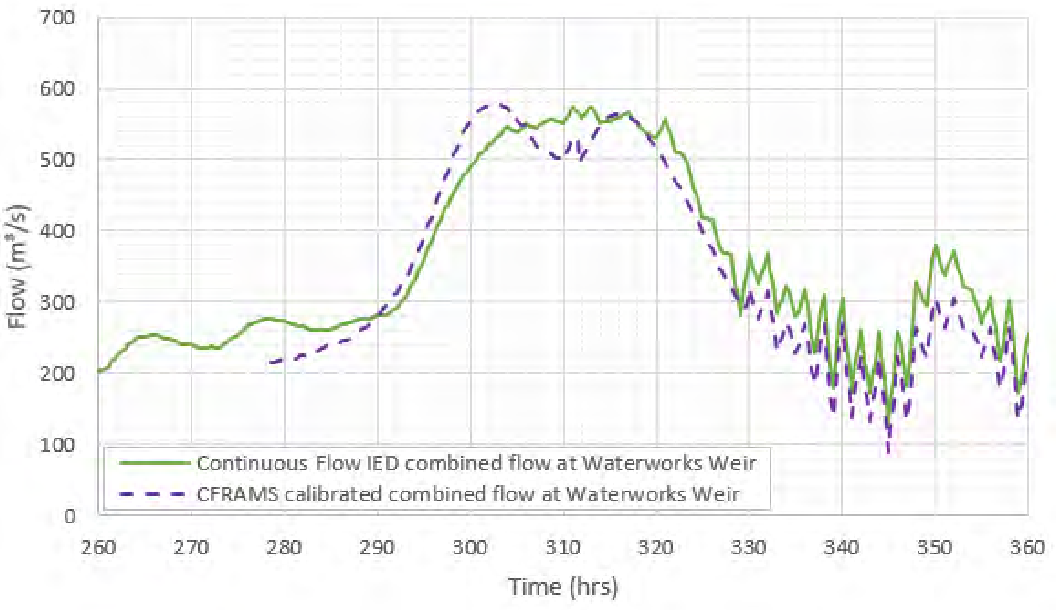
Importing all the calibrated sections and additional flows into a combined simplified hydrological model for the catchment produces a combined flow at Waterworks Weir of 572m^3/s, and adequately represents the drawn-out peak caused by flows from the Upper and Lower Lee catchment areas (Figure 26).

Figure 26: Calibrated flows using the CFRAMS hydrology, with dummy inflows from Inniscarra IED for the rising and falling limb of the reservoir from hours 0-30 and 50-100, respectively.



Once the flows in the hydrological model were calibrated, they were modified using a NFM optioneering tool to simulate the impact of mapped NFM opportunities in the River Lee Catchment. Figure 27 shows a comparison of the calibrated combined Lee CFRAMS hydrographs with the combined Continuous Flow hydrographs to demonstrate the impact of the calibration in the simplified hydrological model for the catchment.

Figure 27: Comparison of calibrated Lee CFRAMS flows and continuous flow simulation for Waterworks Weir

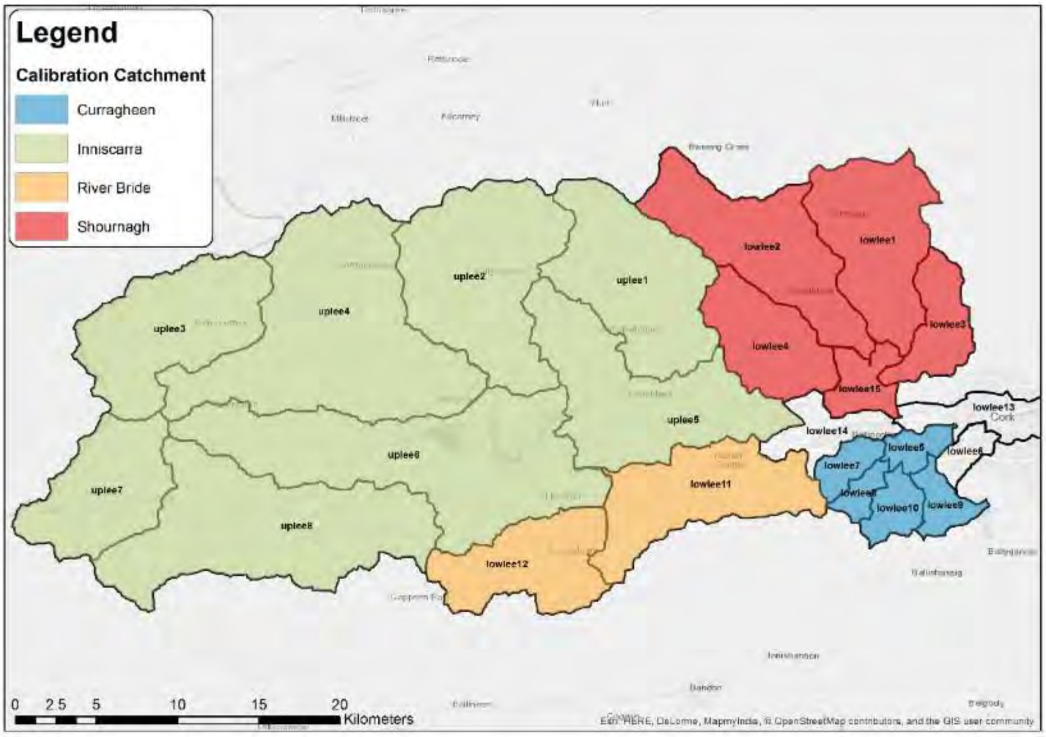


3 NFM Modelling Results

3.1 Introduction

In order to tabulate the results of the NFM study, the sub-catchments were ordered in a logical way from the headwaters of the Upper Lee to the Waterworks Weir and the catchments that flow and join the Lee downstream of Waterworks Weir. Figure 28 shows the grouping of sub-catchments and can be used as a guide when looking at results tables for the NFM mapping.

Figure 28: Graphic to illustrate the sub-catchments containing Lee CFRAMS hydrology for comparison with the hydrology from the continuous flow IEDs



The tables that follow are designed to flow from the top of the Upper Lee Catchment to Waterworks Weir. They are colour-coded based on Figure 28. Each table is followed by a hydrograph comparison of the calibrated baseline and mitigated flows at Waterworks Weir.

The storage calculations in Section 3.5 were applied to the sub-catchments of the River Lee to calculate total NFM storage and the number of NFM features in each sub-catchment area – assuming a 1.5m high, 30m long barrier to flow (Table 9). All results relate to the simulated impact of NFM interventions during the 1 in 100 year return period event.

The number of properties at risk of flooding, and referenced in the below sections, has been derived by counting the number of residential properties in each catchment that are located within the PFRA Q100 flood extent.

It is therefore a conservative estimate of the number of properties at risk, as the PFRA flood extent is conservative and does not account for the benefit offered by any flood protection measures in the catchment.

Table 9: Calculated storage totals, based on a 1.5m high 30m long barrier, and number of Runoff Attenuation Features (RAFs) in each CFRAMS sub-catchment (Note: number of overland flow and floodplain features is based on a ratio, so does not necessarily add to equal the total number of RAFs when rounded to the nearest whole number)

IED Catchment Hydrograph	Sub-Catch	Volume (m^3)	Number of RAFs	No. of Overland Flow Features	No. of Floodplain Features	Av. vol per RAF (m^3)
Upper Lee to Inniscarra Reservoir outlet	Uplee3	110,938	341	239	101	325
	Uplee4	253,269	634	471	167	399
	Uplee7	75,237	215	148	66	350
	Uplee8	194,149	517	381	136	376
	Uplee2	169,468	414	309	106	409
	Uplee6	260,936	561	420	144	465
	Uplee1	163,281	339	260	80	482
	Uplee5	182,952	356	268	88	514
River Bride	Lowlee12	105,452	200	153	49	527
	Lowlee11	129,860	249	187	59	522
Shournagh	Lowlee2	149,493	320	245	76	467
	Lowlee1	138,976	308	241	69	451
	Lowlee4	87,585	190	145	46	461
	Lowlee3	50,565	110	86	27	460
	Lowlee15	25,877	69	52	17	375
D/S Inniscarra	Lowlee14	N/A	-	-	-	-
Waterworks Weir	Lowlee13	N/A	-	-	-	-
Curragheen	Lowlee7	19,410	39	30	9	498
	Lowlee8	13,212	24	18	6	551
	Lowlee10	26,043	52	39	12	501
	Lowlee9	21,861	41	33	12	533
	Lowlee5	20,347	46	35	10	442
Glasheen	Lowlee6	13,990	30	24	7	466

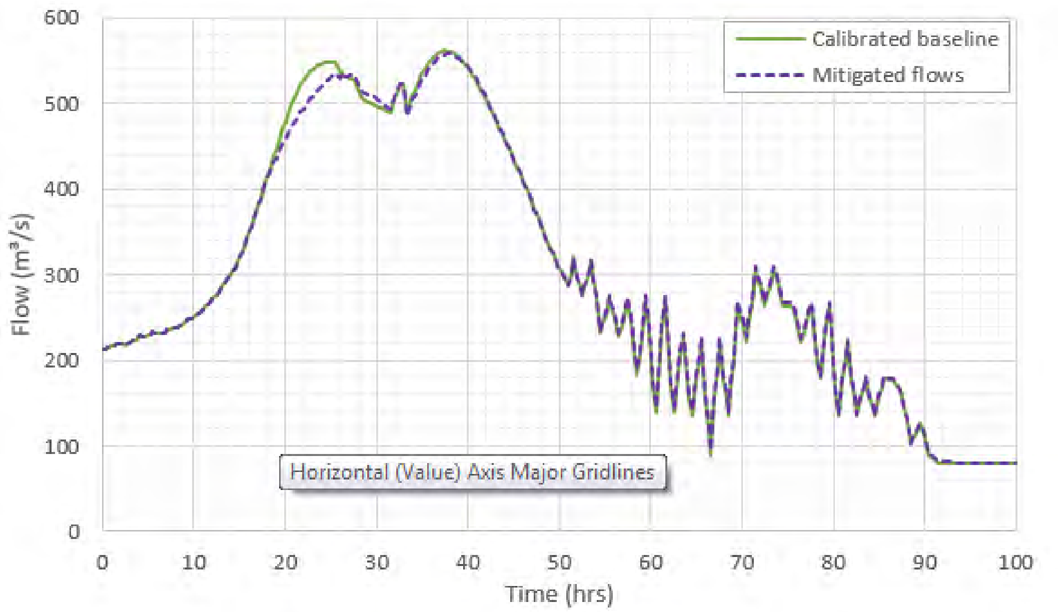
3.2 Scenario 1 – All NFM Opportunities

Applying all the mapped NFM opportunities for the whole catchment involves installing approximately 5,055 NFM features (3,780 Overland Flow and 1,275 Floodplain) capable of storing 2,213,000m^3 of water – assuming a 1.5m high, 30m long barrier to flow. The NFM optioneering tool is used to find the most efficient threshold flows for the allocated storage in each sub-catchment.

Table 10: NFM modelling results based on all-mapped opportunities across the sub-catchments (Note: Colour coding on '% reduction' is from red (high impact) to green (low or negative impact)

IED Catchment Hydrograph	Sub-catchment (CFRAMS)	Sub-catchment flows			Full catchment flows (at point in model)		
		Peak flow	Mitigated peak flow	Local % reduction	Peak Flow	Mitigated peak flow	% reduction at point
Upper Lee to Inniscarra Reservoir outlet	Uplee3	139.77	128.56	8.0%	139.77	128.56	8.0%
	Uplee4	148.28	132.05	10.9%	264.81	254.69	3.8%
	Uplee7	66.45	59.93	9.8%	66.45	59.93	9.8%
	Uplee8	66.48	58.00	12.7%	98.46	99.96	-1.5%
	Uplee2	99.42	87.91	11.6%	99.42	87.91	11.6%
	Uplee6	63.29	54.43	14.0%	486.41	465.15	4.4%
	Uplee1	66.69	56.64	15.1%	66.69	56.64	15.1%
	Uplee5	33.61	28.16	16.2%	565.91	535.99	5.3%
River Bride (West)	Lowlee12	37.42	31.60	15.6%	37.42	31.60	15.6%
	Lowlee11	28.95	23.83	17.7%	66.22	55.42	16.3%
Shournagh	Lowlee2	52.67	44.46	15.6%	52.67	44.46	15.6%
	Lowlee1	40.60	33.60	17.2%	40.60	33.60	17.2%
	Lowlee4	28.47	23.18	18.6%	28.47	23.18	18.6%
	Lowlee3	16.82	14.04	16.6%	16.82	14.04	16.6%
	Lowlee15	11.07	9.79	11.5%	149.53	124.89	16.5%
D/S Inniscarra	Lowlee14	12.09	10.30	14.8%	470.91	463.63	1.5%
Waterworks Weir	Lowlee13	12.79	12.79	0.0%	561.42	557.41	0.7%
Curragheen	Lowlee7	6.93	5.96	14.0%	6.93	5.96	14.0%
	Lowlee8	5.44	4.70	13.6%	5.44	4.70	13.6%
	Lowlee10	9.12	7.69	15.7%	9.12	7.69	15.7%
	Lowlee9	9.02	7.61	15.6%	9.02	7.61	15.6%
	Lowlee5	5.54	4.62	16.7%	35.13	30.32	13.7%
Glasheen	Lowlee6	7.87	6.79	13.7%	7.87	6.79	13.7%

Figure 29: Scenario 1 – Baseline and mitigated flows at Waterworks Weir



It can be seen in Figure 29 that the NFM mitigation is having a more measurable impact upon the hydrograph that precedes the peak magnitude of the storm.

3.3 Scenario 2 – Full Catchment (Excluding Curragheen and Glasheen Catchments)

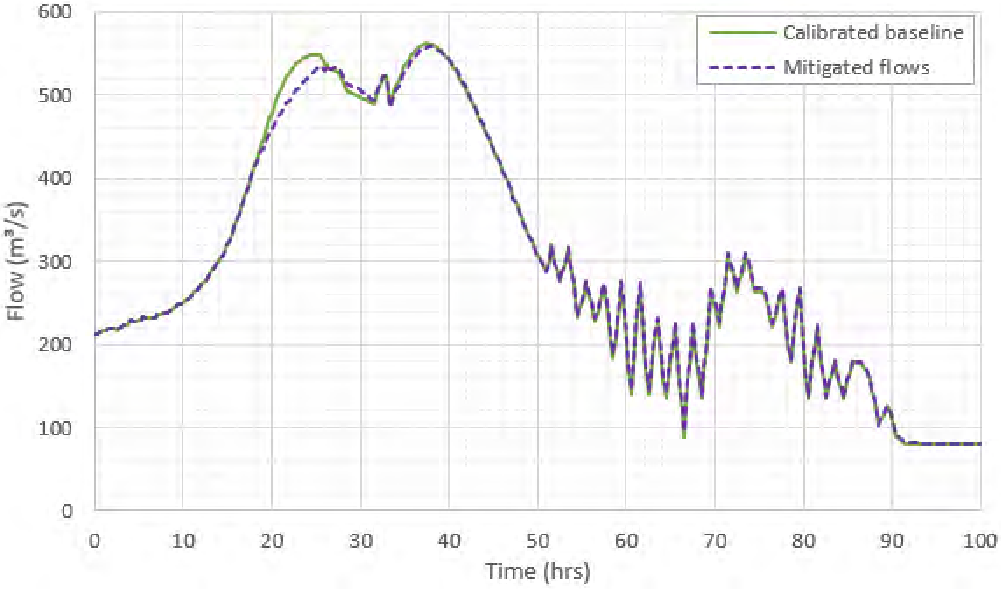
The modelling investigation has determined several options for NFM mitigation. The large catchment area lends itself to different levels of intervention. The first scenario modelled is excluding the Curragheen and Glasheen sub-catchments from the analysis, as they join the River Lee downstream of Waterworks Weir. Applying NFM opportunities in these areas involves installing approximately 4,823 NFM features (3,598 Overland Flow and 1,223 Floodplain) capable of storing 2,098,000m^3 of water – assuming a 1.5m high, 30m long barrier to flow.

Table 11: NFM modelling results based on all-mapped opportunities across the sub-catchments (excluding the Curragheen and Glasheen catchments as they join downstream of Waterworks Weir)

IED Catchment Hydrograph	Sub-catchment (CFRAMS)	Sub-catchment flows			Full catchment flows (at point in model)		
		Peak flow	Peak Flow	Peak Flow	Peak Flow	Mitigated peak flow	% reduction at point
Upper Lee to Inniscarra Reservoir outlet	Uplee3	139.77	128.56	8.0%	139.77	128.56	8.0%
	Uplee4	148.28	132.05	10.9%	264.81	254.69	3.8%
	Uplee7	66.45	59.93	9.8%	66.45	59.93	9.8%
	Uplee8	66.48	58.00	12.7%	98.46	99.96	-1.5%

IED Catchment Hydrograph	Sub-catchment (CFRAMS)	Sub-catchment flows			Full catchment flows (at point in model)		
		Peak flow	Peak Flow	Peak Flow	Peak Flow	Mitigated peak flow	% reduction at point
	Uplee2	99.42	87.91	11.6%	99.42	87.91	11.6%
	Uplee6	63.29	54.43	14.0%	486.41	465.15	4.4%
	Uplee1	66.69	56.64	15.1%	66.69	56.64	15.1%
	Uplee5	33.61	28.16	16.2%	565.91	535.99	5.3%
River Bride (West)	Lowlee12	37.42	31.60	15.6%	37.42	31.60	15.6%
	Lowlee11	28.95	23.83	17.7%	66.22	55.42	16.3%
Shournagh	Lowlee2	52.67	44.46	15.6%	52.67	44.46	15.6%
	Lowlee1	40.60	33.60	17.2%	40.60	33.60	17.2%
	Lowlee4	28.47	23.18	18.6%	28.47	23.18	18.6%
	Lowlee3	16.82	14.04	16.6%	16.82	14.04	16.6%
	Lowlee15	11.07	9.79	11.5%	149.53	124.89	16.5%
D/S Inniscarra	Lowlee14	12.09	10.30	14.8%	470.91	463.63	1.5%
Waterworks Weir	Lowlee13	12.79	12.79	0.0%	561.42	557.41	0.7%
Curragheen	Lowlee7	6.93	6.93	0.0%	6.93	6.93	0.0%
	Lowlee8	5.44	5.44	0.0%	5.44	5.44	0.0%
	Lowlee10	9.12	9.12	0.0%	9.12	9.12	0.0%
	Lowlee9	9.02	9.02	0.0%	9.02	9.02	0.0%
	Lowlee5	5.54	5.54	0.0%	35.13	35.13	0.0%
Glasheen	Lowlee6	7.87	7.87	0.0%	7.87	7.87	0.0%

Figure 30: Scenario 2 – Baseline and mitigated flows at Waterworks Weir



Note: As the Curragheen and Glasheen Rivers join the Lee downstream of Waterworks Weir, the Graphs in Figure 29 and Figure 30 are identical.

3.4 Scenario 3 – Upper Lee Measures

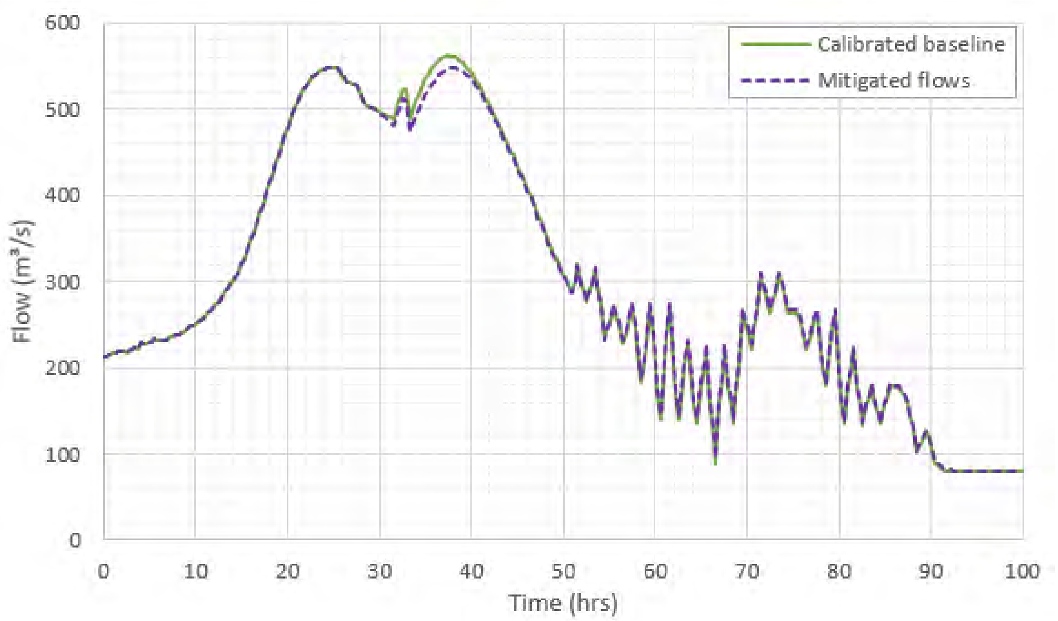
The next scenario modelled only considers the Upper Lee sub-catchments. Applying NFM opportunities in these areas involves installing approximately 3,377 NFM features (2,492 Overland Flow and 885 Floodplain) capable of storing 1,410,000m^3 of water – assuming a 1.5m high, 30m long barrier to flow.

Table 12: NFM modelling results based on mapped features in the Upper Lee sub-catchments only

IED Catchment Hydrograph	Sub-catchment (CFRAMS)	Sub-catchment flows			Full catchment flows (at point in model)		
		Peak flow	Peak Flow	Peak Flow	Peak Flow	Mitigated peak flow	% reduction at point
Upper Lee to Inniscarra Reservoir outlet	Uplee3	139.77	128.56	8.0%	139.77	128.56	8.0%
	Uplee4	148.28	132.05	10.9%	264.81	254.69	3.8%
	Uplee7	66.45	59.93	9.8%	66.45	59.93	9.8%
	Uplee8	66.48	58.00	12.7%	98.46	99.96	-1.5%
	Uplee2	99.42	87.91	11.6%	99.42	87.91	11.6%
	Uplee6	63.29	54.43	14.0%	486.41	465.15	4.4%
	Uplee1	66.69	56.64	15.1%	66.69	56.64	15.1%
	Uplee5	33.61	28.16	16.2%	565.91	535.99	5.3%

IED Catchment Hydrograph	Sub-catchment (CFRAMS)	Sub-catchment flows			Full catchment flows (at point in model)		
		Peak flow	Peak Flow	Peak Flow	Peak Flow	Mitigated peak flow	% reduction at point
River Bride (West)	Lowlee12	37.42	37.42	0.0%	37.42	37.42	0.0%
	Lowlee11	28.95	28.95	0.0%	66.22	66.22	0.0%
Shournagh	Lowlee2	52.67	52.67	0.0%	52.67	52.67	0.0%
	Lowlee1	40.60	40.60	0.0%	40.60	40.60	0.0%
	Lowlee4	28.47	28.47	0.0%	28.47	28.47	0.0%
	Lowlee3	16.82	16.82	0.0%	16.82	16.82	0.0%
	Lowlee15	11.07	11.07	0.0%	149.53	149.53	0.0%
D/S Inniscarra	Lowlee14	12.09	12.09	0.0%	470.91	458.66	2.6%
Waterworks Weir	Lowlee13	12.79	12.79	0.0%	561.42	547.57	2.5%
Curragheen	Lowlee7	6.93	6.93	0.0%	6.93	6.93	0.0%
	Lowlee8	5.44	5.44	0.0%	5.44	5.44	0.0%
	Lowlee10	9.12	9.12	0.0%	9.12	9.12	0.0%
	Lowlee9	9.02	9.02	0.0%	9.02	9.02	0.0%
	Lowlee5	5.54	5.54	0.0%	35.13	35.13	0.0%
Glasheen	Lowlee6	7.87	7.87	0.0%	7.87	7.87	0.0%

Figure 31: Scenario 3 – Baseline and mitigated flows at Waterworks Weir



It can be seen, through this analysis and its assumptions, that a greater flow reduction is achieved at Waterworks Weir without the inclusion of NFM storage in the Lower Lee sub-catchments. This can be attributed to a synchronisation of flows resulting from NFM in the Lower Lee – delaying flood peaks from the Shournagh River catchment, to coincide with peaks from the Upper Lee draining through Inniscarra (Figure 31).

Logically this is an expected result, due to the massive attenuation effect that Inniscarra and Carrigadrohid reservoirs have upon flows from the Upper Lee.

3.5 Scenario 4 – Lower Lee Measures

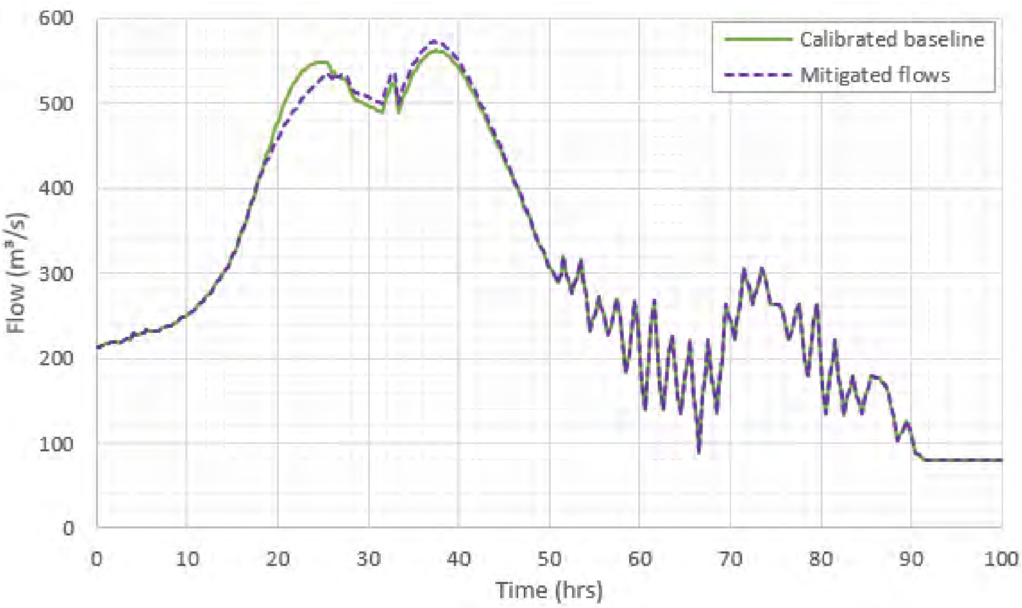
The next scenario modelled only considers the Lower Lee sub-catchments. Applying NFM opportunities in these areas involves installing approximately 1,678 NFM features (1,282 Overland Flow and 396 Floodplain) capable of storing 803,000m^3 of water – assuming a 1.5m high, 30m long barrier to flow.

Table 13: NFM modelling results based on mapped features in the Lower Lee sub-catchments only

IED Catchment Hydrograph	**Sub-catchment (CFRAMS)**	**Sub-catchment flows**			**Full catchment flows (at point in model)**		
		Peak flow	**Peak Flow**	**Peak Flow**	**Peak Flow**	**Mitigated peak flow**	**% reduction at point**
Upper Lee to Inniscarra Reservoir outlet	Uplee3	139.77	139.77	0.0%	139.77	139.77	0.0%
	Uplee4	148.28	148.28	0.0%	264.81	264.81	0.0%
	Uplee7	66.45	66.45	0.0%	66.45	66.45	0.0%
	Uplee8	66.48	66.48	0.0%	98.46	98.46	0.0%
	Uplee2	99.42	99.42	0.0%	99.42	99.42	0.0%
	Uplee6	63.29	63.29	0.0%	486.41	486.41	0.0%
	Uplee1	66.69	66.69	0.0%	66.69	66.69	0.0%
	Uplee5	33.61	33.61	0.0%	565.91	565.91	0.0%
River Bride (West)	Lowlee12	37.42	31.60	15.6%	37.42	31.60	15.6%
	Lowlee11	28.95	23.83	17.7%	66.22	55.42	16.3%
Shournagh	Lowlee2	52.67	44.46	15.6%	52.67	44.46	15.6%
	Lowlee1	40.60	33.60	17.2%	40.60	33.60	17.2%
	Lowlee4	28.47	23.18	18.6%	28.47	23.18	18.6%
	Lowlee3	16.82	14.04	16.6%	16.82	14.04	16.6%
	Lowlee15	11.07	9.79	11.5%	149.53	124.89	16.5%
D/S Inniscarra	Lowlee14	12.09	10.30	14.8%	470.91	476.11	-1.1%

IED Catchment Hydrograph	**Sub-catchment (CFRAMS)**	**Sub-catchment flows**			**Full catchment flows (at point in model)**		
		Peak flow	**Peak Flow**	**Peak Flow**	**Peak Flow**	**Mitigated peak flow**	**% reduction at point**
Waterworks Weir	Lowlee13	12.79	12.79	0.0%	561.42	571.92	-1.9%
Curragheen	Lowlee7	6.93	5.96	14.0%	6.93	5.96	14.0%
	Lowlee8	5.44	4.70	13.6%	5.44	4.70	13.6%
	Lowlee10	9.12	7.69	15.7%	9.12	7.69	15.7%
	Lowlee9	9.02	7.61	15.6%	9.02	7.61	15.6%
	Lowlee5	5.54	4.62	16.7%	35.13	30.32	13.7%
Glasheen	Lowlee6	7.87	6.79	13.7%	7.87	6.79	13.7%

Figure 32: Scenario 4 – Baseline and mitigated flows at Waterworks Weir



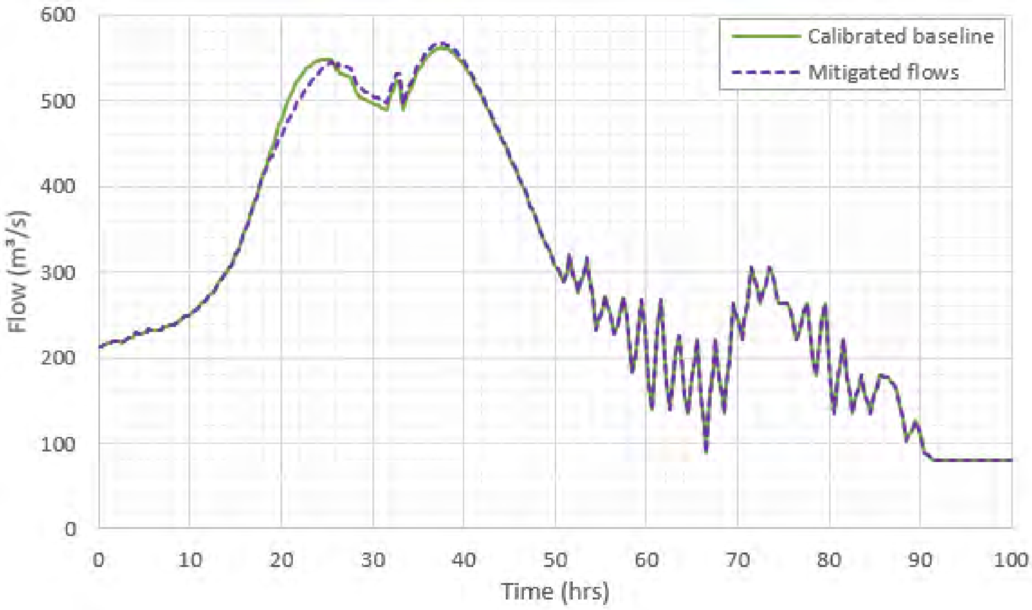
3.6 Scenario 5 – Shournagh Measures

The next scenario modelled only considers the Shournagh sub-catchments, due to the number of residential properties identified in the mapping exercise. Applying NFM opportunities in these areas involves installing approximately 997 NFM features (764 Overland Flow and 233 Floodplain) capable of storing 452,000m^3 of water – assuming a 1.5m high, 30m long barrier to flow.

Table 14: NFM modelling results based on mapped features in the Shournagh sub-catchments only

IED Catchment Hydrograph	Sub-catchment (CFRAMS)	Sub-catchment flows			Full catchment flows (at point in model)		
		Peak flow	Peak Flow	Peak Flow	Peak Flow	Mitigated peak flow	% reduction at point
Upper Lee to Inniscarra Reservoir outlet	Uplee3	139.77	139.77	0.0%	139.77	139.77	0.0%
	Uplee4	148.28	148.28	0.0%	264.81	264.81	0.0%
	Uplee7	66.45	66.45	0.0%	66.45	66.45	0.0%
	Uplee8	66.48	66.48	0.0%	98.46	98.46	0.0%
	Uplee2	99.42	99.42	0.0%	99.42	99.42	0.0%
	Uplee6	63.29	63.29	0.0%	486.41	486.41	0.0%
	Uplee1	66.69	66.69	0.0%	66.69	66.69	0.0%
	Uplee5	33.61	33.61	0.0%	565.91	565.91	0.0%
River Bride (West)	Lowlee12	37.42	37.42	0.0%	37.42	37.42	0.0%
	Lowlee11	28.95	28.95	0.0%	66.22	66.22	0.0%
Shournagh	Lowlee2	52.67	44.46	15.6%	52.67	44.46	15.6%
	Lowlee1	40.60	33.60	17.2%	40.60	33.60	17.2%
	Lowlee4	28.47	23.18	18.6%	28.47	23.18	18.6%
	Lowlee3	16.82	14.04	16.6%	16.82	14.04	16.6%
	Lowlee15	11.07	9.79	11.5%	149.53	124.89	16.5%
D/S Inniscarra	Lowlee14	12.09	12.09	0.0%	470.91	470.91	0.0%
Waterworks Weir	Lowlee13	12.79	12.79	0.0%	561.42	566.45	-0.9%
Curragheen	Lowlee7	6.93	6.93	0.0%	6.93	6.93	0.0%
	Lowlee8	5.44	5.44	0.0%	5.44	5.44	0.0%
	Lowlee10	9.12	9.12	0.0%	9.12	9.12	0.0%
	Lowlee9	9.02	9.02	0.0%	9.02	9.02	0.0%
	Lowlee5	5.54	5.54	0.0%	35.13	35.13	0.0%
Glasheen	Lowlee6	7.87	7.87	0.0%	7.87	7.87	0.0%

Figure 33: Scenario 5 – Baseline and mitigated flows at Waterworks Weir



In line with the previous results, the analysis shows that attenuating flows in the Shournagh Catchment has the potential to increase flows at Waterworks Weir, due to the coincidence of flood peaks from the wider catchment area.

3.7 Scenario 6 – Bride (West) Measures

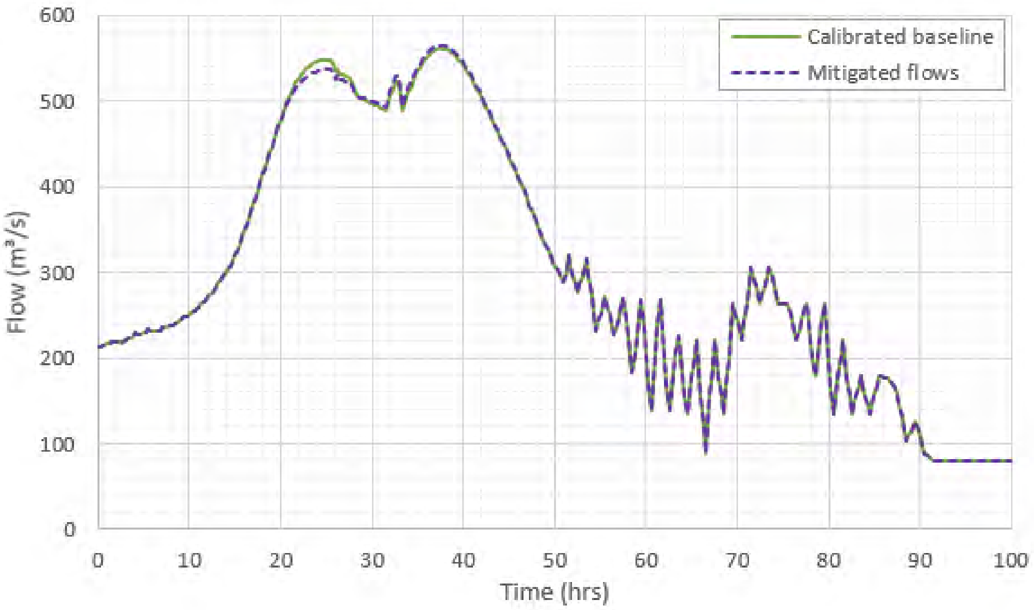
The next scenario modelled only considers the River Bride (West) sub-catchments, due to the number of residential properties identified in the mapping exercise. Applying NFM opportunities in these areas involves installing approximately 449 NFM features (341 Overland Flow and 108 Floodplain) capable of storing 235,000m^3 of water – assuming a 1.5m high, 30m long barrier to flow.

Table 15: NFM modelling results based on mapped features in the River Bride (West) sub-catchments only

IED Catchment Hydrograph	Sub-catchment (CFRAMS)	Sub-catchment flows			Full catchment flows (at point in model)		
		Peak flow	Peak Flow	Peak Flow	Peak Flow	Mitigated peak flow	% reduction at point
Upper Lee to Inniscarra Reservoir outlet	Uplee3	139.77	139.77	0.0%	139.7 7	139.77	0.0%
	Uplee4	148.28	148.28	0.0%	264.8 1	264.81	0.0%
	Uplee7	66.45	66.45	0.0%	66.45	66.45	0.0%
	Uplee8	66.48	66.48	0.0%	98.46	98.46	0.0%
	Uplee2	99.42	99.42	0.0%	99.42	99.42	0.0%

IED Catchment Hydrograph	Sub-catchment (CFRAMS)	Sub-catchment flows			Full catchment flows (at point in model)		
		Peak flow	Peak Flow	Peak Flow	Peak Flow	Mitigated peak flow	% reduction at point
	Uplee6	63.29	63.29	0.0%	486.41	486.41	0.0%
	Uplee1	66.69	66.69	0.0%	66.69	66.69	0.0%
	Uplee5	33.61	33.61	0.0%	565.91	565.91	0.0%
River Bride (West)	Lowlee12	37.42	31.60	15.6%	37.42	31.60	15.6%
	Lowlee11	28.95	23.83	17.7%	66.22	55.42	16.3%
Shournagh	Lowlee2	52.67	52.67	0.0%	52.67	52.67	0.0%
	Lowlee1	40.60	40.60	0.0%	40.60	40.60	0.0%
	Lowlee4	28.47	28.47	0.0%	28.47	28.47	0.0%
	Lowlee3	16.82	16.82	0.0%	16.82	16.82	0.0%
	Lowlee15	11.07	11.07	0.0%	149.53	149.53	0.0%
D/S Inniscarra	Lowlee14	12.09	12.09	0.0%	470.91	474.65	-0.8%
Waterworks Weir	Lowlee13	12.79	12.79	0.0%	561.42	565.30	-0.7%
Curragheen	Lowlee7	6.93	6.93	0.0%	6.93	6.93	0.0%
	Lowlee8	5.44	5.44	0.0%	5.44	5.44	0.0%
	Lowlee10	9.12	9.12	0.0%	9.12	9.12	0.0%
	Lowlee9	9.02	9.02	0.0%	9.02	9.02	0.0%
	Lowlee5	5.54	5.54	0.0%	35.13	35.13	0.0%
Glasheen	Lowlee6	7.87	7.87	0.0%	7.87	7.87	0.0%

Figure 34: Scenario 6 – Baseline and mitigated flows at Waterworks Weir



In the same way that flows are synchronised through attenuating the Shournagh Catchment, here, flows are also increased at the downstream of Inniscarra, due to the spatial location at which the River Bride joins the River Lee.

3.8 Scenario 7 – Curragheen and Glasheen Measures

The final storage scenario modelled considers the Curragheen and Glasheen sub-catchments. Applying NFM opportunities in these areas involves installing approximately 232 NFM features (176 Overland Flow and 56 Floodplain) capable of storing 115,000m^3 of water – assuming a 1.5m high, 30m long barrier to flow.

Table 16: NFM modelling results based on mapped features in the Curragheen and Glasheen sub-catchments only

IED Catchment Hydrograph	Sub-catchment (CFRAMS)	Sub-catchment flows			Full catchment flows (at point in model)		
		Peak flow	Peak Flow	Peak Flow	Peak Flow	Mitigated peak flow	% reduction at point
Upper Lee to Inniscarra Reservoir outlet	Uplee3	139.77	139.77	0.0%	139.77	139.77	0.0%
	Uplee4	148.28	148.28	0.0%	264.81	264.81	0.0%
	Uplee7	66.45	66.45	0.0%	66.45	66.45	0.0%
	Uplee8	66.48	66.48	0.0%	98.46	98.46	0.0%
	Uplee2	99.42	99.42	0.0%	99.42	99.42	0.0%
	Uplee6	63.29	63.29	0.0%	486.41	486.41	0.0%
	Uplee1	66.69	66.69	0.0%	66.69	66.69	0.0%

IED Catchment Hydrograph	Sub-catchment (CFRAMS)	Sub-catchment flows			Full catchment flows (at point in model)		
		Peak flow	Peak Flow	Peak Flow	Peak Flow	Mitigated peak flow	% reduction at point
	Uplee5	33.61	33.61	0.0%	565.91	565.91	0.0%
River Bride (West)	Lowlee12	37.42	37.42	0.0%	37.42	37.42	0.0%
	Lowlee11	28.95	28.95	0.0%	66.22	66.22	0.0%
Shournagh	Lowlee2	52.67	52.67	0.0%	52.67	52.67	0.0%
	Lowlee1	40.60	40.60	0.0%	40.60	40.60	0.0%
	Lowlee4	28.47	28.47	0.0%	28.47	28.47	0.0%
	Lowlee3	16.82	16.82	0.0%	16.82	16.82	0.0%
	Lowlee15	11.07	11.07	0.0%	149.53	149.53	0.0%
D/S Inniscarra	Lowlee14	12.09	12.09	0.0%	470.91	470.91	0.0%
Waterworks Weir	Lowlee13	12.79	12.79	0.0%	561.42	561.42	0.0%
Curragheen	Lowlee7	6.93	5.96	14.0%	6.93	5.96	14.0%
	Lowlee8	5.44	4.70	13.6%	5.44	4.70	13.6%
	Lowlee10	9.12	7.69	15.7%	9.12	7.69	15.7%
	Lowlee9	9.02	7.61	15.6%	9.02	7.61	15.6%
	Lowlee5	5.54	4.62	16.7%	35.13	30.32	13.7%
Glasheen	Lowlee6	7.87	6.79	13.7%	7.87	6.79	13.7%

Note: No graph is presented as the Curragheen and Glasheen Rivers join the Lee downstream of Waterworks weir.

This scenario was chosen due to the number of residential properties identified in the mapping exercise, and the residual risk which would remain at the downstream end of the Curragheen under the exhibited scheme. It is estimated that in excess of 100 properties are at risk of flooding in the Curragheen/Glasheen catchment. (It should be noted that this is a high level study/assessment of the amount of properties at risk in the catchment, and it would be regarded as indicative only.)

Further study would be required to determine if NFM could deliver worthwhile benefit to these properties taking into account the locations of possible NFM measures, compared with areas that are already known to be at risk of flooding, and a range of other factors, such as the possible delivery/implementation process. The analysis shows that the attenuation of flow in these sub-catchments has no impact upon flows at Waterworks Weir or downstream where the Curragheen and Glasheen converge with the River Lee.

3.9 Sensitivity Testing

3.9.1 Increased Storage Volumes

The mapping identified the greatest storage volumes capable are a result of utilising taller barriers to flow. The following results are based on using a 1.5m tall, 30m wide barrier to flow for each storage feature.

Table 17: Calculated storage totals, based on a 2m high and 30m long barrier, and number of RAFs in each CFRAMS sub-catchment

IED Catchment Hydrograph	Sub-Catch	Volume (m^3)	Number of RAFs	No Overland Flow	No Floodplain	Av. vol per RAF (m^3)
Upper lee to Inniscarra Reservoir outlet	Uplee3	249,610	341	239	101	732
	Uplee4	569,856	634	471	167	899
	Uplee7	169,282	215	148	66	787
	Uplee8	436,836	517	381	136	845
	Uplee2	381,302	414	309	106	921
	Uplee6	587,107	561	420	144	1047
	Uplee1	367,382	339	260	80	1084
	Uplee5	411,641	356	268	88	1156
River Bride	Lowlee12	237,266	200	153	49	1186
	Lowlee11	292,185	249	187	59	1173
Shournagh	Lowlee2	336,359	320	245	76	1051
	Lowlee1	312,695	308	241	69	1015
	Lowlee4	197,067	190	145	46	1037
	Lowlee3	113,771	110	86	27	1034
	Lowlee15	58,223	69	52	17	844
D/S Inniscarra	Lowlee14	N/A	-	-	-	-
Waterworks Weir	Lowlee13	N/A	-	-	-	-
Curragheen	Lowlee7	43,673	39	30	9	1120
	Lowlee8	29,727	24	18	6	1239
	Lowlee10	58,597	52	39	12	1127
	Lowlee9	49,186	41	33	12	1200
	Lowlee5	45,781	46	35	10	995
Glasheen	Lowlee6	31,477	30	24	7	1049

3.9.1.1 Scenario 2 – Full Catchment (Excluding Curragheen)

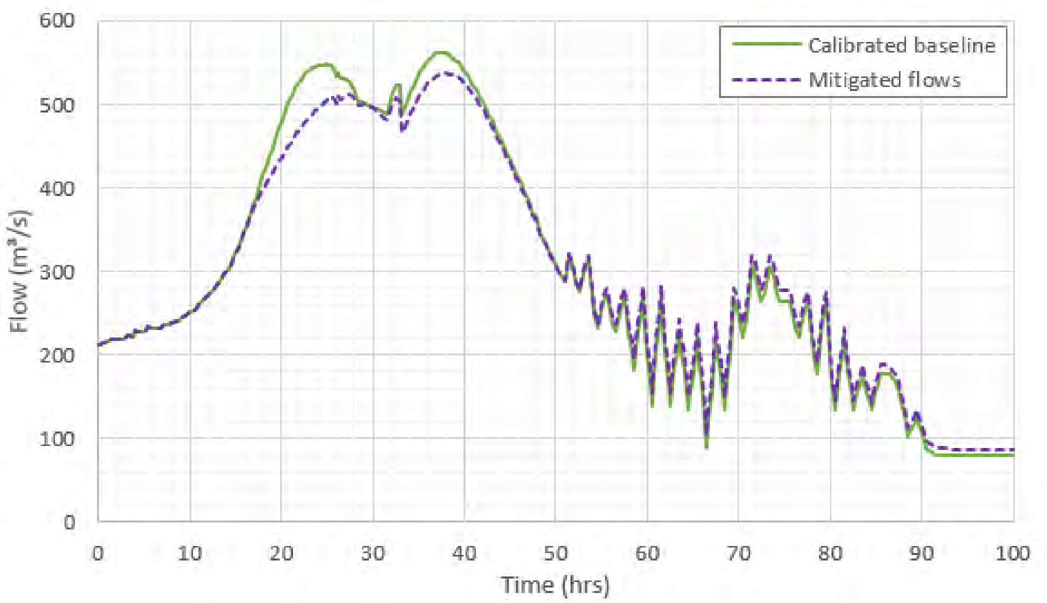
The first scenario modelled is excluding the Curragheen and Glasheen sub-catchments from the analysis, as they join the River Lee downstream of Waterworks Weir. Applying NFM opportunities in these areas involves installing approximately 4,823 NFM features (3,598 Overland Flow and 1,223 Floodplain) capable of storing 4,720,500m^3 of water – assuming a 2m high, 30m long barrier to flow.

Table 18: NFM modelling results based on all-mapped opportunities across the sub-catchments (excluding the Curragheen and Glasheen catchments)

IED Catchment Hydrograph	Sub-catchment (CFRAMS)	Sub-catchment flows			Full catchment flows (at point in model)		
		Peak flow	Peak Flow	Peak Flow	Peak Flow	Mitigated peak flow	% reduction at point
Upper Lee to Inniscarra Reservoir outlet	Uplee3	139.77	120.51	13.8%	139.77	120.51	13.8%
	Uplee4	148.28	120.52	18.7%	264.81	235.82	10.9%
	Uplee7	66.45	55.17	17.0%	66.45	55.17	17.0%
	Uplee8	66.48	51.71	22.2%	98.46	96.80	1.7%
	Uplee2	99.42	79.63	19.9%	99.42	79.63	19.9%
	Uplee6	63.29	47.98	24.2%	486.41	437.09	10.1%
	Uplee1	66.69	49.59	25.6%	66.69	49.59	25.6%
	Uplee5	33.61	24.14	28.2%	565.91	501.70	11.3%
River Bride (West)	Lowlee12	37.42	27.37	26.9%	37.42	27.37	26.9%
	Lowlee11	28.95	20.15	30.4%	66.22	47.50	28.3%
Shournagh	Lowlee2	52.67	38.59	26.7%	52.67	38.59	26.7%
	Lowlee1	40.60	28.59	29.6%	40.60	28.59	29.6%
	Lowlee4	28.47	19.47	31.6%	28.47	19.47	31.6%
	Lowlee3	16.82	11.99	28.7%	16.82	11.99	28.7%
	Lowlee15	11.07	8.66	21.8%	149.53	107.06	28.4%
D/S Inniscarra	Lowlee14	12.09	8.87	26.6%	470.91	440.62	6.4%
Waterworks Weir	Lowlee13	12.79	12.79	0.0%	561.42	536.81	4.4%
Curragheen	Lowlee7	6.93	6.93	0.0%	6.93	6.93	0.0%
	Lowlee8	5.44	5.44	0.0%	5.44	5.44	0.0%
	Lowlee10	9.12	9.12	0.0%	9.12	9.12	0.0%

IED Catchment Hydrograph	Sub-catchment (CFRAMS)	Sub-catchment flows			Full catchment flows (at point in model)		
		Peak flow	Peak Flow	Peak Flow	Peak Flow	Mitigated peak flow	% reduction at point
	Lowlee9	9.02	9.02	0.0%	9.02	9.02	0.0%
	Lowlee5	5.54	5.54	0.0%	35.13	35.13	0.0%
Glasheen	Lowlee6	7.87	7.87	0.0%	7.87	7.87	0.0%

Figure 35: Scenario 1 – Baseline and mitigated flows at Waterworks Weir



The additional attenuation storage in the catchment is able to deliver a marked impact on the hydrograph. The storage in the catchment is approximately double that of the previous example. Given the volume of flow in the storm event is unchanged, it explains the fact that the percentage reduction has more than doubled.

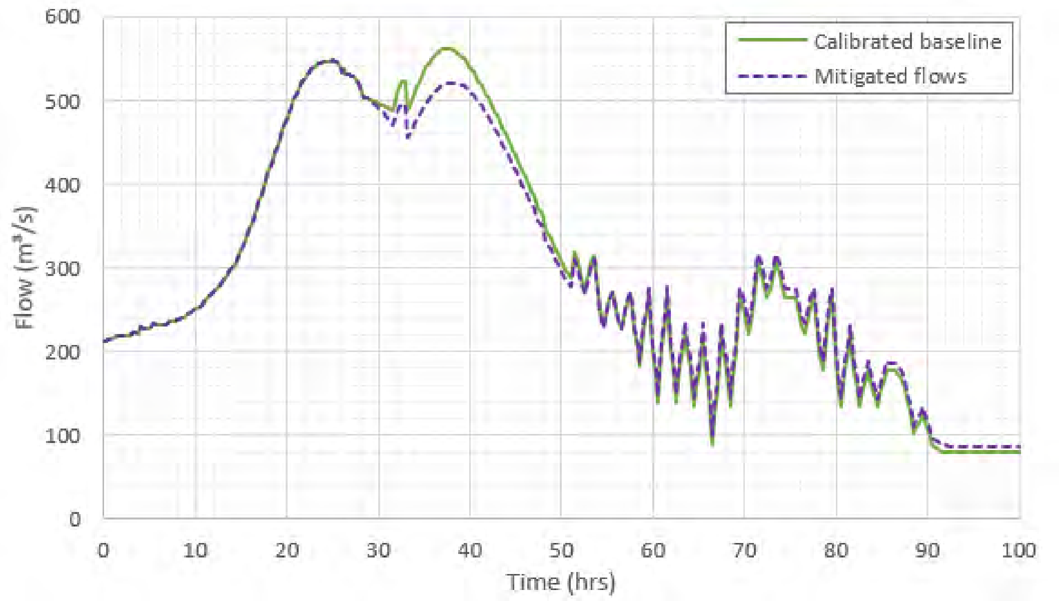
3.9.1.2 Scenario 3 - Upper Lee Measures

The next scenario modelled only considers the Upper Lee sub-catchments. Applying NFM opportunities in these areas involves installing approximately 3,377 NFM features (2,492 Overland Flow and 885 Floodplain) capable of storing 3,173,000m^3 of water – assuming a 2m high, 30m long barrier to flow.

Table 19: NFM modelling results based on mapped features in the Upper Lee sub-catchments only

IED Catchment Hydrograph	Sub-catchment (CFRAMS)	Sub-catchment flows			Full catchment flows (at point in model)		
		Peak flow	Peak Flow	Peak Flow	Peak Flow	Mitigated peak flow	% reduction at point
Upper Lee to Inniscarra Reservoir outlet	Uplee3	139.77	120.51	13.8%	139.77	120.51	13.8%
	Uplee4	148.28	120.52	18.7%	264.81	235.82	10.9%
	Uplee7	66.45	55.17	17.0%	66.45	55.17	17.0%
	Uplee8	66.48	51.71	22.2%	98.46	96.80	1.7%
	Uplee2	99.42	79.63	19.9%	99.42	79.63	19.9%
	Uplee6	63.29	47.98	24.2%	486.41	437.09	10.1%
	Uplee1	66.69	49.59	25.6%	66.69	49.59	25.6%
	Uplee5	33.61	24.14	28.2%	565.91	501.70	11.3%
River Bride (West)	Lowlee12	37.42	37.42	0.0%	37.42	37.42	0.0%
	Lowlee11	28.95	28.95	0.0%	66.22	66.22	0.0%
Shournagh	Lowlee2	52.67	52.67	0.0%	52.67	52.67	0.0%
	Lowlee1	40.60	40.60	0.0%	40.60	40.60	0.0%
	Lowlee4	28.47	28.47	0.0%	28.47	28.47	0.0%
	Lowlee3	16.82	16.82	0.0%	16.82	16.82	0.0%
	Lowlee15	11.07	11.07	0.0%	149.53	149.53	0.0%
D/S Inniscarra	Lowlee14	12.09	12.09	0.0%	470.91	433.67	7.9%
Waterworks Weir	Lowlee13	12.79	12.79	0.0%	561.42	547.57	2.5%
Curragheen	Lowlee7	6.93	6.93	0.0%	6.93	6.93	0.0%
	Lowlee8	5.44	5.44	0.0%	5.44	5.44	0.0%
	Lowlee10	9.12	9.12	0.0%	9.12	9.12	0.0%
	Lowlee9	9.02	9.02	0.0%	9.02	9.02	0.0%
	Lowlee5	5.54	5.54	0.0%	35.13	35.13	0.0%
Glasheen	Lowlee6	7.87	7.87	0.0%	7.87	7.87	0.0%

Figure 36: Scenario 3 – Baseline and mitigated flows at Waterworks Weir



In the increased volume example of Scenario 3, the attenuation of flows from the Upper Lee alone is not enough to reduce the flows at waterworks weir. This is a result of much of the rising limb of the hydrograph impacted by Lower Lee sub-catchments. Therefore, in the increased volume example, a full catchment scenario is required to have the most impact at Cork.

3.9.1.3 Scenario 5 - Shournagh Measures

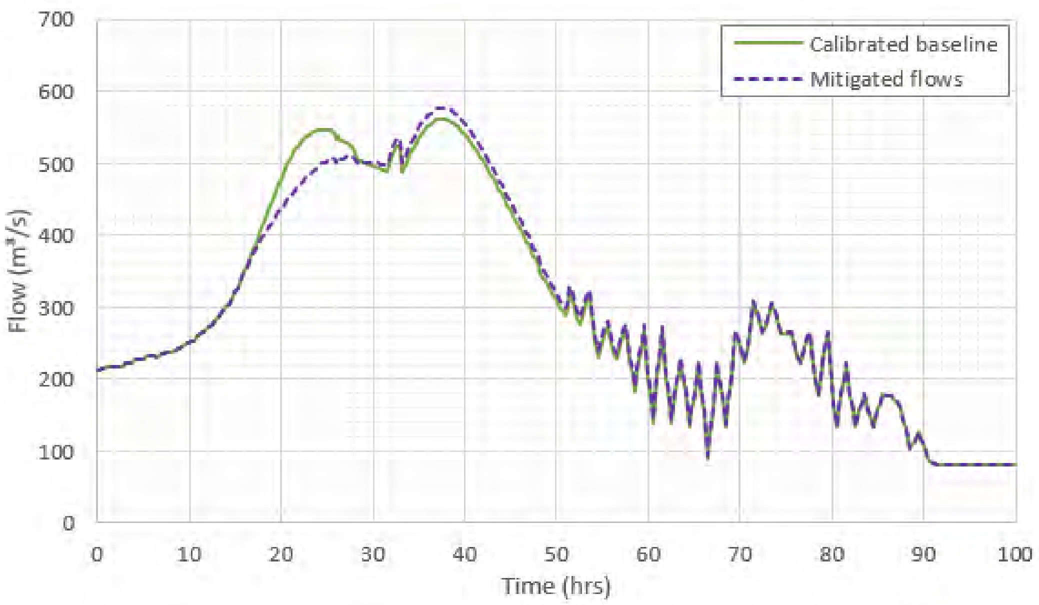
The next scenario modelled only considers the Shournagh sub-catchments, due to the number of residential properties identified in the mapping exercise. Applying NFM opportunities in these areas involves installing approximately 997 NFM features (764 Overland Flow and 233 Floodplain) capable of storing 1,018,000m^3 of water – assuming a 2m high, 30m long barrier to flow.

Table 20: NFM modelling results based on mapped features in the Shournagh and River Bride (West) sub-catchments only

IED Catchment Hydrograph	Sub-catchment (CFRAMS)	Sub-catchment flows			Full catchment flows (at point in model)		
		Peak flow	Peak Flow	Peak Flow	Peak Flow	Mitigated peak flow	% reduction at point
Upper Lee to Inniscarra Reservoir outlet	Uplee3	139.77	139.77	0.0%	139.7 7	139.77	0.0%
	Uplee4	148.28	148.28	0.0%	264.8 1	264.81	0.0%
	Uplee7	66.45	66.45	0.0%	66.45	66.45	0.0%
	Uplee8	66.48	66.48	0.0%	98.46	98.46	0.0%
	Uplee2	99.42	99.42	0.0%	99.42	99.42	0.0%

IED Catchment Hydrograph	Sub-catchment (CFRAMS)	Sub-catchment flows			Full catchment flows (at point in model)		
		Peak flow	Peak Flow	Peak Flow	Peak Flow	Mitigated peak flow	% reduction at point
	Uplee6	63.29	63.29	0.0%	486.41	486.41	0.0%
	Uplee1	66.69	66.69	0.0%	66.69	66.69	0.0%
	Uplee5	33.61	33.61	0.0%	565.91	565.91	0.0%
River Bride (West)	Lowlee12	37.42	37.42	0.0%	37.42	37.42	0.0%
	Lowlee11	28.95	28.95	0.0%	66.22	66.22	0.0%
Shournagh	Lowlee2	52.67	38.59	26.7%	52.67	38.59	26.7%
	Lowlee1	40.60	28.59	29.6%	40.60	28.59	29.6%
	Lowlee4	28.47	19.47	31.6%	28.47	19.47	31.6%
	Lowlee3	16.82	11.99	28.7%	16.82	11.99	28.7%
	Lowlee15	11.07	8.66	21.8%	149.53	107.06	28.4%
D/S Inniscarra	Lowlee14	12.09	8.87	26.6%	470.91	472.11	-0.3%
Waterworks Weir	Lowlee13	12.79	12.79	0.0%	561.42	571.24	-1.7%
		6.93	6.93	0.0%	6.93	6.93	0.0%
Curragheen	Lowlee7	5.44	5.44	0.0%	5.44	5.44	0.0%
	Lowlee8	9.12	9.12	0.0%	9.12	9.12	0.0%
	Lowlee10	9.02	9.02	0.0%	9.02	9.02	0.0%
	Lowlee9	5.54	5.54	0.0%	35.13	35.13	0.0%
	Lowlee5	7.87	7.87	0.0%	7.87	7.87	0.0%
Glasheen	Lowlee6	139.77	139.77	0.0%	139.77	139.77	0.0%

Figure 37: Scenario 5 – Baseline and mitigated flows at Waterworks Weir



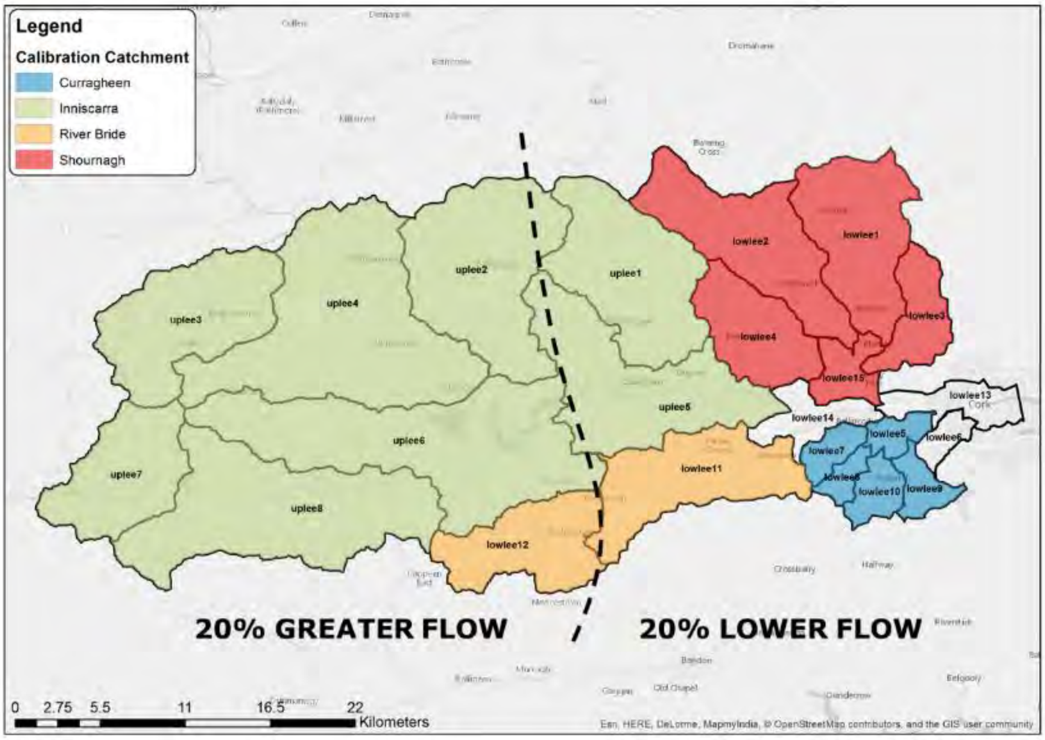
In a similar argument to the increased volume example of Scenario 3, this option further demonstrates the dangers of synchronising peak flows from the Upper and Lower Lee sub-catchments. As the augmented hydrographs for the Shournagh reduce peak flows at the beginning of the storm event, they become coincident with the flows from the Upper Lee, causing an increase in flood flows in Cork.

3.9.2 Alternative Rainfall Patterns

3.9.2.1 Spatial Variability of Rainfall Magnitude

All the modelling of NFM scenarios assumes spatially homogenous rainfall. To understand the influence of spatially variable rainfall over the catchment, it was decided to test an option by splitting the River Lee catchment in two dominant areas. This assumes that the west of the catchment is more likely to be subject to greater magnitudes of rainfall. The 100 year design storm was used to test the impact of varied rainfall using multipliers for the sub-catchment flows. A factor of 1.2 was applied to all flows in Uplee2, 3, 4, 6, 7 and 8 and Lowlee12, and a factor of 0.8 was used on all the flows in the rest of the sub-catchments.

Figure 38: Simple representation of spatially varied rainfall



Applying these multipliers to the flows in the River Lee catchment has a measurable impact on the efficiency of the modelled NFM scheme. The RAFs are designed to function perfectly for the design event requiring mitigation. The threshold flow that enables the storage volume to fill in each sub-catchment is critical to the effectiveness of the NFM within the catchment. Should the threshold be too low, the storage volume will fill up too quickly causing the storage features to reach capacity and overtop. If the threshold is too high, potential catchment storage can be left un-utilised.

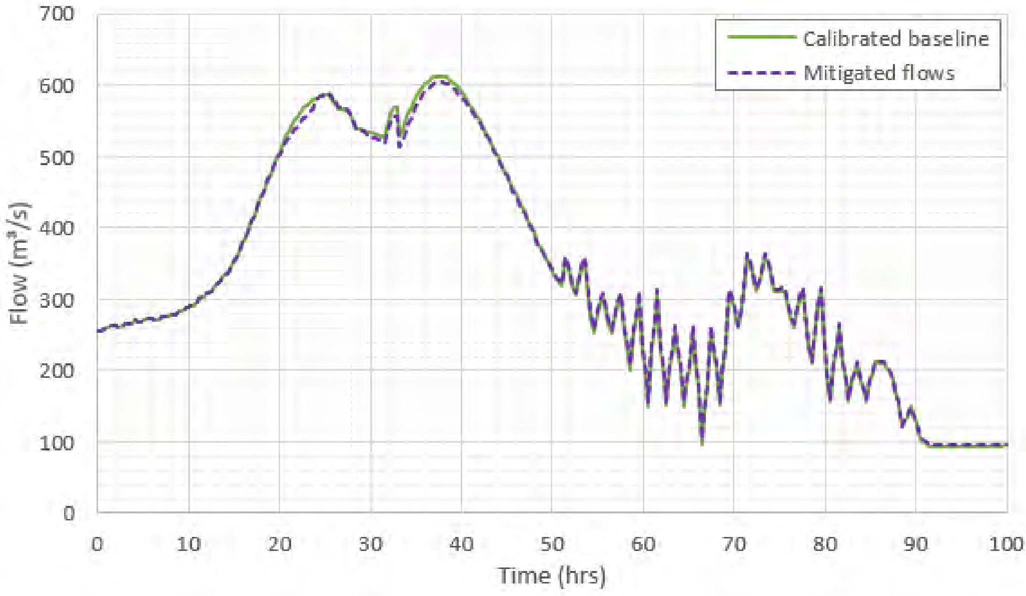
In the alternate rainfall scenario, there is a greater volume of water in some sub-catchments and a decrease in others. The impact is that the Threshold flows, targeting the rainfall from the 1:100 year event are no longer functioning perfectly for the storage volumes being filled in the catchments. Table 21 shows that the effectiveness of the NFM features in the River Lee catchment have decreased because of this issue.

Table 21: Table showing the impact of NFM during the 100 year design storm with modifications to flow in the two dominant catchment areas (as a result of alternate rainfall patterns)

IED Catchment Hydrograph	Sub-catchment (CFRAMS)	Sub-catchment flows			Full catchment flows (at point in model)		
		Peak flow	Peak Flow	Peak Flow	Peak Flow	Mitigated peak flow	% reduction at point
Upper Lee to Inniscarra	Uplee3	167.72	167.72	0.0%	167.72	167.72	0.0%

IED Catchment Hydrograph	**Sub-catchment (CFRAMS)**	**Sub-catchment flows**			**Full catchment flows (at point in model)**		
		Peak flow	**Peak Flow**	**Peak Flow**	**Peak Flow**	**Mitigated peak flow**	**% reduction at point**
Reservoir outlet	Uplee4	177.94	177.94	0.0%	317.77	311.98	1.8%
	Uplee7	79.74	79.74	0.0%	79.74	79.74	0.0%
	Uplee8	79.77	79.77	0.0%	118.15	118.15	0.0%
	Uplee2	119.30	119.30	0.0%	119.30	119.30	0.0%
	Uplee6	75.95	75.95	0.0%	583.69	576.45	1.2%
	Uplee1	53.35	51.76	3.0%	53.35	51.76	3.0%
	Uplee5	26.88	25.13	6.5%	647.29	639.78	1.2%
River Bride (West)	Lowlee12	44.91	44.85	0.1%	44.91	44.85	0.1%
	Lowlee11	23.16	21.36	7.8%	67.94	65.95	2.9%
Shournagh	Lowlee2	42.14	40.40	4.1%	42.14	40.40	4.1%
	Lowlee1	32.48	30.37	6.5%	32.48	30.37	6.5%
	Lowlee4	22.78	22.19	2.6%	22.78	22.19	2.6%
	Lowlee3	13.46	12.67	5.8%	13.46	12.67	5.8%
	Lowlee15	8.85	8.51	3.9%	119.62	114.11	4.6%
D/S Inniscarra	Lowlee14	9.67	9.02	6.7%	540.73	531.98	1.6%
Waterworks Weir	Lowlee13	10.23	10.23	0.0%	613.28	604.37	1.5%
Curragheen	Lowlee7	5.55	5.17	6.7%	5.55	5.17	6.7%
	Lowlee8	4.35	4.07	6.4%	4.35	4.07	6.4%
	Lowlee10	7.30	6.74	7.7%	7.30	6.74	7.7%
	Lowlee9	7.22	6.70	7.2%	7.22	6.70	7.2%
	Lowlee5	4.43	4.13	6.9%	28.11	26.56	5.5%
Glasheen	Lowlee6	6.30	5.96	5.4%	6.30	5.96	5.4%

Figure 39: Scenario 1 – Baseline and mitigated flows at Waterworks Weir under the altered rainfall scenario



Note: Due to the altered rainfall representation, the hydrograph being mitigated is different to the previous scenarios. The impact of greater rainfall in the Upper Lee is that in an area of the catchment where most storage opportunities were located, the volumetric capacity was surpassed slightly earlier than the previous design storms.

3.9.2.2 Rainfall Tracking

A further rainfall scenario was tested to represent the movement (tracking) of rainfall over the catchment. Figure 40 shows the spatial variability of rainfall across Ireland. Here, a simple representation of rainfall tracking was achieved by delaying the hydrograph timings of sub-catchments relative to Uplee3 and Uplee7 (the sub-catchments at the westernmost point of the River Lee catchment (Figure 41).

Figure 40: Mean annual rainfall across Ireland (1981-2010) – From the Irish Meteorological Service Online

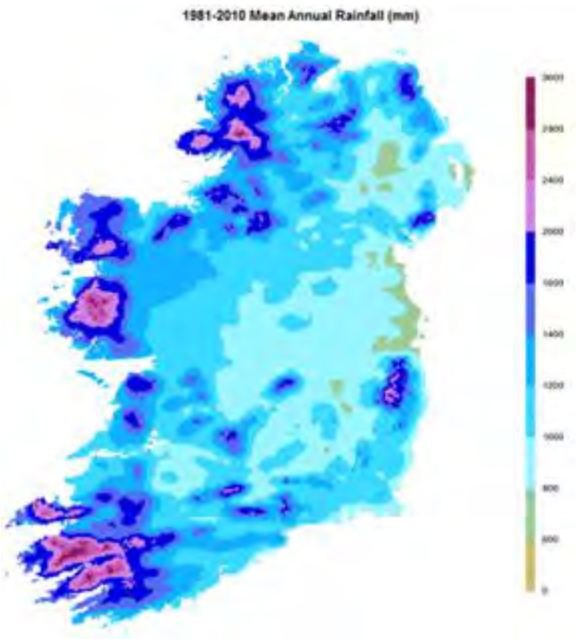


Figure 41: Simple representation of rainfall tracking across the River Lee catchment

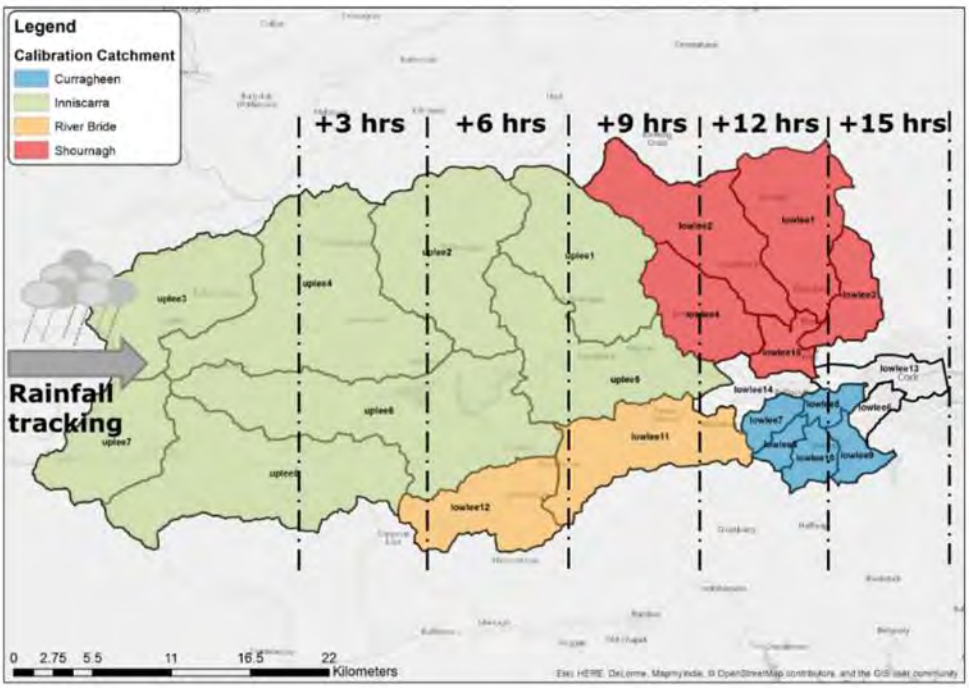
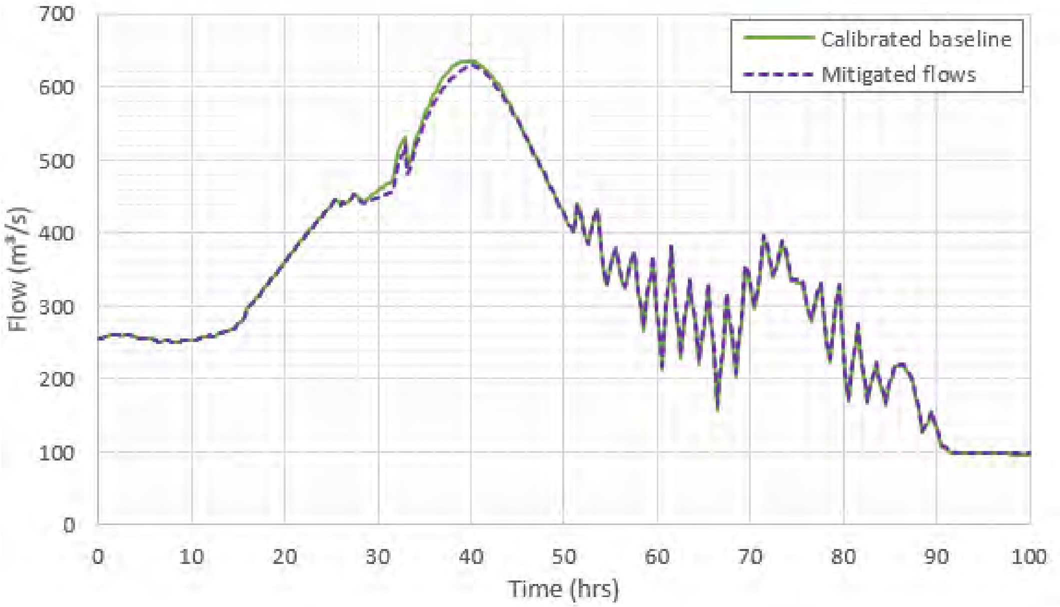


Table 22: Table showing the impact of NFM during the 100 year design storm with modifications to rainfall timing over the catchment areas (as a result of alternate rainfall patterns)

IED Catchment Hydrograph	Sub-catchment (CFRAMS)	Sub-catchment flows			Full catchment flows (at point in model)		
		Peak flow	Peak Flow	Peak Flow	Peak Flow	Mitigated peak flow	% reduction at point
Upper Lee to Inniscarra Reservoir outlet	Uplee3	167.72	167.72	0.0%	167.72	167.72	0.0%
	Uplee4	177.94	177.94	0.0%	273.05	271.59	0.5%
	Uplee7	79.74	79.74	0.0%	79.74	79.74	0.0%
	Uplee8	79.77	79.77	0.0%	103.72	103.72	0.0%
	Uplee2	119.30	119.30	0.0%	119.30	119.30	0.0%
	Uplee6	75.95	75.95	0.0%	489.88	487.84	0.4%
	Uplee1	53.35	51.76	3.0%	53.35	51.76	3.0%
	Uplee5	26.88	25.13	6.5%	536.95	537.67	-0.1%
River Bride (West)	Lowlee12	44.91	44.85	0.1%	44.91	44.85	0.1%
	Lowlee11	23.16	21.36	7.8%	65.46	64.58	1.4%
Shournagh	Lowlee2	42.14	40.40	4.1%	42.14	40.40	4.1%
	Lowlee1	32.48	30.37	6.5%	32.48	30.37	6.5%
	Lowlee4	22.78	22.19	2.6%	22.78	22.19	2.6%
	Lowlee3	13.46	12.67	5.8%	13.46	12.67	5.8%
	Lowlee15	8.85	8.51	3.9%	116.48	113.17	2.8%
D/S Inniscarra	Lowlee14	9.67	9.02	6.7%	509.47	502.40	1.4%
Waterworks Weir	Lowlee13	10.23	10.23	0.0%	636.21	629.38	1.1%
Curragheen	Lowlee7	5.55	5.17	6.7%	5.55	5.17	6.7%
	Lowlee8	4.35	4.07	6.4%	4.35	4.07	6.4%
	Lowlee10	7.30	6.74	7.7%	7.30	6.74	7.7%
	Lowlee9	7.22	6.70	7.2%	7.22	6.70	7.2%
	Lowlee5	4.43	4.13	6.9%	28.33	26.63	6.0%
Glasheen	Lowlee6	6.30	5.96	5.4%	6.30	5.96	5.4%

Figure 42: Scenario 1 – Baseline and mitigated flows at Waterworks Weir under the rainfall tracking scenario



Note: Due to the altered rainfall representation, the hydrograph being mitigated is different to the previous scenarios.

3.10 Discussion

A number of scenarios have been modelled using the 1 in 100 year return period event (Table 23). The summary table indicates the percentage reduction of peak flow throughout the model at key node locations and states the amount of NFM features (and combined NFM attenuation storage) required to achieve this reduction.

Table 23: Summary of storage scenarios (excluding further storage and rainfall testing)

Scenario	Node in model	Location	% reduction at node	NFM Features and storage	Areas benefiting besides Cork
1	Uplee5	Inniscarra	5.3	5,055 features storing 2,213,000m³	All
	Lowlee11	River Bride (West)	16.3		
	Lowlee15	Shournagh	16.5		
	Lowlee13	Waterworks Weir	0.7		
	Lowlee5	Curragheen	13.7		
	Lowlee6	Glasheen	13.7		
2	Uplee5	Inniscarra	5.3	4,823 features storing 2,098,000m³	All, excluding Curragheen / Glasheen
	Lowlee11	River Bride (West)	16.3		
	Lowlee15	Shournagh	16.5		
	Lowlee13	Waterworks Weir	0.7		

Scenario	Node in model	Location	% reduction at node	NFM Features and storage	Areas benefiting besides Cork
	Lowlee5	Curragheen	0		
	Lowlee6	Glasheen	0		
3	Uplee5	Inniscarra	5.3	3,377 features storing 1,410,000m³	Upper Lee Catchments
	Lowlee11	River Bride (West)	0		
	Lowlee15	Shournagh	0		
	Lowlee13	Waterworks Weir	2.5		
	Lowlee5	Curragheen	0		
	Lowlee6	Glasheen	0		
4	Uplee5	Inniscarra	0	1,678 features storing 803,000m³	Lower Lee Catchments
	Lowlee11	River Bride (West)	16.3		
	Lowlee15	Shournagh	16.5		
	Lowlee13	Waterworks Weir	-1.9		
	Lowlee5	Curragheen	13.7		
	Lowlee6	Glasheen	13.7		
5	Uplee5	Inniscarra	0	997 features storing 452,000m³	Shournagh Catchments
	Lowlee11	River Bride (West)	0		
	Lowlee15	Shournagh	16.5		
	Lowlee13	Waterworks Weir	-0.9		
	Lowlee5	Curragheen	0		
	Lowlee6	Glasheen	0		
6	Uplee5	Inniscarra	0	449 features storing 235,000m³	River Bride (West) Catchments
	Lowlee11	River Bride (West)	16.3		
	Lowlee15	Shournagh	0		
	Lowlee13	Waterworks Weir	-0.7		
	Lowlee5	Curragheen	0		
	Lowlee6	Glasheen	0		
7	Uplee5	Inniscarra	0	232 features storing 115,000m³	Curragheen and Glasheen Catchments
	Lowlee11	River Bride (West)	0		
	Lowlee15	Shournagh	0		
	Lowlee13	Waterworks Weir	0		
	Lowlee5	Curragheen	13.7		
	Lowlee6	Glasheen	13.7		

A range of reductions and increases to flow have been observed at Waterworks Weir in Cork, from the scenarios tested. Scenarios 1-3 are the only ones to reduce flows at Waterworks Weir in Cork, which is the main objective for the Lower Lee FRS.

There are 1021 properties identified at risk in the River Lee Catchment besides those in Cork City. Again it should be noted that these numbers have been derived by counting the number of residential properties located within the PFRA Q100 flood extent. It is therefore a conservative estimate of the number of properties at risk as the PFRA flood extent is basic and does not account for the benefit offered by any flood protection measures in the catchment.

Of these only 220 are in the Upper Lee Catchments, where it has been identified in Scenario 2 that it would have the best reduction in flows for Waterworks Weir.

It is apparent that NFM measures on the River Bride (West) and Shournagh could worsen flood risk at Waterworks weir. This is due to synchronisation of flood peaks between the tributaries and the main River Lee (observed within the model). However, there are almost 300 properties identified at risk in these sub-catchments, and some of the best percentage reduction of flows are possible in these sub-catchments as a result of NFM. It is noted that this is not the objective of the Lower Lee FRS.

A scheme on the Curragheen and Glasheen Catchments has the potential to benefit over 100 at-risk properties. This would achieve no benefit for reducing flows at Waterworks Weir, but it has been identified that targeted NFM in these sub-catchments would not lead to synchronisation of flows, therefore, not adversely impacting other areas as a result. It is noted, that while not being an objective of the Lower Lee FRS, an NFM Scheme on the Curragheen and Glasheen would require the least number of features and therefore the least investment.

It should be noted that this is a high level study/assessment of the amount of properties at risk in the catchment, and it would be regarded as indicative only. Further work would be required to assess the level of risk to the properties before any consideration would be given to implementing any such measures. This level of study is sufficient for the purposes of this report at this time.

Alternate rainfall patterns have been explored. Benefit from NFM measures is sensitive to different rainfall patterns. This would make it extremely difficult to design and calibrate a robust scheme which would target the 1 in 100 year event in Cork city. The likelihood is that due to spatial variability of rainfall, not all of the measures would work at full efficiency across the catchment. This would be expected to erode the potential flow reduction in Cork city and in the Curragheen and Glasheen catchments.

4 Preliminary NFM Cost Estimate

Cost estimates were produced as part of the economic assessment using SPON's Civil Engineering and Highways Pricing Book 2017, and converted from GBP to Euros using a rate of £1 : €1.12. Two types of features were identified: floodplain storage and overland flow pond storage. These features could be constructed either as a soil bund (a cheaper structure) or a timber leaky dam (a more expensive structure, which uses a negligible footprint and requires no soil for construction). The cost estimates use the average cost of these two methods and apply this across the overland flow and floodplain features for the River Lee sub-catchments. The derivation of the costs for construction and maintenance are detailed in Table 24 and Table 25.

The costs include an annual maintenance figure of €336,000 (€2,800/10km^2/year) and a reconstruction cost for circa 50% of the timber elements after 25 years. The reconstruction cost assumes that all timber features need replacing every 25 years.

The cost estimates assume installing approximately 5,055 NFM features (3,780 Overland Flow and 1,275 Floodplain) capable of storing 2,213,000m3 of water – based on a 1.5m high, 30m long barrier to flow.

Table 24: NFM feature assumptions and cost derivation (Photos shown from Belford NFM Scheme, Northumberland © Newcastle University)

<table>
<tr><th rowspan="2">Schematisation</th><th colspan="3">Soil bund and storage pond</th><th colspan="3">Timber leaky dam</th></tr>
<tr><td colspan="3">Overland Flow:

Floodplain:
</td><td colspan="3">Overland Flow:

Floodplain:
</td></tr>
<tr><th>Dimensions</th><td colspan="3">Length of bund: 30m
Crest width: 2m
Height of bund: 1m
Side slope: 1 in 3</td><td colspan="3">Length of barrier: 30m
Height: 1m
Material: Untreated hardwood
Dimensions of timber (mm): 75 x 150 x 1500</td></tr>
<tr><th rowspan="2">Assumed water storage (m^3)</th><th>Overland Flow</th><th colspan="2">Floodplain</th><th>Overland Flow</th><th colspan="2">Floodplain</th></tr>
<tr><td>450</td><td colspan="2">450</td><td>450</td><td colspan="2">450</td></tr>
<tr><th>Cost per m^3 water stored (€)</th><td>3.47</td><td colspan="2">1.62</td><td>18.03</td><td colspan="2">9.02</td></tr>
<tr><th colspan="2" rowspan="3">Cost per m^3 of water stored (€)</th><th colspan="3">Overland flow</th><th colspan="2">Floodplain</th></tr>
<tr><th>Upper</th><th colspan="2">Lower</th><th>Upper</th><th>Lower</th></tr>
<tr><td>9.60</td><td colspan="2">3.10</td><td>4.75</td><td>1.44</td></tr>
<tr><th colspan="2">Total cost of storage (€) to the nearest thousand</th><td>16,923,000</td><td colspan="2">5,470,000</td><td>2,789,000</td><td>849,000</td></tr>
</table>

Table 25: Totalled capital and maintenance costs assuming a 50 year design life (using average of upper and lower estimates)

Cost Item	Amount (€)	Comments
Subtotal Baseline Construction Costs	**€15,618,600**	
Add Optimism Bias/Contingency	€6,872,184	44%
Construction Cost Total	**€22,490,784**	
Add Surveys/SI /Fees/Supervision	€2,698,894	12%
Add Land Acquisition / Compensation	€2,249,078	10%
Add Art Allowance	€64,000	
Initial Capital Cost Total	**€27,502,756**	
NPV Maintenance Cost (including partial reconstruction after 25 years)	€10,890,123	4% discount rate applied to all
Total Whole Life Cost (NPV)	**€38,392,879**	

5 Qualitative Land Use Assessment

5.1 Introduction

Land cover in the River Lee Catchment is introduced in Section 3.3 (Table 2). The final row in Table 2 shows the percentage of the whole catchment covered by a particular land class. According to the Corine 2012 data, more than 60% of the River Lee Catchment is classed as pasture, with less than 12% classed as woodland and less than 10% peat bogs. In this Section, a brief review of literature is presented to qualitatively infer the impact of change to land cover in the River Lee Catchment.

5.2 Woodland Benefits

Woodland attenuates flooding through different mechanisms. Trees and woodland can take up more water compared to other vegetation types because they have higher rainwater interception rates. Moreover, the organic matter in the soil beneath trees as well as the soil fauna, evapotranspiration and the tree root action that creates soil porosity and often limited disturbance from humans gives woodland a relatively high capacity to hold back water and delay its passage to streams and rivers.

In addition, a number of factors give woodland a relatively high capacity to hold back water and delay its passage to streams and rivers:

- The organic matter in the soil beneath trees;
- Soil fauna;
- Evapotranspiration;
- Tree root action that creates soil porosity; and
- Limited disturbance from humans.

There are other factors that contribute to the overall impact that woodland has on flood risk. These are:

- Woodland location (upland or lowland);
- Type of woodland (coniferous versus deciduous); and
- Tree age (older forests generally exhibit higher infiltration rates).

5.2.1 Evidence through Studies into Woodland

Afforestation measures that have a capacity to reduce flood risk have been demonstrated in a number of studies. Increasing the coverage of forests and woodland in upstream areas was convincingly shown to reduce downstream flood peaks and baseflows in the Polo, Iller and Parrett catchments (Francés *et al.,* 2008; Park *et al.,* 2006). A study by Wheater *et al.* (2010) reported a peak flow reduction of up to 60% for the full afforestation of a 4km2 sub-catchment in Pontbren.

A study in the Plynlimon catchments of Wales found in general that water yields can be reduced by 1.5 - 2% for every 10% of land cover in the upland catchment changed to additional coniferous forest woodland (Calder & Newson, 1979). Though it is noted that this refers to annual water yields as opposed to peak flows in intense storm events. In dry lowland areas, interception losses had a larger impact because the link between the rainfall and evapotranspiration rate is stronger and the water yields are lower (Forestry Commission, 2005).

The UK Centre for Ecology & Hydrology (CEH) has written a review[21] of the current evidence base for tree cover as an effective flood mitigation measure using a range of studies. The key findings of this review are outlined below.

- The majority of case studies that assess increasing tree cover showed a significant reduction in fluvial flood peaks, with a small number reporting no influence and an even smaller number reporting an increase;
- Of the case studies that investigated the effects of decreasing tree cover, none found evidence of a decrease in flood peaks, while the majority found an increase; and
- Observational results from the majority of studies found that increasing tree cover decreases flood peaks however, a number of studies found the opposite effect or no effect.

5.3 Woodland Versus other Land Use

5.3.1 Difference Across Land Uses

Forests remove more water than non-forested land areas, though the difference depends on the alternative land cover, tree types and the management of trees. The forestry commission outlines these differences, which are summarised in Table 26. The table below shows that the total evaporation rates are highest for woodland areas and lowest for grassland, heather and arable areas.

Table 26: Percentage of annual evaporation losses - typical ranges for different land covers (adapted from Forestry Commission, 2005)

Land cover	Transpiration (%)	Interception (%)	Total evaporation (%)
Coniferous	30-35	25-45	55-80
Deciduous	30-39	10-25	40-64
Grassland	40-60	-	40-60
Heather	20-42	16-19	36-61
Arable	37-43	-	37-43

[21] Stratford, C., et al., 2017. Do trees in UK-relevant catchments influence fluvial flood peaks? Wallingford, UK, NERC/Centre for Ecology & Hydrology, 46pp. (CEH Project no. NEC06063)

5.3.2 Arable Land

Due to intense agricultural land use, most arable soils in the UK are highly degraded due to soil compaction, soil erosion and loss of organic matter. Poor soil quality is related to the infiltration capacity of soils.

Studies have shown that arable land cover type has no significant influence on the soil's hydraulic properties, which is partly the result of the short roots and seasonal variation. This indicates that the hydraulic conductivity is more dependent on the soil structure than on the land cover (Gonzalez-Sosa *et al.,* 2010). Soils under natural forests are generally porous and have high infiltration rates. Therefore, forests have the potential to lower surface runoff rates by influencing the water retention capacity of the landscape. Tree roots loosen the soil and thus increase the overall water storage capacity, buffering the effect of rainfall on flood generation and reducing flood peaks

For grassland, the hydraulic conductivity is noted by Archer *et al.* (2013) and confirmed by Jarvis *et al.* (2013) to increase up to two times compared to arable land cover. The dwarf shrub and montane habitats cover has a similar impact as grassland on a soil's hydraulic properties. Forest cover has the highest impact on soil properties (Archer *et al.,* 2013; Jarvis et al., 2013) with soils in forested areas having hydraulic conductivities around four times higher than those of grasslands.

Ciria's report on land use management effects on flood flows and sediments[22] presents the scientific basis for natural flood management and sediment management through rural land use management practices in the UK.

Intense agricultural land use practices are widespread across the UK, with increases in ploughing, drainage fields, use of heavy machinery, and the removal of trees and hedgerows from the landscape becoming increasingly commonplace.

Rural land use changes have been observed to affect local surface runoff, but at times the evidence base is limited to a relatively small range of land use actions. The results of the FRMRC and other studies have demonstrated that using the appropriate land use management measures in rural areas can significantly reduce the peak flood flows. This report notes, however, that the effects of land use management on flooding are expected to reduce as the scale of the catchment increases. Studies on the Hodder and Parrett catchments have shown this finding, while the Parrett case study also showed that on-farm storage can be more effective than land use change. There is substantial evidence that local surface runoff is increased by a number of farm management practices, in addition to reduced infiltration.

It should be noted that the wider extent of storage required to have a significant effect on flood risk benefits would require concerted actions from a large number of land owners, which can be difficult to achieve on the required scale.

[22] McIntyre, N. & Thorne, C. (2013). Land use management effects on flood flows and sediments - guidance on prediction, London: Ciria.

5.4 Influence of Land Cover on Flooding

A recent literature review from the Royal Society found that the effect of land cover and land management on flood flows is evident at small spatial scales (less than 20km^2), but not for the most extreme floods[23]. Dadson et al. (2017) state that measured evidence from peatland studies show marked differences between management techniques. However, most of this evidence is at the small catchment scale, rather than the large catchment scale (more than 100km^2).

Despite studies quantifying local changes in runoff response resulting from land use change, there is very little evidence that these changes propagate through the river network to enhance flooding at the catchment scale, or indeed evidence to the contrary. In the most comprehensive analysis of UK flooding trends, no significant impacts of land-use change were detected on flow hydrographs[24,25]. A review by McIntyre & Thorne (2013) states that the effects of land use management on flooding are expected to diminish as the scale of the catchment increases. For example, in the 260km^2 Hodder catchment the median reduction in the flood peak associated with an extreme rainfall event produced by a realistic suite of land use changes was only two per cent, assuming that channel conveyance did not change[26,27]. In most cases, it is observed that the effects of land use change are relatively large in only a small number of catchments. This is in part due to the direct effects of scale (e.g. the fraction of land area affected by change tends to fall as the catchment area increases) and also to various inefficiencies in the way that effects propagate downstream through the stream network (McIntyre & Thorne, 2013). Also, the effects of land use change are generally more significant for smaller events compared to larger ones. This is primarily because the relatively small changes in storage related to most land management interventions become less significant and can be overwhelmed by large events (McIntyre & Thorne, 2013).

When it comes to quantifying the effect of man-made interventions with respect to changes in flood peak, it will clearly depend on the nature of the examined flood event[28]. Hollis (1975) demonstrated that the effect of urbanisation on the peak discharge has a lower impact than increasing return period of the rainfall event[29].

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[23] Dadson, S. J. et al. (2017). A restatement of the natural science evidence concerning catchment-based 'natural' flood management in the UK. Proc. R. Soc. A, 473: 20160706

[24] Robson, A. J., Jones, T. K., Reed, D. W. & Bayliss, A. C. (1998). A study of the national trend and variation in UK floods. International Journal of Climatology, Volume 18, pp. 165-182.

[25] Robson, A. J. (2003). Evidence for trends in UK flooding. Phil. Trans: Mathe. Phys. Eng. Sci., Volume 360, pp. 1327-1343.

[26] O'Donnell, G. M., Ewen, J., & O'Connell, P. E. (2011). Sensitivity maps for impacts of land management on an extreme flood in the Hodder catchment, UK. Physics and Chemistry of the Earth, Parts A/B/C, 36(11), 630-637.

[27] Geris, J. R. M. C. (2012). Multiscale Impacts of Land Use/Management Changes on Flood Response in the River Hodder Catchment, North-West England, Newcastle upon Tyne: PhD Thesis, Newcastle University.

[28] Brath, A., Montanari, A. & Moretti, G. (2006). Assessing the effect on flood frequency of land use change via hydrological simulation (with uncertainty). J. Hydrol., Issue 324, pp. 141-153.

[29] Hollis, G. E. (1975). The effect of urbanisation on flood of different recurrence interval. Water Resour. Res, Issue 11, pp. 431-435.

Hollis' conclusion is justified when considering that extreme flood events are produced by storms that induce soil saturation, therefore storage within the soil, allowed by infiltration, diminishes so rapidly that the impact of preventing this infiltration has little effect on surface runoff.

5.5 River Lee Land Cover

Section 3.3 presents the Corine land cover data for 2012 and shows the percentage of land classes in each sub-catchment. The following figures present the Land Cover Change that has occurred in the River Lee Catchment between the years 1990 to 2000, 2000 to 2006, and 2006 to 2012, respectively.

Figure 43: Land Cover Change 1990-2000 (CORINE)

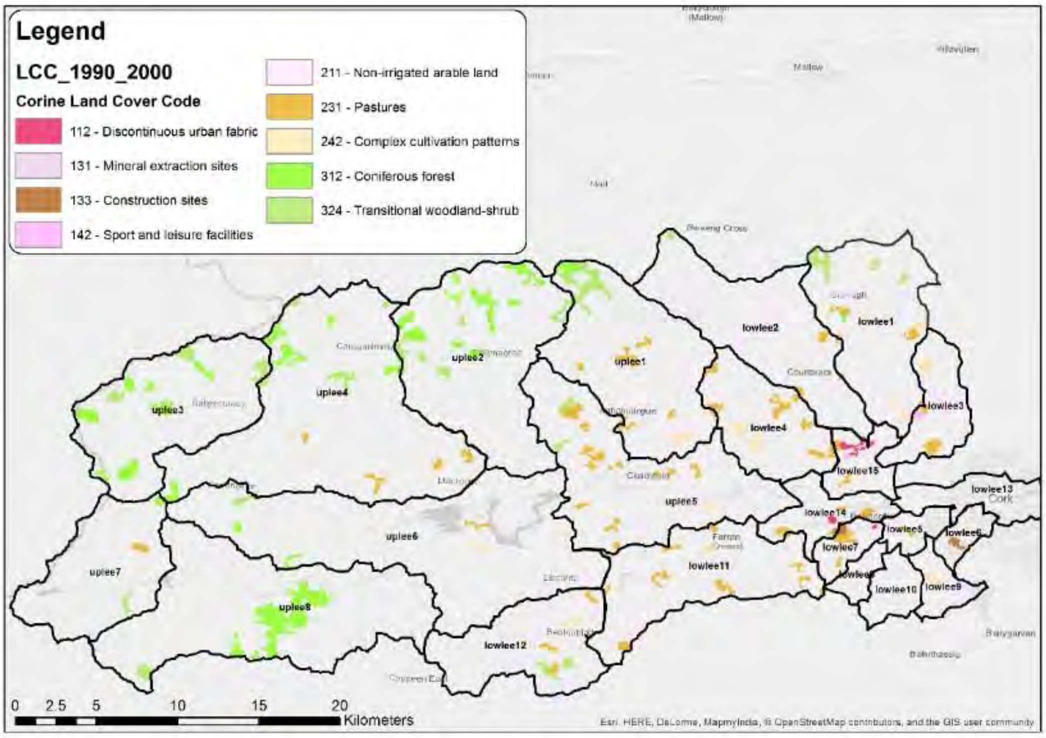


Figure 44: Land Cover Change 2000-2006 (CORINE)

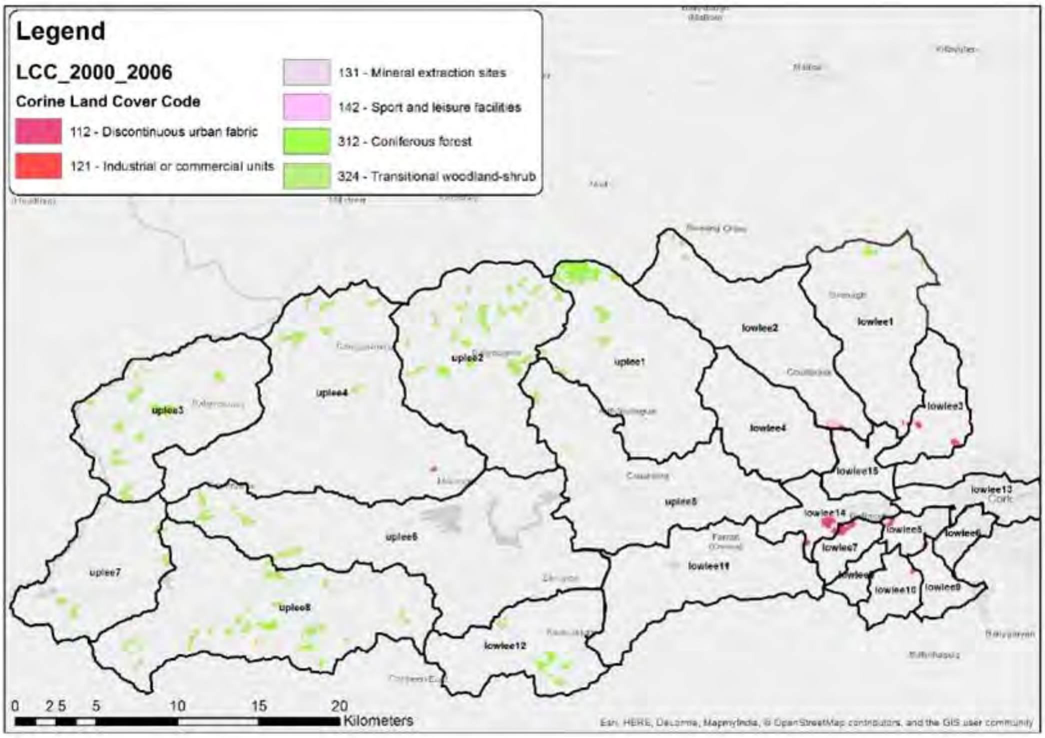
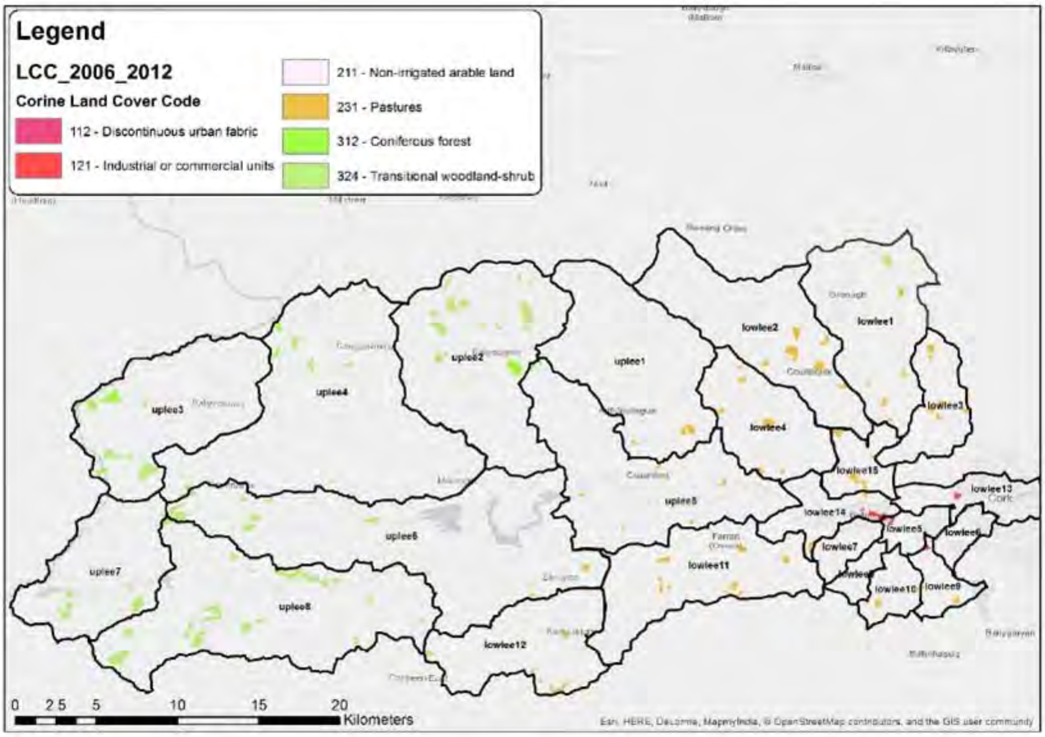


Figure 45: Land Cover Change 2006-2012 (CORINE)



5.6 Role of the Planning System and Flood Risk Management Guidelines

It is important to note the role of the Planning and Development System in managing flood risk related to land use change, in the context of development proposals requiring planning consent.

In November 2009, the then Department of Environment, Heritage and Local Government and the Office of Public Works jointly published a Guidance Document for Planning Authorities entitled 'The Planning System and Flood Risk Management' ("the Guidelines").

The guidelines are issued under Section 28 of the Planning and Development Act 2000; and Planning Authorities and An Bord Pleanála are therefore required to implement the Guidelines in carrying out their functions under the Planning Acts.

The aim of the guidelines is to ensure that flood risk is neither created nor increased by inappropriate development.

The guidelines require the planning system to avoid development in areas at risk of flooding, unless they can be justified on wider sustainability grounds, where the risk can be reduced or managed to an acceptable level.

Planning authorities are now required to ensure that development is not permitted in areas of flood risk, particularly floodplains, except where there are no suitable alternative sites available in areas at lower risk that are consistent with the objectives of proper planning and sustainable development. Where such development has to take place, in the case of urban regeneration for example, the type of development has to be carefully considered and the risks should be mitigated and managed through location, layout and design of the development to reduce flood risk to an acceptable level, and that the development proposed will not increase flood risk elsewhere.

Planning authorities are also now required to ensure that only developments consistent with the overall policy and technical approaches of the Guidelines will be approved and permission will be refused where flood issues have not been, or cannot be, addressed successfully and where the presence of unacceptable residual flood risks to the development, its occupants or users and adjoining property remains.

5.7 Summary

According to the data presented in Figure 43 – Figure 45, the forest cover (in the combined form of Transitional woodland-scrub, Coniferous forest, mixed forest and broad-leaved forest) has decreased by 7.5% throughout the catchment since 1990 (covering an area of 140km^2 in 2012). In addition, pastoral land area has increased by 15.5% of the catchment since 1990 (covering an area of 742km^2 in 2012).

There is little measured evidence to suggest that this decrease in forest cover and increase in pasture has led to an increase in flood hazard in the River Lee Catchment. However, a significant amount of literature has shown that land cover has the potential to control runoff rates for the small catchment scale and, in particular, relatively low intensity storm events.

Here, it is noted that the River Lee Catchment at Waterworks weir is approximately 1,200km^2 and the event being considered is a 1 in 100 year return period.

6 Identification of Potential NFM Scheme Delivery Routes

6.1 Introduction

In this section, a preliminary review of potential scheme delivery routes is presented. The review identifies the current policy and typical project delivery routes in the UK, along with possible options for delivery and funding in the Irish context.

6.2 Natural Flood Management in the UK

6.2.1 Policy

The Flood and Water Management Act 2010 establishes primary flood risk management policy for England and Wales. The Act lists "maintaining or restoring natural processes" as a way of managing flood risk, and permits the designation of natural features that can reduce this risk. It also requires the creation of national and local flood risk management plans. The EA's national plan provides the framework for managing flood risk. The local plans focus on surface water, groundwater and small watercourses, and are the responsibility of "Lead Local Flood Authorities".

For Scotland, the Flood Risk Management Act (Scotland) 2009 is the main policy driver. This promotes NFM directly and requires the mapping of "natural features" that contribute to a reduction in flood risk, and an assessment of places in which the alteration, enhancement or restoration of natural features could further reduce flood risk.

6.2.2 Project Delivery and Funding

In general in the UK, it is not yet common practice for a statutory authority to enter private land to unilaterally carry out an NFM scheme. What is more common is for private landowners, individually or in local partnerships, to apply for funding to construct the works themselves. Usually this is done with technical support from a University and/or a statutory authority.

There are several potential funding sources for NFM available in the UK. The main statutory source is the Flood and Coastal Erosion Risk Management Grant in Aid (FCERM GiA). This is sourced from central government and is administered through the Environment Agency. Individual landowners or partnerships can access this funding if they can prove flood risk reduction at an area of risk, and only if their project is included in the "Medium Term Plan" for the fund, which runs on a six-year cycle.

There are also some "agri-environmental" sources of funding available, such as the "Countryside Stewardship Facilitation Fund" in England, which promotes improve the local natural environment at a landscape scale.

This funding originates from the European Agricultural Fund for Rural Development, and is administered by Natural England.

6.3 Natural Flood Management in Ireland

6.3.1 Policy

Flood risk management policy in Ireland is outlined in the Report of the Flood Policy Review Group (2004). While the adopted policy does not specifically mention Natural Flood Management, it does promote a "catchment-based" approach and greater emphasis on "non-structural" flood relief measures.

Core components of national flood policy and the EU Floods Directive[30] are being delivered under the national CFRAM programme. The draft Catchment Flood Risk Management Plans (CFRMP) typically make reference to non-structural measures under the headings of 'land use management and natural water retention measures'. Pilot studies for such measures have been proposed as part of some CFRMP's.

6.3.2 Project Delivery

Delivery of an NFM scheme would be completely new in Ireland, and would require development of appropriate funding and institutional arrangements. This could potentially be explored through small pilot studies.

Table 27 below presents a summary of several possible project delivery options and associated issues.

[30] European Directive on the Assessment and Management of Flood Risks (2007/60/EC) and Irish Law (Statutory Instrument No. 122 of 2010)

Table 27: Summary of Potential NFM Project Delivery Routes in Ireland

	Statutory Authority-Led		Landowner-Led	Comment
Possible Project Leader	Office of Public Works	Local Authority (typically in partnership with the Office of Public Works)	Individual Landowners (or Registered Farm Partnerships) in partnership with funding authority and/or Office of Public Works	• Landowner-led schemes would have less control and less certainty of outcome compared with statutory authority-led schemes
Statutory Consent Route	Arterial Drainage Act	Planning and Development Act	Unlikely to require statutory consent	• Risk that large projects led by Statutory Authorities would trigger an EIA (refer to Schedule 5, Part 2, section 10 (f) (ii) of the Planning Regulations) • Landowner-led projects would be smaller and would likely fall under exempted development provisions (Schedule 2, Part 3, Class 3&4 of the Planning Regulations) • Note that in the UK, storage areas with volumes over 10,000m3 fall under the provisions of the Reservoirs Act (as amended). Large storage areas, or a series of NFM measures with this cumulative volume could in theory exceed this threshold. There is currently no such legislation for reservoirs in Ireland.
Potential funding source(s)	OPW flood risk management budget (as part of a major drainage scheme)	OPW flood risk management budget, drawn down via: • A major drainage scheme or • A “minor works” scheme	• Currently only available source appears to be agri-environmental funding (refer to Section 6.3.3) • Potential for development of a “minor works” style scheme which could be accessed by individual landowners or farm partnerships?	• Agri-environmental funding unlikely to be available at the scale required to effect significant change in large catchments. • Timescale of agri-environmental funds is relatively short – risk of loss of funding for scheme maintenance. • Likely that majority of funding would still need to be sourced from OPW budget, however no mechanism currently exists for such funding to be applied for by individuals or partnerships. • The existing OPW “minor works” scheme is not particularly suited to promotion of NFM (although it is not precluded from the scheme). Minor works schemes to date have tended to be localised and confined to individual Local Authority functional areas. There may be potential in the future to adapt the minor works scheme to promote measures such as NFM

	Statutory Authority-Led		**Landowner-Led**	**Comment**
Maintenance responsibility	Statutory requirement for the works to be maintained in proper repair and effective condition by OPW	Statutory obligation for maintenance of the works would likely be contained within the planning consent. Responsibility would likely lie with the Local authority (potentially with support from OPW)	Responsibility for maintenance would lie with the landowners, and would likely form part of the funding agreements	• Risk associated with lack of maintenance would be significantly higher with landowner-led projects
Power of Entry onto private lands by Statutory Authority (for carrying out works or maintenance)	Landowner agreement typically desired, however the Act grants power of entry to carry out works, maintenance etc. without transfer of title to the land	Landowner agreement typically desired, otherwise compulsory purchase of the affected land may be required (and/or new wayleaves and rights of way)	None	• Landowner-led projects are inherently dependent on the goodwill of the landowners. • Maintenance of a statutory authority-led scheme delivered under the Planning and Development System may be difficult unless legally binding agreements are put in place

6.3.3 Agri-Environmental Funding in Ireland

In 2013, the Common Agricultural Policy reform was initiated which resulted in the Rural Development Programme 2014 - 2020. As a part of the programme, there are two main streams of funding that farmers can access which are:

- The Green, Low-carbon, Agri-Environment Scheme (GLAS) and
- Basic Payment, that can be coupled with the Greening Payment.

These funding options replace former schemes, for example the Agri-environment Options Scheme (AEOS) which is in its final stages of releasing payments for farmers who participated.

6.3.3.1 Green, Low-Carbon, Agri-Environment Scheme (GLAS)

The Green, Low-Carbon Agri-Environment Scheme is part of the Rural Development Programme 2014 - 2020[31]. It provides funding to farmers in return for delivering environmental management on their land. Farmers must commit to the scheme for a minimum period of 5 years.

GLAS has a number of interlinked aims, which include:

- Protecting agricultural land, its habitats and biodiversity.
- Promoting environmentally sustainable methods of farming.
- Addressing issues of climate change mitigation, water quality and the preservation of habitats and species.
- Maintaining features such as traditional drystone walls and hedgerows.

The scheme's three key pillars include being

- Green - as it preserves traditional hay meadows and low-input pastures.
- Low-carbon - as it retains the carbon stocks in soil through margins, habitat preservation and practices such as minimum tillage.
- Agri-environment - as it promotes agricultural actions, which introduce or continue to apply agricultural production methods compatible with the protection of the environment, water quality, the landscape and its features, endangered species of flora and fauna and climate change mitigation.

All farmers in GLAS must comply with a list of mandatory core requirements, which aim to ensure that farmers have an enhanced level of environmental knowledge. Farmers must keep records of relevant actions delivered and must also have a plan for nutrient resource efficiency on their holding. They must also undergo training in environmental practices and standards.

[31] Citizens Information, 2016. Rural environmental schemes. Available at: http://www.citizensinformation.ie/en/environment/agriculture_and_forestry/rural_environmental_protection_scheme.html. Accessed 9 October 2017.

GLAS is structured into tiers and sub-tiers of funding based on the level of priority of the land that the farmer owns and the level of priority of the environmental actions that they take.

Some farmers undertaking particularly challenging actions may qualify for GLAS+, a mechanism to provide additional compensation in return for exceptional environmental commitment.

In general, the maximum GLAS payment is €5,000 per year. However, some farmers undertaking particularly challenging actions may qualify for GLAS+ and for a top-up payment of up to €2,000 per year.

For example, measures that address NFM include minimum tillage, planting a grove of native trees, planting new hedgerows and creating riparian margins[32].

6.3.3.2 Basic Payment and Greening Payment

The Basic Payment Scheme (BPS) replaced the Single Payment System in 2015 and it is a payment that must applied for annually[33]. In order to qualify under the Basic Payment Scheme, the farmer must have at least one entitlement linked to one hectare of eligible land and from there one hectare of eligible land declared equals one BPS entitlement activated for payment purposes. Land eligibility requirements include: agricultural activity must be the main activity on the land, there must be appropriate fencing, the land must be managed by the farmer and the land must be available to access by animals and/or machinery via a public or private roadway or by a defined right of way. The payment amount will be determined annually based on payments for the previous financial year, land area and the subsequent amount of entitlements but the minimum amount is 100 euros.

The Basic Payment is topped up by the Greening Payment which accounts for approximately 30% of the total payment[34]. The average greening payment is 100 euros per hectare. In order to receive the Greening Payment, farmers must adhere to greening obligations. However, the vast majority of farmers will not have to make any changes to their current farming practices to meet greening obligations because the requirements are mostly baseline to meet general farming standards.

Greening measures include:

- Crop diversification: If a farmer has 10 or more hectares of arable land, they will be required to sow a number of different crops (2 or 3) unless they qualify for an exemption.
- Ecological Focus Area (EFA): If a farmer has more than 15 hectares of arable land, they will need to declare at least 5% of Ecological Focus Area on their arable land unless they qualify for an exemption.

[32] Department of Agriculture, Food and Marine. GLAS Structure. Available at: https://www.agriculture.gov.ie/media/migration/farmingschemesandpayments/glastranche1/GLASStructure240215.pdf. Accessed 9 October 2017.
[33] The Irish Farmers Association, 2017. Basic Payment. Available at: https://www.ifa.ie/bps/#.Wds4AFtSzmE. Accessed 9 October 2017.
[34] The Irish Farmers Association, 2017. Greening. Available at: https://www.ifa.ie/greening/#.Wds9WFtSzmE. Accessed 9 October 2017.

- Protection of permanent grassland: This measure is managed at national level and so no requirement will be placed on individual farmers.

  However, if the ratio of permanent grassland to agricultural land in Ireland falls by more than 5%, farmers who have ploughed permanent grassland will have to reinstate it. This would also mean there would be restrictions on further ploughing.

- Environmentally sensitive grassland: Under this measure, permanent pasture designated as Environmentally Sensitive must not be ploughed or converted. In Ireland, these are specific areas within the Natural 2000 designated sites.

6.3.3.3 Result-Based Agri-Environment Payment Schemes

Results Based Agri-environmental Payment Schemes (RBAPS) in Ireland and Spain are a collaboration launched in 2014 and will run until 2018[35]. RBAPS award payments to farmers on the basis of the quality of the desired environmental outcome that is delivered. This contrasts with the standard schemes like GLAS and Basic Payment mentioned above, where payments are awarded for complying with certain conditions, whether prohibitions or mandatory actions.

With result-based schemes, the habitat condition is scored, with the highest payment awarded to the best quality habitat. Assessments are based on objective assessment criteria, which are chosen to reflect the overall biodiversity and ecological integrity of the habitat while also responding to agricultural management practices.

Result-based schemes may involve payments awarded solely on results achieved or may be a blended model with payments for ‘non-productive investments’ which support the delivery of biodiversity (e.g. removal of scrub encroaching on species-rich grassland; or creating a chick feeding area on important wading bird habitat); and can be complemented by some prescriptive elements where necessary.

By linking payments to assessment criteria (which indicate the quality of the biodiversity) RBAPS make it financially beneficial for participating farmers to gain an understanding of the conditions needed for delivery of the biodiversity. This creates a new market for biodiversity; where those farmers who better deliver market requirements can be better rewarded.

In Ireland, there are 31 farmers participating in the RBAPS project: 13 in County Leitrim and 18 in the Shannon Callows. These participants have entered almost 120 hectares of farmed habitats across 106 land parcels. In County Leitrim, the participants are creating either species-rich grassland or marsh fritillary butterfly habitat; on the Shannon Callows the options available to farmers are to create species-rich flood meadow or wet grassland suitable for breeding waders.

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[35] RBAPS Project. About this project. Available at: https://rbaps.eu/about/. Accessed 9 October 2017.

For all RBAPS measures in both 2016 and 2017, each management unit entered under RBAPS is assessed and given marks out of 10 based on the ecological quality of the habitat; payments are based on the annual scores.

6.4 Summary

In this section, a preliminary review of potential scheme delivery routes has been presented.

The review identifies the current policy and typical project delivery routes in the UK, along with the current policy and possible options for delivery and funding in the Irish context.

In general in the UK, it is not yet common practice for a statutory authority to enter private land to unilaterally carry out an NFM scheme. What is more common is that private landowners, individually or in local partnerships, would apply for funding to construct the works themselves. There are several funding sources for NFM available in the UK.

Delivery of an NFM scheme would be completely new in Ireland, and would require development of appropriate funding and institutional arrangements. Potentially NFM projects could be led by the Office of Public Works or the Local Authority with funding from the OPW flood risk management budget.

Alternatively, NFM projects could be led by individual landowners in partnership with a funding authority. However for such a scheme, there are currently no suitable funding sources for the promotion of NFM. There appears to be some potential for agri-environmental funding to play a role, however such funding would not be available on a scale to effect any major change to flood risk in Cork City.

Considering the various issues discussed above, a landowner-led delivery route would not be recommended if an NFM scheme on the Lee catchment were to be advanced. For a scheme to have reliable benefits, it would need to be delivered through a strong statutory mechanism such as the Arterial Drainage Act or the Planning Acts, accompanied by legal instruments granting powers of entry for construction and maintenance. Anything less robust carries a significant risk of the scheme not being fully deliverable, or falling into disrepair.

7 Responses to Key Questions raised through Statutory Exhibition Process

During the exhibition stage, members of the public were invited and encouraged to submit their views in relation to the preferred Scheme. Several submissions received suggested that Natural Flood Management (NFM) measures should be considered in further detail. The responses to key questions raised during the Statutory Exhibition Process are outlined below.

Question: Can the flooding problem be solved/mitigated by implementing natural flood risk (NFM) management measures upstream, including for example: Measures to slow or reroute water upstream; Planting for greater water absorption; Restoration of flood plains, woodlands and wetland/bogland/marshes.

Natural flood management (NFM) is the alteration, restoration or use of landscape features to reduce flood risk. NFM takes an 'engineered' approach to deliver many small landscape interventions that intercept and attenuate hydrological flow pathways to emulate natural processes and provide multiple benefits, including flood management and improving water quality. Put simply, the design philosophy is to create features that 'slow, store and filter' runoff and peak flow in the landscape.

This report presents the findings of an NFM opportunity/intervention mapping exercise within both the Upper and Lower Lee catchment. This information was then combined with high-level modelling to represent the impact of these NFM interventions for the River Lee Catchment to Cork. (Note that while the project brief assumed that flood mitigation measures would be contained within the Lower Lee catchment (i.e. downstream of Inniscarra dam), this analysis has also assessed potential measures in the Upper Lee catchment.)

The scale of intervention studied here is between 10 and 100 times larger than any other such scheme that has successfully been implemented. Such a project could involve several hundred landowners and several different management authorities. This also assumes that all landowners are amenable to the proposed features, which would require extensive change of use of large tracts of private lands. This would be very difficult to achieve logistically, both for construction and how the scheme could be reliably monitored and maintained in the long term.

The detailed assessment of the Lee Catchment concluded that approximately 5,000 potential NFM interventions combined would still only reduce the 100 year flow at Waterworks Weir by between 0.5 - 4.5%. This would have negligible effects on defence heights in the city and in fact, it identified that there was a risk that NFM measures could give rise to a potential for delayed peak flows on Shournagh which could actually increase flood risk in Cork.

This report also investigated the decrease in forest cover and increase in pasture within the River Lee Catchment. There is little measured evidence to suggest that this has led to an increase in flood hazard in the River Lee Catchment.

At other locations, literature has shown that land cover has the potential to control runoff rates for the small catchment scale and, in particular, relatively low intensity storm events. However in this case, it is noted that the River Lee Catchment at Waterworks Weir is approximately 1,200km^2 and the event being considered is a 1 in 100 year return period.

In conclusion implementation of NFM measures is not a technically feasible alternative for the flood risk management for Cork city or even in combination with other measures.

Question: Has the River Lee catchment been considered in full, from source to sea, for suitable NFM solutions to resolve the flooding issue?

Under the headings of Land Use management and storage, Natural Flood Management (NFM) measures were screened out as part of the Lower Lee FRS Options Report, as they have limited benefit in large catchments and for large events. The scale of reduction in design flow needed to avoid the need for direct defences in Cork cannot be delivered by NFM. In addition, the reservoirs already provide far greater attenuation than can be provided by NFM and would negate changes arising from NFM measures.

Notwithstanding this, in response to the large number of submissions received, OPW and its consultants have undertaken a further assessment of the applicability of NFM measures in the context of Cork to provide further information to the public explaining why they are not a viable solution. The findings are included in this report.

Question: Are there funding or grant-based incentives available to landowners for water absorption or diversion schemes (NFM measures)?

Currently the only available source of funding for landowners for environmental management of their land appears to be agri-environmental funding (e.g. measures that address NFM include minimum tillage, planting a grove of native trees, planting new hedgerows and creating riparian margins). This funding is unlikely to be suitable at the scale required to effect significant change.

Question: Have other NFM schemes in the UK/Europe been studied and aspects considered for implementation on this project?

As outlined in this report, natural flood management measures have been found to be effective in small local scale schemes in upstream headwaters at lower return periods. However, the size of the catchment in the case of the River Lee under assessment is far larger than would typically be encountered in an NFM study (by a factor of approximately 10 - 100 times), and it has been found that NFM measures have limited benefit at larger scales and at higher return periods.

Question: Suggestion that the Gearagh could be used for flow management.

The Gearagh is significantly upstream of Cork city and any NFM intervention at this location would have minimal/no impact on reduction of peak flow at the Waterworks Weir.

In addition, the reservoirs already provide far greater attenuation than can be provided by NFM and would negate changes arising from any NFM measures.

Furthermore, the Gearagh is a designated environmental site of international importance and so it is unlikely that significant NFM measures could be undertaken without impacted the site.

8 Conclusion

This report has assessed the options for reducing extreme fluvial flows entering Cork city through implementation of Natural Flood Management measures in the upstream catchment. It has been prepared in response to submissions received through the statutory exhibition process for the Lower Lee (Cork City) Drainage Scheme (flood relief scheme).

The following issues should be noted when interpreting this report:

- The report has generally taken a "no-constraints" approach in terms of the scale and practicality of the NFM interventions. However, the scale of intervention studied here is between 10 and 100 times larger than any other such scheme that has successfully been implemented. Such a project could involve several hundred landowners and several different management authorities. This raised concerns as to how the scheme could be reliably monitored and maintained in the long term. Furthermore, even if the scheme could be implemented, modelling indicates that the reduction in flood risk at Cork would be very small.
- The modelling assumes a series of well-designed attenuation storage features, which 'target' peak flow in the river catchment. Achieving this level of design on a smaller catchment may be feasible. However, more than 5,000 features over a catchment area of 1,200km^2 presents a difficult task.
- In the context of flows at Cork city, the achievable benefit of NFM measures has been shown to be sensitive to a number of factors including rainfall patterns and relative timings of tributary flood peaks. In particular, there is a risk that implementation of NFM on the Lower Lee tributaries would result in synchronisation of the flood peaks with the main Lee and therefore worsen flood risk in the city.
- The representation of Carrigadrohid and Inniscarra reservoirs has been simplified for the modelling of NFM. It is possible that more detailed modelling of the reservoirs may show a much lower benefit resulting from NFM in the Upper Lee catchment.
- The flood risk mapping data used for the study is potentially limited in accuracy. However, it allows for a comparison of risk throughout the catchment.
- Only one return interval has been modelled in the simulations (the 1 in 100 year return period event). As peak flow is 'targeted' by interventions different return periods will have varying levels of reduction in peak flow resulting from NFM.
- The modelling carried out for this study has demonstrated that NFM has the potential to reduce extreme flows locally within individual tributary sub-catchments, within the range 10% - 20%, based on a number of high-level modelled scenarios. This is potentially significant when considering flood risk receptors local to those sub-catchments.

- However, the modelling concluded that almost 5000 potential interventions would only be capable of reducing flows entering Cork City at Waterworks Weir within the range 0.5% - 4.5%. This would have negligible effects on defence heights in the city and in fact, it identified that there was a risk that NFM measures could give rise to a potential for delayed peak flows on Shournagh which could actually increase flood risk in Cork.

Therefore, it is evident that a Natural Flood Management solution is not technically viable as an alternative to the proposed scheme or even in combination with other measures.

Appendix A

Glossary of NFM Features

A1 Glossary of NFM Features

The following headings introduce the NFM features considered in this analysis.

A1.1 Floodplain

A1.1.1 Floodplain Reconnection

Some large areas of floodplain are disconnected from interaction with adjacent watercourses. Where suitable, these areas can be reconnected with the river channel to promote floodplain function and natural attenuation.

Reconnecting the floodplain involves removing raised embankments which will allow the river to flood naturally. If this is not appropriate for flood defence reasons but there is a sufficiently wide corridor then the embankments could be set back to increase floodplain area. This has an additional benefit that usually set back embankments can be lower than ones along the river bank, which means that they are cheaper to build or maintain. Therefore this should be considered in cases where existing embankments need to be replaced.

Note: Where re-connection with floodplains or maximising floodplain storage are discussed, the timing of when this storage is available is of extreme importance. An area of floodplain that becomes active too early in a storm event may already reach capacity by the time the flood peak arrives. An incised channel that conveys flood peaks past floodplains without interaction achieves a similar effect. The target level of protection needs to drive the timing of floodplain interaction. When designing for a 1 in X year flood event, it is critical to make sure the floodplain is capable of storing a proportion of the flood peak.

A1.1.2 Offline Attenuation Features

These are ponds or water storage areas which are constructed away from the stream (Figure 46). Peak flows can be diverted out of the watercourse and into a storage pond. This is done using a barrier across the stream which allows normal flows to pass but causes peak water levels to spill out of the bank, which has been lowered to a predetermined flood level. This water is then directed into the storage area by reprofiling the ground into an informal channel. The route taken should be as long as possible to slow the water and thereby increase attenuation. The storage can be in the form of a pond contained within a soil bund or wooden structure. This structure should gradually leak allowing the water to pass back into the stream once the peak flow has passed.

Figure 46: Offline diversion pond in Belford tapping peak flow from the river

A1.1.3 Optimise Floodplain Storage

Existing floodplain, which is able to interact with the watercourse, can have increased capacity if natural flood storage areas are less than required to deliver flood risk benefits. Increasing the capacity gives greater attenuation effects of an existing flood reduction measure[36]. Methods of achieving this involve strategic placement of earth bunds (see Figure 47 and Figure 48) or other simple landscaping techniques to slow the water flowing over the floodplain. Planting of hedges can also achieve similar results.

[36] National Trust (2015). From source to sea: Natural Flood Management – The Holnicote Experience. Defra Multi-objective Flood Management Demonstration project

Figure 47: Shallow storage bund from Holnicote Source to Sea (copyright JBA Consulting)

Figure 48: Floodplain meadows from Holnicote Source to Sea (copyright UK National Trust)

A1.2 Capture Overland Flow

When heavy rainfall hits either dry or saturated ground in the catchment, runoff is greatly increased. This surface water is transferred to the watercourses very rapidly and can lead to a significant rise in water levels downstream. This rapid change results in the flashy nature of some WBs.

This surface water can be slowed or diverted which will prevent the rapid transference of rainwater into the streams and further help by reducing the amount of sediment or pollutants entering the river. This can be done by building low bunds or other ground reprofiling to disconnect the pathways and divert them into low points, ponds, buffer zones or woodlands.

https://research.ncl.ac.uk/proactive/belford/papers/Runoff_Attenuation_Features_Handbook_final.pdf

Pathways can be identified using LiDAR or analysis of contours, however the most effective method is a site visit during heavy rainfall. Flow pathways can be broken up using soil bunds or wooden barriers

A1.2.1 Interception Bunds

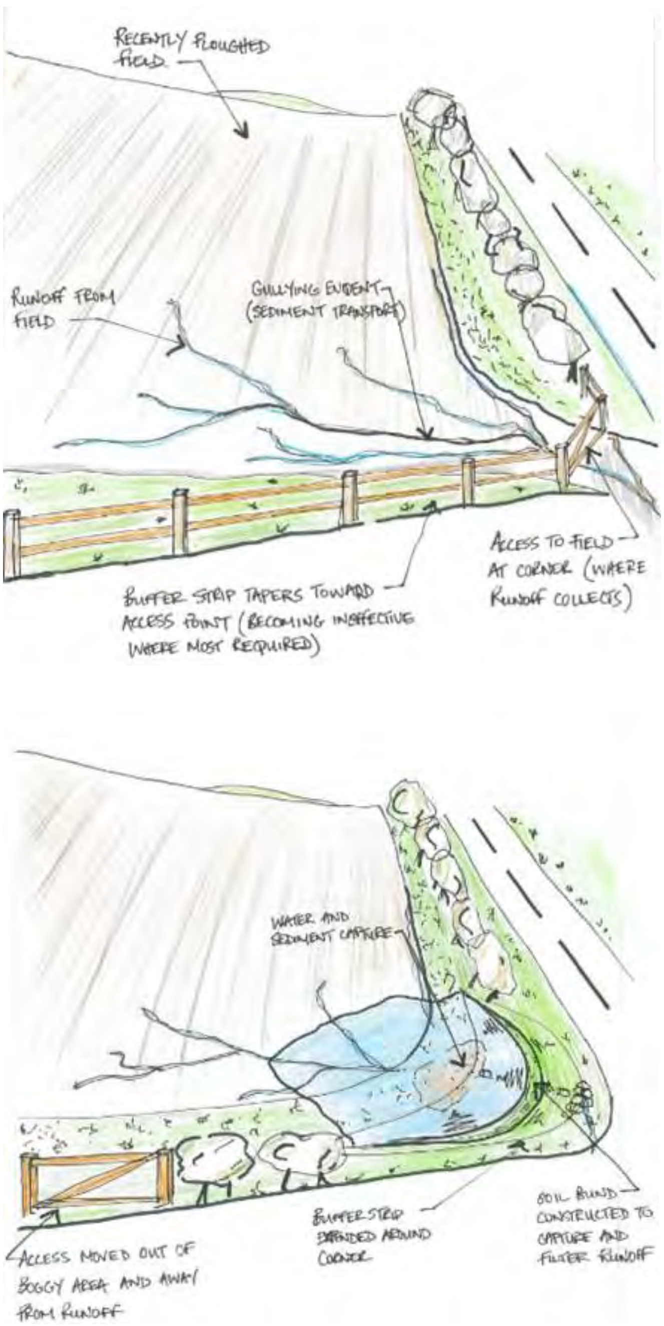
The creation of a bund (soil, wood or stone barrier) across a flow path will slow the propagation of runoff and create temporary storage. These features are designed to drain slowly; the barrier may be 'leaky', have an outlet drainage pipe installed, or often incorporates both of these options. Figure 49 shows a road that was constructed for the farmer, which also reduced the problem of driving across saturated ground. The feature also acts as a sediment trap for the runoff generated in the arable field uphill.

Figure 49: Overland flow interception bund in Belford slowing the movement of runoff as it flows downhill

A1.2.2 Corner of Field Bunds

Overland flow over bare soil, either from recently ploughed/drilled arable land or heavily poached livestock fields, should be slowed both to reduce peak flows entering the watercourses but also to prevent sediment ingress. If the field slopes in such a way that overland flow is channelled through a narrow section or corner a bund can be built to trap it and form a pond or pool behind. This will both slow the water and allow sediment to settle and can then be dug out and spread back on the field. This is shown in a conceptual diagram in Figure 50.

Table 28: Conceptual sketch of corner of field bund for capturing overland flow.



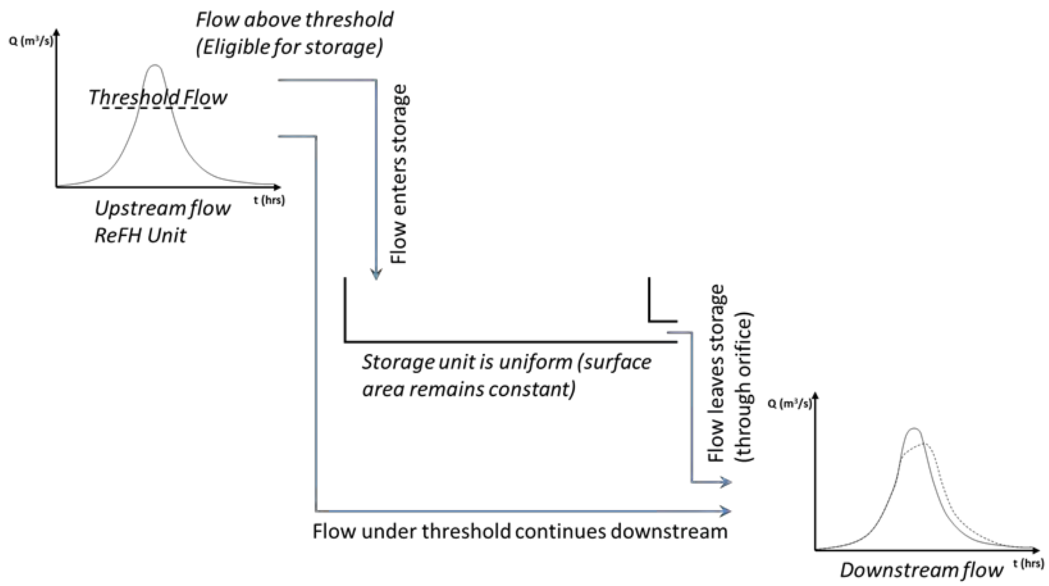
Appendix B

Storage Modelling Concept and ‘Threshold Flow’

B1 Storage Modelling Concept and 'Threshold Flow'

The NFM optioneering tool was developed to assess the synchronicity of flows from each of the sub-catchments in a wider catchment area. The tool allows the user to allocate a total (or aggregate) storage volume to each of the sub-catchments to assess the impact of storage on both the selected sub-catchment and the total downstream flow at the point of interest. The total storage may be made up of a number of feasibly-sized 'ponds' (or pond objects). The ponds are an essential component of the storage unit as the number of attenuation features dictates how rapidly the storage unit can drain. Mass-balance is conserved with the tool. Figure 51 shows a conceptual schematic, similar to a linear storage (bucket) model[37], which demonstrates the role of storage units within the tool.

Figure 50: Conceptual model schematic of storage units



The tool assesses the aggregate effects of new storage being added to sub-catchments in the form of attenuation. The tool simulates the effect of the total feasible storage quantities in a given sub-catchment (based on the mapped interventions), utilising a user-defined 'Threshold Flow'. The threshold flow is an absolute value that, once exceeded, will allow a percentage of flow to enter the storage unit. A graph within the analysis tool shows the performance of the storage unit in the current configuration and allows the user to change the threshold flow and the number of ponds until they are satisfied that the storage unit is performing correctly within the sub-catchment. In this case, the storage volumes (and number of ponds) identified in the mapping exercise were allocated to each sub-catchment.

[37] Nash, J. E. (1957). "The form of instantaneous unit hydrograph." Int. Assn. Sci. Hydro. Publ. No. 51, 546-557, IAHS, Gentbrugge, Belgium.

The Threshold Flow was determined iteratively by allowing increasing flow (from the 1 in 100-year design storm) to enter the storage unit. The most efficient scenario is when the Threshold Flow is low enough to allow the storage unit to fill significantly, but high enough to prevent it becoming entirely full.

Inflow Condition

As described above, the threshold flow is iteratively calculated using the high-level analysis tool (alongside the storage unit volume and number of ponds). The inflow condition is such that once flow in the upstream channel exceeds the threshold, anything above the threshold is eligible to enter the storage unit using Equation 1, where C_d is a coefficient of discharge for flow entering the storage area (as it is unlikely an intake structure would be 100% efficient), Q_{HBU} is the flow from the upstream hydrological boundary unit, and $Q_{threshold}$ is the flow at which, once exceeded, water is able to enter the storage unit. In this case the C_d value is 0.8, which means that when the storage unit is filling (when the threshold flow is exceeded) 20% of the flow above the threshold will continue downstream (along with all flow under the threshold and the outflow from the storage unit)[38].

Equation 1:

$$Q_{in} = C_d.(Q_{HBU} - Q_{threshold})$$

Storage Unit

The storage unit can be iteratively calculated using the high-level analysis tool. In this case, however, the feasible storage capable of being stored in the sub-catchments was assessed, using the mapping analysis, prior to this stage. Evidence gained from the Belford study and Doctoral Research in Newcastle University have shown this approach to be valid and representative of the monitored impact of NFM interventions[39]. To achieve more or less impact, the storage unit is increased or decreased in magnitude. A linear relationship exists between the area and maximum height of the storage unit. If, for example, the maximum height of the storage unit is 1m and the maximum area is 10,000m^2, then at 0.5m depth, the volume will be 5,000m^3 and at 1m depth the volume will be 10,000m^3.

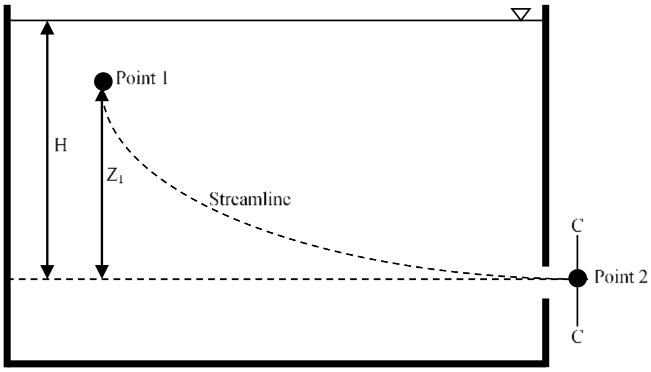
Outflow Conditions

The outflow condition from the storage unit is simulated using a generic formula, which is based on hydrostatic flow through a small orifice to ensure model transferability to similar storage types.

[38] Nicholson, A. R., 2013. Quantifying and simulating the impact of flood mitigation features in a small rural catchment. Available at https://theses.ncl.ac.uk/dspace/handle/10443/2382
[39] Quinn, P. F., et al., 2013. Potential Use of Runoff Attenuation Features in Small Rural Catchments for Flood Mitigation

It assumes that the water inside the storage unit is static; a similar assumption is made in engineering studies on lakes and reservoirs despite discharge currents being present in the water body (Figure 52).

Figure 51: Diagram showing flow through a small orifice



Equation 2 describes the outflow[40] where 'a' is the cross sectional area of the orifice (m^2), 'H' is the depth of water in the storage unit (m), 'g' is acceleration due to gravity (m/s^2), and 'C_d', the coefficient of discharge through the outlet pipe, which is given by Equation 3.

Equation 2:

$$Q_{out} = C_d . a\sqrt{2gH}$$

Equation 3:

$$C_d = C_c C_v$$

C_v, the coefficient of velocity, is given by Equation 4.

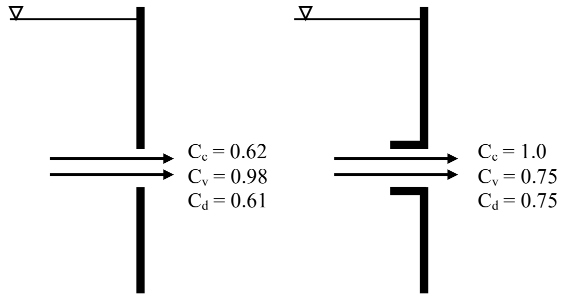
Equation 4:

$$C_v = \frac{actual\ velocity\ at\ vena\ contracta}{ideal\ velocity\ at\ vena\ contracta}$$

Sample values of C_d for a negligible approach velocity for a bevelled small orifice and a Borda's (re-entrant) mouthpiece are shown in Figure 52 (Marriot, Featherstone, & Nalluri, 2009). Typically, C_d can range between 0.61 and 0.75.

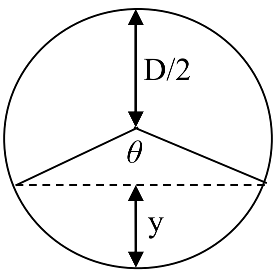
40 Marriot, M. J., Featherstone, R. E., & Nalluri, C. (2009). *Nalluri & Featherstone's civil engineering hydraulics: essential theory with worked examples* (Vol. 5). Chichester, West Sussex, United Kingdom: John Wiley & Sons Ltd.

Figure 52: Diagram showing typical values for C_d: Left – Bevelled orifice; Right – Borda's (re-entrant) mouthpiece



A function for a partially submerged outflow pipe allows for a more accurate assessment of outflow from the storage. Figure 53 and the equations that follow show water at level y in the outflow pipe. The angle (θ) between the pipe centre and the water level at the edges of the pipe is used to determine the submerged area of the pipe. The equation for angle θ is given in Equation 5 and Equation 6.

Figure 53: Partially submerged pipe



Equation 5:

$$\theta = 2\cos^{-1}\left[\frac{\frac{D}{2} - y}{\frac{D}{2}}\right] \; if \; y < \frac{D}{2}$$

Equation 6:

$$\theta = 2\pi + 2\cos^{-1}\left[\frac{\frac{D}{2} - y}{\frac{D}{2}}\right] \; if \; y > \frac{D}{2}$$

The equations above allow the angle between the centre of a partially submerged pipe and the water level to be determined. The effective area of the pipe can then be calculated using the equation (from Chadwick & Morfett, 1986):

Equation 7:

$$a = \frac{D^2}{8}(\theta - \sin\theta)$$

The effective area (a) is used in the outflow equation to accurately represent flow through the outflow pipe at low water levels. The outflow from the storage unit is a function of the water level and submerged pipe area.

Equation 8:

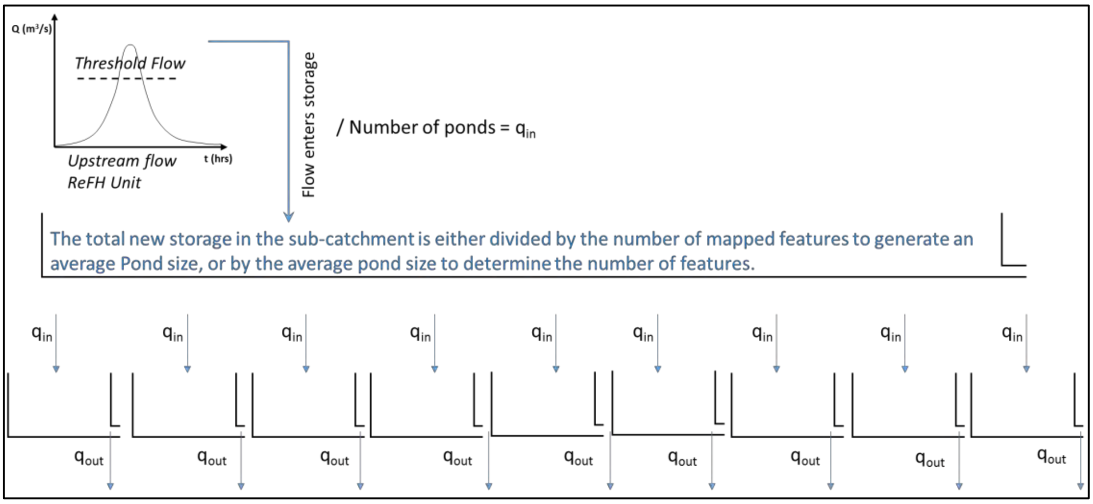
$$q_{out} = C_d . a\sqrt{2gH}$$

The number of mapped features plays an important role in the representation of total storage. The total storage uses the number of ponds to create a 'mean pond size' (Figure 54).

Equation 9:

$$Q_{out} = \sum q_{out}$$

Figure 54: Representation of outflow from a collection of mean ponds (Qout = Σqout where qout = Cd . A . SQRT(2gh) and qin = Qin / No of Ponds)



The mitigated (Q_{mit}) flow for the sub-catchments is determined using Equation 10.

Equation 10:

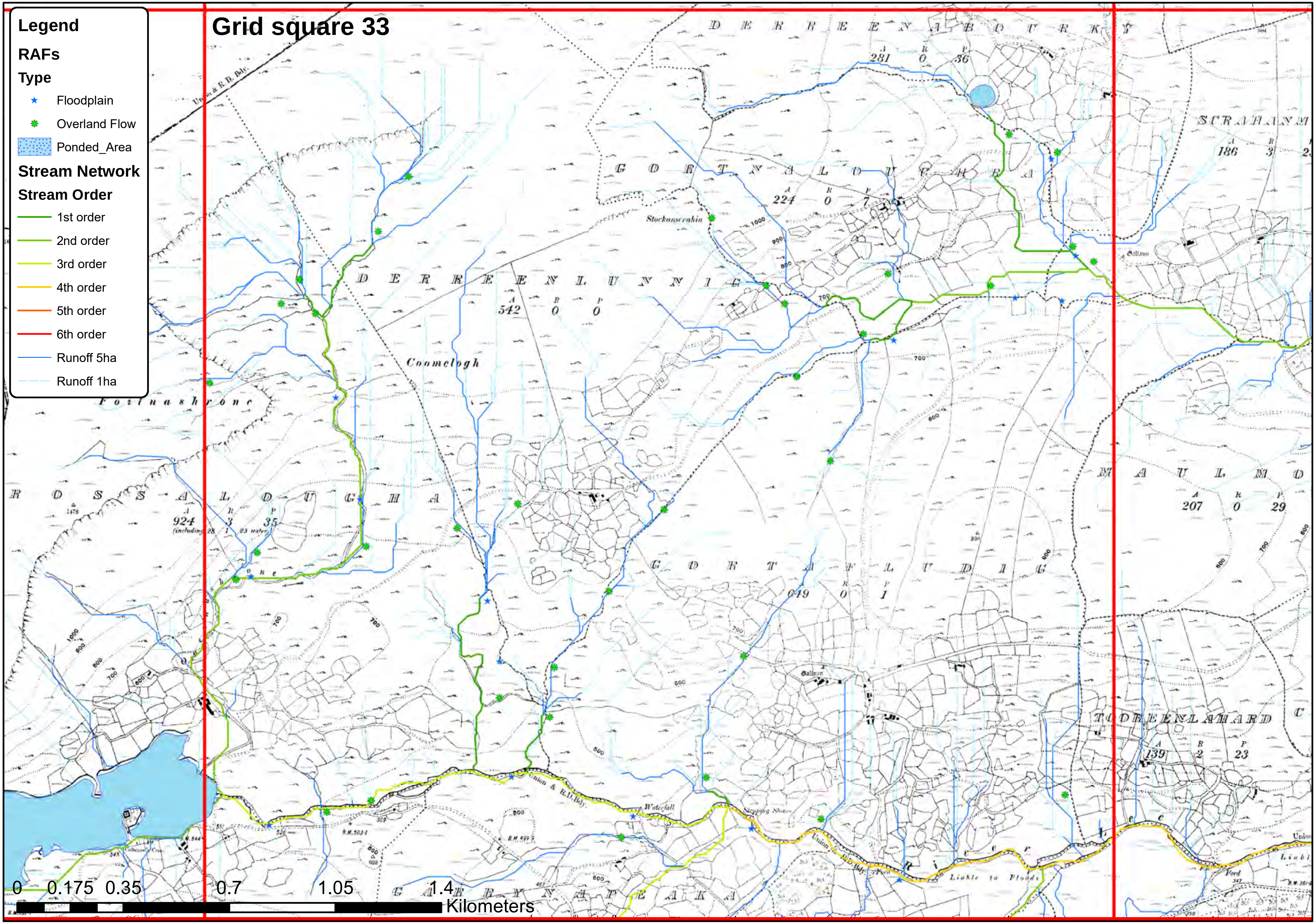
$$Q_{mit} = Q_{HBU} - Q_{in} + Q_{out}$$

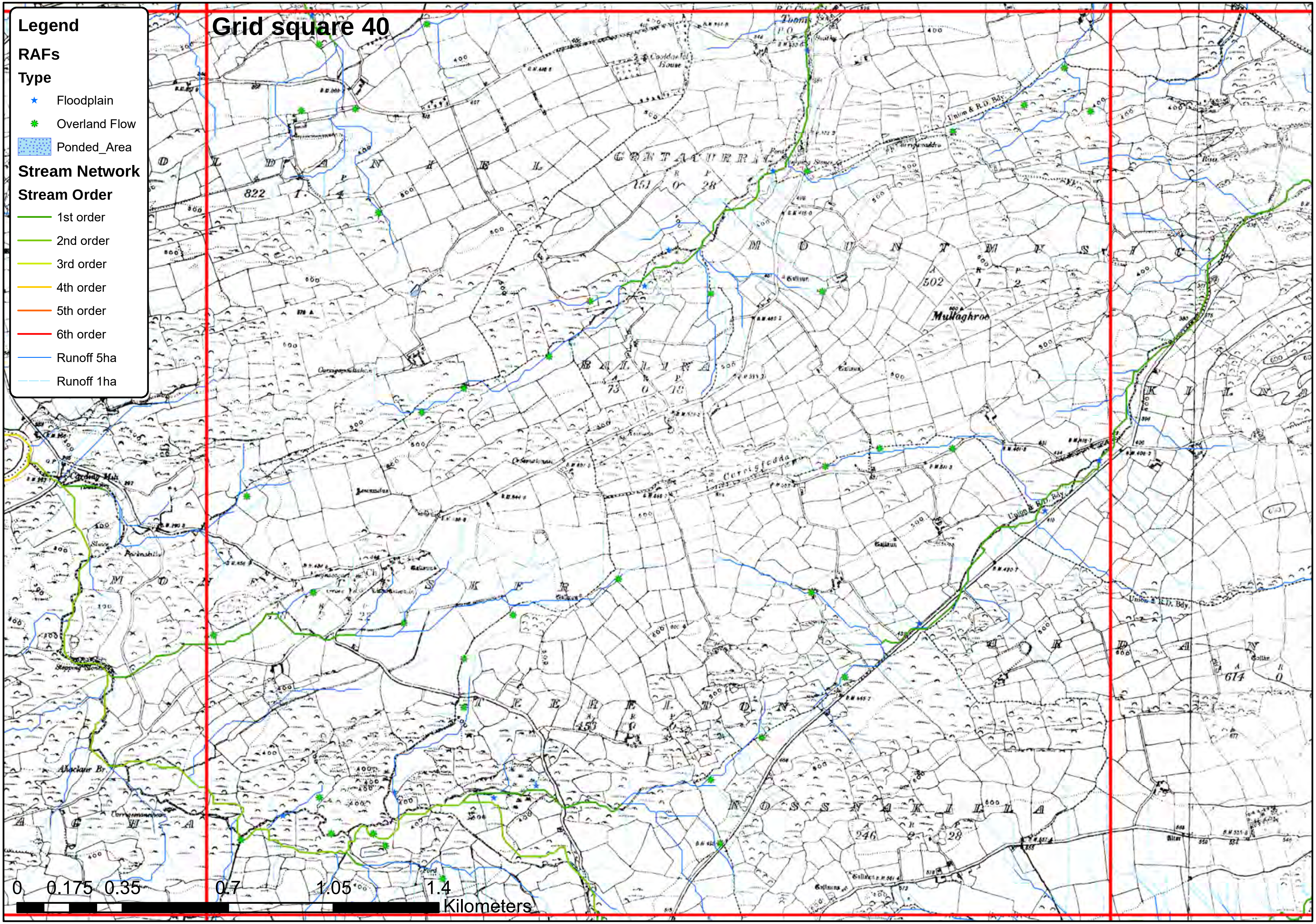
Note: This theory is not meant to be definitive, but the equations and storage function do control the simulations to reasonable physical constraints.

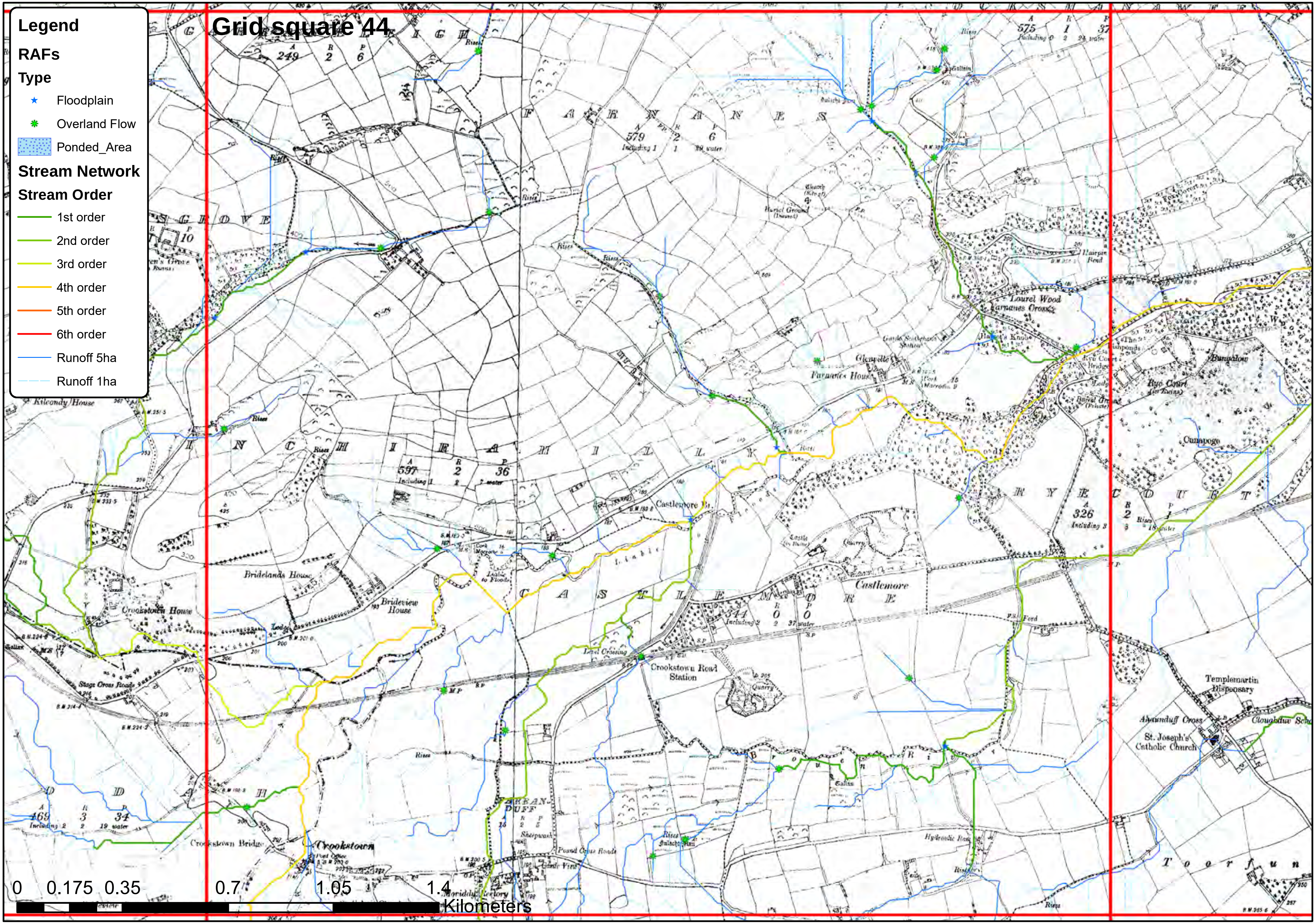
For this theoretical representation any NFM feature gives attenuation. Attenuation yields storage. Storage is mimicked/emulated through a 'pond' object.

Appendix C

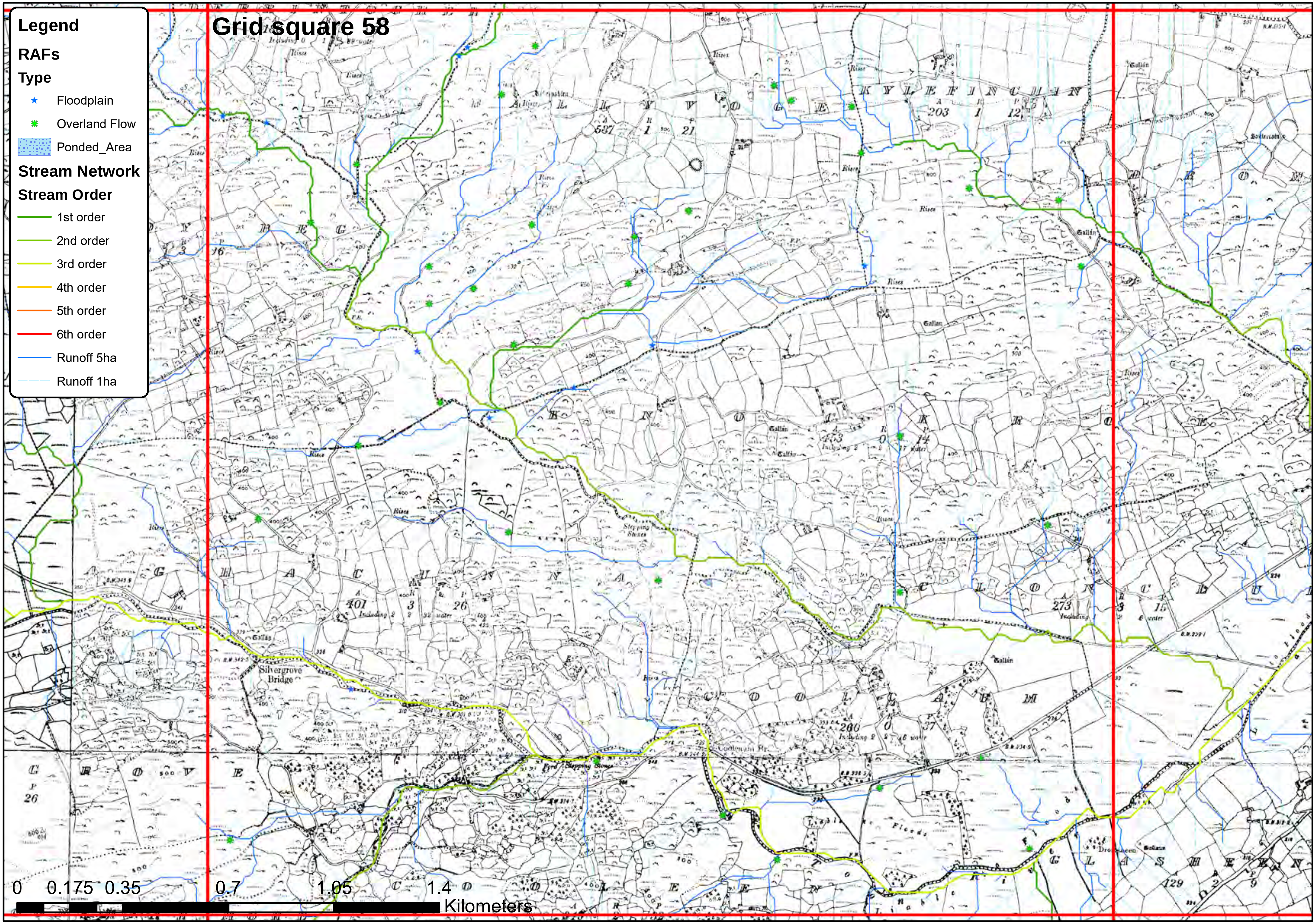
NFM Mapping of Selected Grid Squares

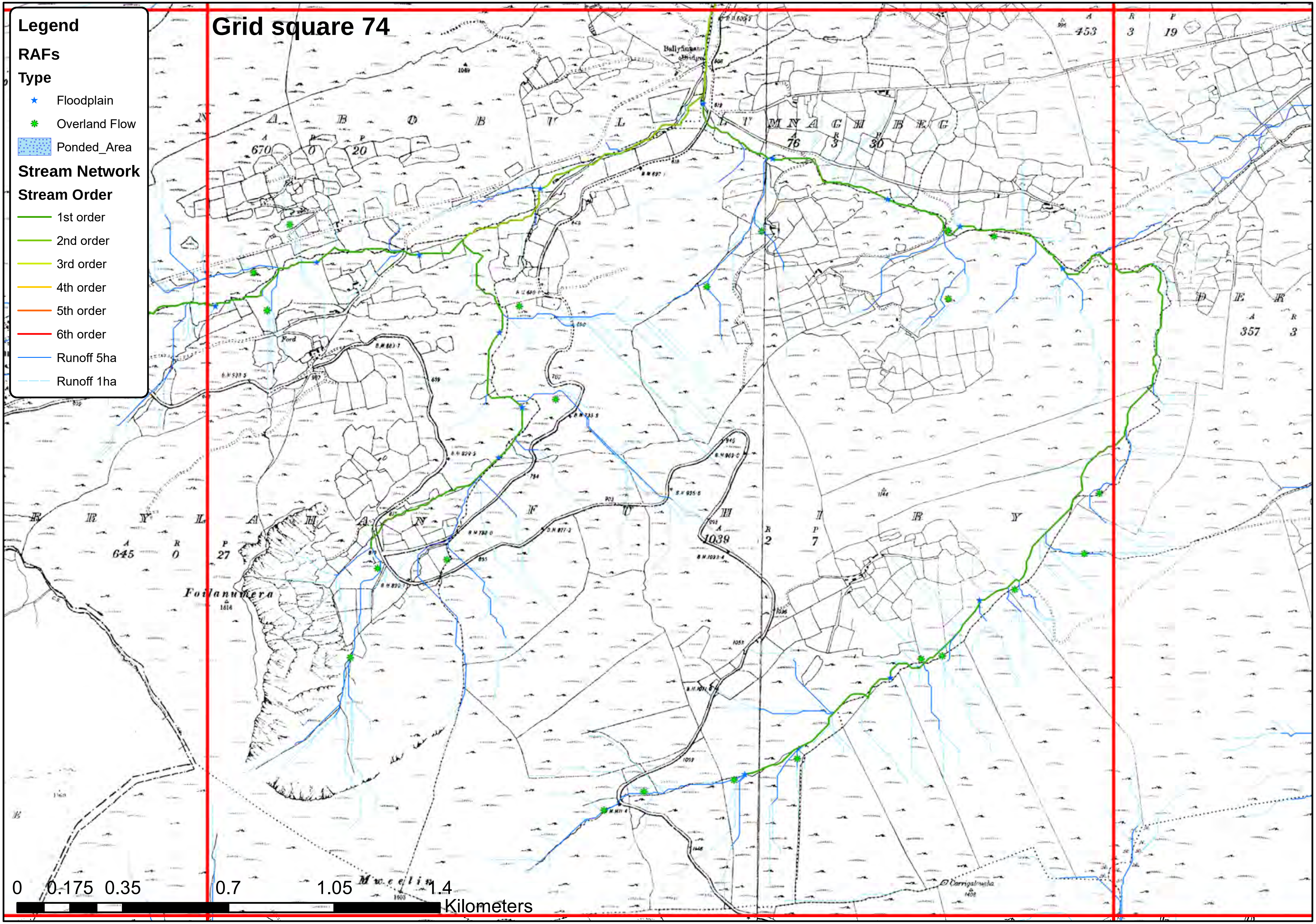

Grid square 33
Legend
RAFs
Type
Floodplain
Overland Flow
Ponded_Area
Stream Network
Stream Order
1st order
2nd order
3rd order
4th order
5th order
6th order
Runoff 5ha
Runoff 1ha
0 0.175 0.35 0.7 1.05 1.4
Kilometers
Coomelogh
Storkanscrahin
Waterfall
Stepping Stones
Liable to Floods
Union & R.D. Bdy.
Gallaun
Ford


Grid square 40
Legend
RAFs
Type
Floodplain
Overland Flow
Ponded_Area
Stream Network
Stream Order
1st order
2nd order
3rd order
4th order
5th order
6th order
Runoff 5ha
Runoff 1ha
Mullaghroe
0 0.175 0.35 0.7 1.05 1.4
Kilometers



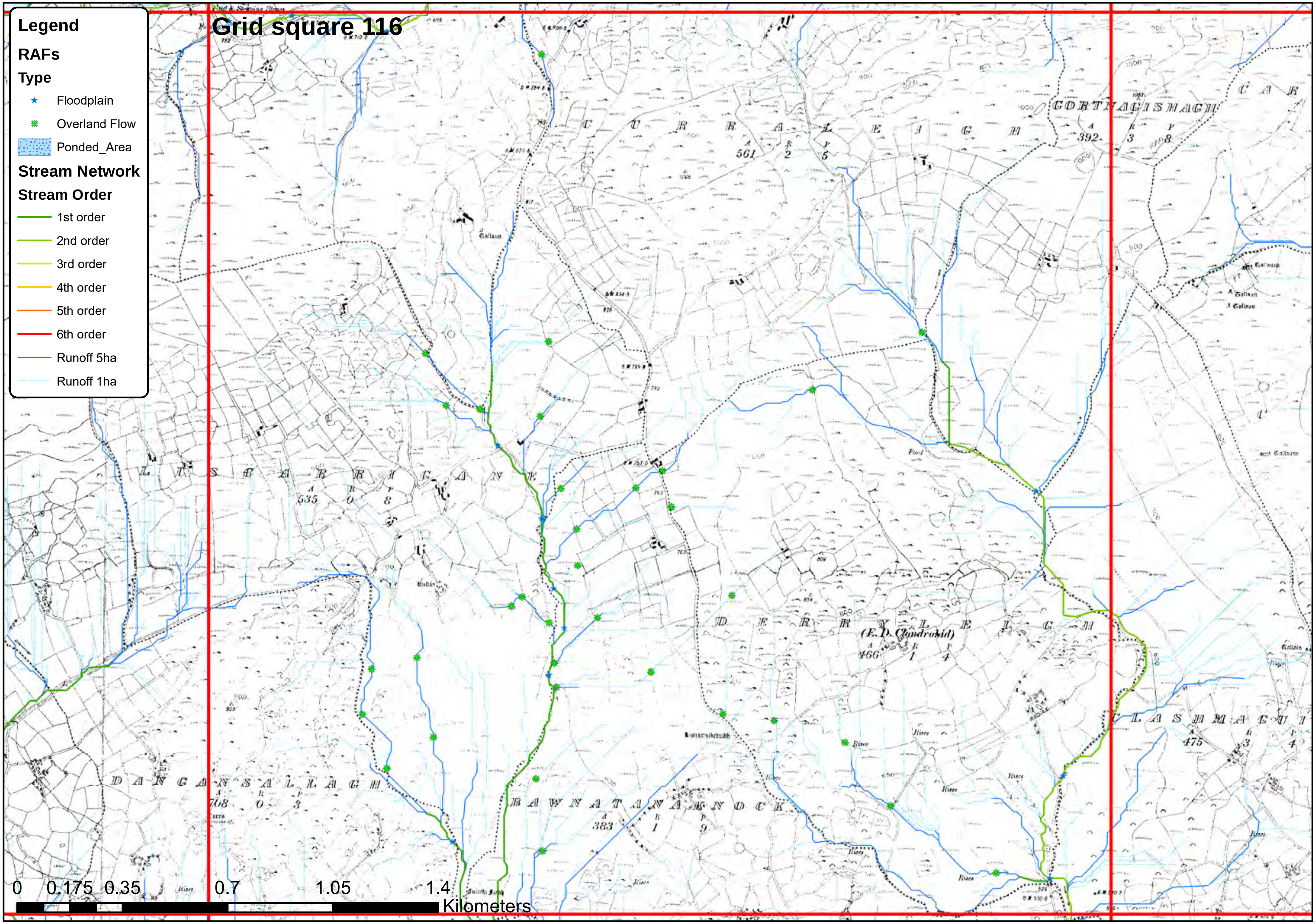
Grid square 44
Legend
RAFs
Type
Floodplain
Overland Flow
Ponded_Area
Stream Network
Stream Order
1st order
2nd order
3rd order
4th order
5th order
6th order
Runoff 5ha
Runoff 1ha
0 0.175 0.35 0.7 1.05 1.4
Kilometers
Crookstown Road Station
Castlemore
Crookstown
Templemartin Dispensary
St. Joseph's Catholic Church
Farnanes Cross
Laurel Wood
Rye Court
Bridelands House
Brideview House
Crookstown House
Glenville
Farnanes House

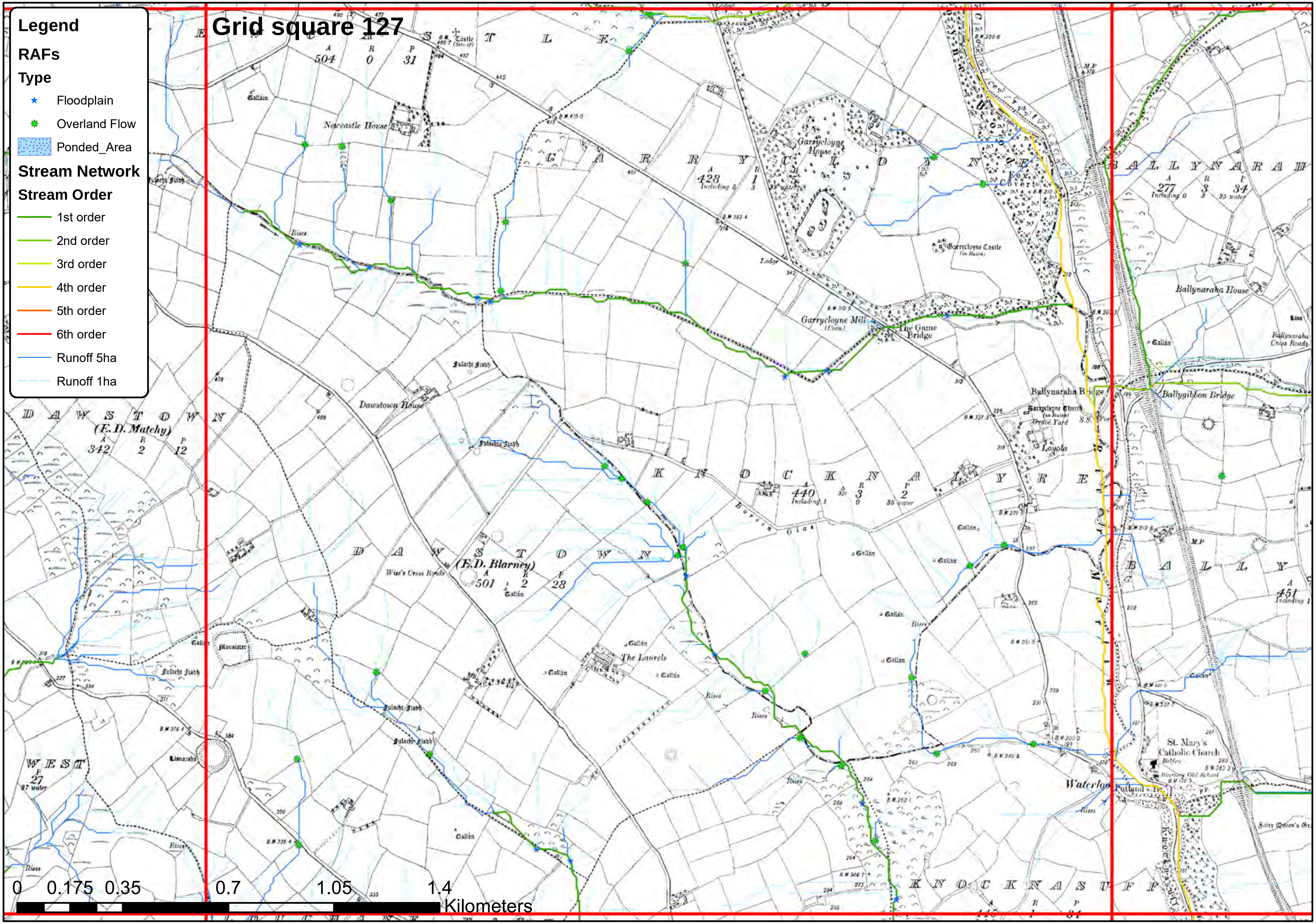

Grid square 58
Legend
RAFs
Type
Floodplain
Overland Flow
Ponded_Area
Stream Network
Stream Order
1st order
2nd order
3rd order
4th order
5th order
6th order
Runoff 5ha
Runoff 1ha
0 0.175 0.35 0.7 1.05 1.4
Kilometers
Silvergrove Bridge

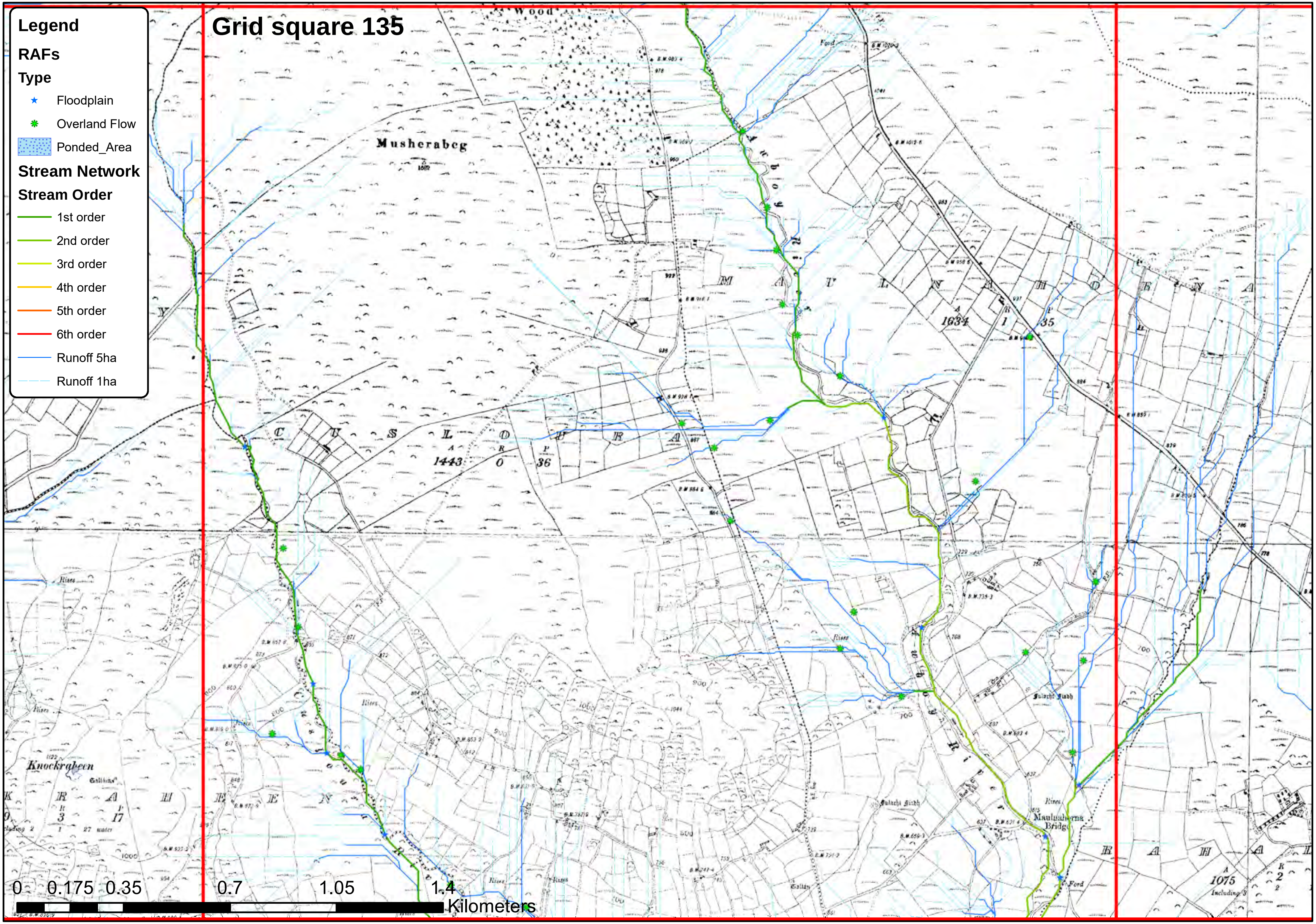


Grid square 74
Legend
RAFs
Type
Floodplain
Overland Flow
Ponded_Area
Stream Network
Stream Order
1st order
2nd order
3rd order
4th order
5th order
6th order
Runoff 5ha
Runoff 1ha
0 0.175 0.35 0.7 1.05 1.4
Kilometers

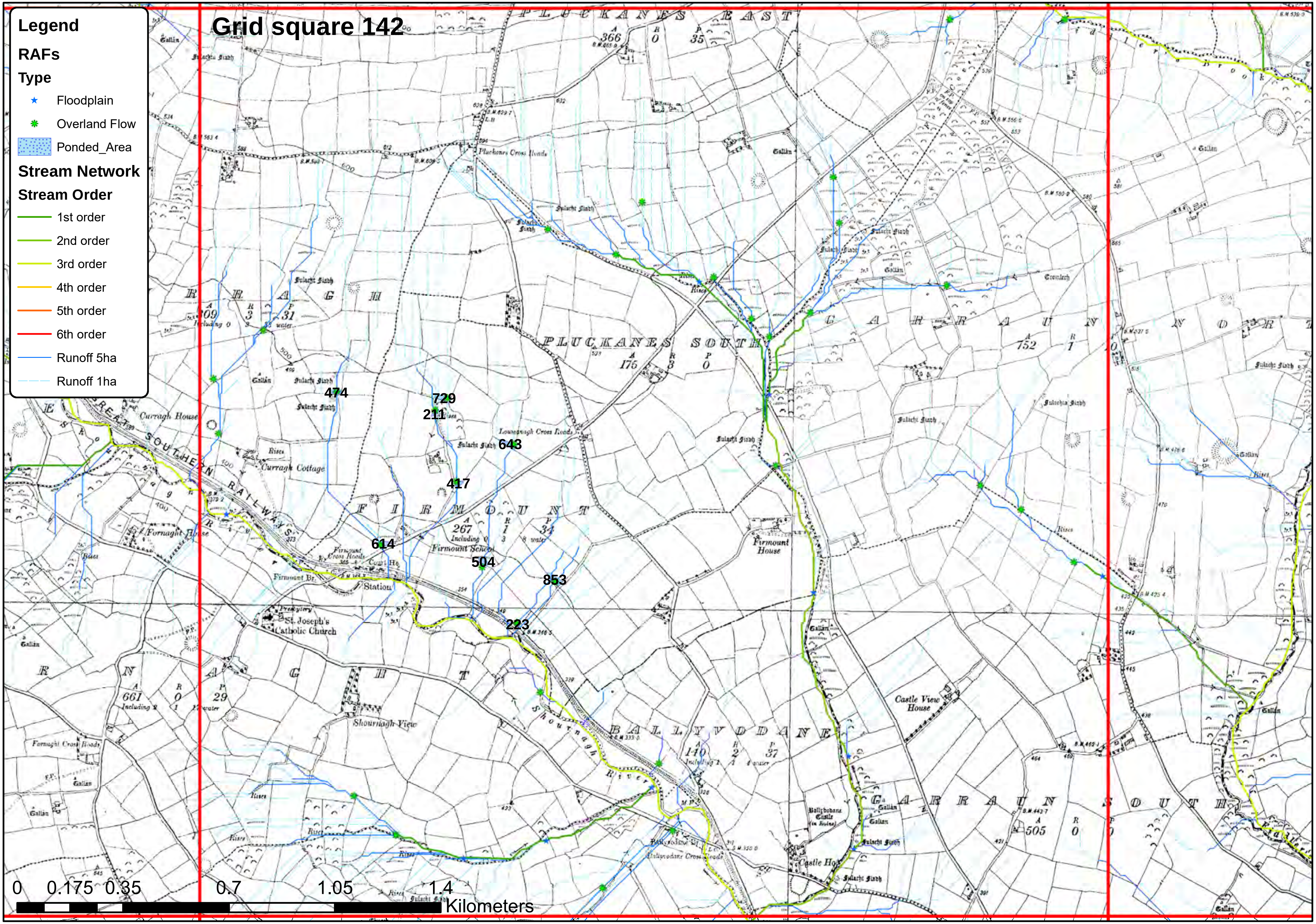

Grid square 85
Legend
RAFs
Type
Floodplain
Overland Flow
Ponded_Area
Stream Network
Stream Order
1st order
2nd order
3rd order
4th order
5th order
6th order
Runoff 5ha
Runoff 1ha
0 0.175 0.35 0.7 1.05 1.4
Kilometers
Coachford
Clontead School
Clontead House
St. John's Catholic Ch.
Christ Church
Green Lodge
Leemount
Lakefield
Oldtown House
Drohideenacloghduff
Broom Hill
Shandy Hall
Kill Abbey
Dripsey Br.
Godfrey's Cross Roads
Riversdale House
Windpump
Classas


Grid square 116
Legend
RAFs
Type
Floodplain
Overland Flow
Ponded_Area
Stream Network
Stream Order
1st order
2nd order
3rd order
4th order
5th order
6th order
Runoff 5ha
Runoff 1ha
0 0.175 0.35 0.7 1.05 1.4
Kilometers


Grid square 127
Legend
RAFs
Type
Floodplain
Overland Flow
Ponded_Area
Stream Network
Stream Order
1st order
2nd order
3rd order
4th order
5th order
6th order
Runoff 5ha
Runoff 1ha
0 0.175 0.35 0.7 1.05 1.4
Kilometers
Newcastle House
Garrycloyne House
Garrycloyne Castle (in Ruins)
Garrycloyne Mill (Corn)
The Game Bridge
Dawstown House
Ballynaraha House
Ballynaraha Bridge
Ballygibbon Bridge
The Laurels
Loyola
St. Mary's Catholic Church
Waterloo
Monaster
Lisnaraha



Grid square 135
Legend
RAFs
Type
Floodplain
Overland Flow
Ponded_Area
Stream Network
Stream Order
1st order
2nd order
3rd order
4th order
5th order
6th order
Runoff 5ha
Runoff 1ha
Musherabeg
Knockrabeen
Maulnaherna Bridge
0 0.175 0.35 0.7 1.05 1.4
Kilometers



Grid square 142
Legend
RAFs
Type
Floodplain
Overland Flow
Ponded_Area
Stream Network
Stream Order
1st order
2nd order
3rd order
4th order
5th order
6th order
Runoff 5ha
Runoff 1ha
474
729
211
643
417
614
504
853
223
0
0.175
0.35
0.7
1.05
1.4
Kilometers