Identifying and prioritising landscape-based surface water management interventions in the Winford Brook catchment

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Abstract

In response to the UK’s severe flooding events of 2007, and the resulting publication of the Pitt Review, there has been a shift from engineered flood defences aimed at keeping flood water in channels through towns and cities, to landscape-based measures aimed at storing or delaying flood water further up the catchment. This is often called working with natural processes, or natural flood management.

The Winford Brook catchment south of Bristol has a history of flooding. It also suffers from soil erosion, causing sedimentation in the local reservoir and high phosphate levels in watercourses. These problems have one thing in common: surface water runoff.

Engineered flood defences have been largely ruled out, but landscape-based measures offer an alternative solution. Case studies of catchments have identified woodland planting, large woody debris dams, runoff retention ponds and buffer strips as interventions that could act to reduce flood risk and manage soil erosion through control of surface water.

Rainfall runoff methods were used to estimate the flood flow in a 1 in 10-year storm and the volume of water needed to attenuate the flood peak by 25%. A GIS approach was then taken to find locations where these interventions could be applied. This study shows that a combination of landscape-based measures has the potential to reduce the flood peak in a 1 in 10-year storm by 25%. Whilst runoff retention ponds offer the greatest contribution towards attenuating flood flows, no single intervention can solve the problem. It was clear that many interventions of different types, distributed across the catchment, are required. Careful scheduling of such interventions is required in order to avoid problems of flood peak synchronisation.
Acknowledgements

The author would like to acknowledge the assistance given by the Chew Valley Flood Forum as well as the help and guidance provided by Associate Professor Nevil Quinn in preparing this work, and finally the support and patience of his colleagues at JBA Consulting in Wallingford.
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1 Introduction

1.1 The Village of Chew Magna

The village of Chew Magna in North Somerset has history of flooding with major events over the last 50 years (e.g. 1968 and 2012) (JBA Consulting, 2013a). In the latter flood, at least 30 properties were damaged, and one person was killed in the neighbouring Chew Stoke catchment (ITV News, 2012). Minor repeat flooding is also a problem and has caused the primary school to be evacuated more than once per year (CVFF, 2017).

Engineering consultants have visited and assessed the flooding, and examined potential flood defence options (Babtie Brown & Root, 2004). However, a cost-benefit analysis ruled out major engineering works and so with the exception of dredging and property level protection (PLP) (JBA Consulting, 2013c) little has been done.

In 2014 environmental consultants were commissioned to investigate the possibility of a payment for ecosystem services approach in the Chew Valley, whereby landowners receive a payment to manage their land in a way that provides wider benefits. Sherrington et al. (2015) identified three problems that could be targeted in the valley: flooding, sedimentation in Chew Magna Reservoir, and phosphate pollution.

Building on the Eunomia report, the work presented here focuses on whether landscape-based interventions are viable, and identifies which measures may be appropriate and in what location.

1.2 Introduction to the catchment

The Winford Brook rises north of Winford and flows east through Chew Magna where it joins the River Chew (Figure 1.1). The catchment drains an area approximately 19.5 km² of mostly agricultural land with a mix of livestock and arable farming. Chew Magna has a population of approximately 1,200 (Chew Magna Parish Council, 2011) and was voted one of the best places to live in England (Somerset Live, 2013). The other significant settlements in the catchment are the village of Winford in the centre of the catchment and Felton, east of Bristol airport.
Figure 1.1 Map of the Winford Brook catchment
The valley is steep, particularly to the north and the flood plain narrow, with tributaries feeding into Winford Brook from the high ground. The geology is predominantly mudstone and sandstone in the lower catchment and limestone in the upper catchment. The combination of these features produces a rapid response to rainfall (JBA Consulting, 2013a).

Upstream of Chew Magna is Chew Magna Reservoir; originally built as a source of water for local villages. It is now a feeder for the much larger Chew Valley Lake to the south, an important source of water for Bristol and the surrounding area. Bristol Water, who manage the reservoir, report that the volume is approximately 70,000 m$^3$ and can fill and empty extremely quickly.

1.3 History of flooding in Chew Valley

The Environment Agency historic flood map dataset shows the combined extent of flooding from rivers, the sea and groundwater springs. Buildings that lie within this flood extent are highlighted in red (Figure 1.2). The blue square north of the village represents an area where flooding from groundwater has occurred.

![Figure 1.2 Historic flood map of Chew Magna](https://example.com/floodmap.png)

The 1968 flood resulted from a rainfall event in which 175 mm fell in 18 hours onto an already saturated catchment. Within Chew Magna 88 properties were damaged, with some buildings flooded to a depth of 2.5 m (Environment Agency, 2008). Photograph 1.1 shows the resulting damage in the village.

Photograph 1.1 Devastation at the back of the Queen’s Arms in Chew Magna in the 1968 floods (Environment Agency, 2008)

The flooding that occurred in 2012 was less severe in flood depth, but it occurred over several months, with floods in September, November and December. In many cases properties were affected more than once. JBA Consulting (2013b) estimated the return period to be 1 in 100-years for the September event in which 33 properties were damaged, and 1 in 10-years for the November event. Photograph 1.2 shows the view along the Batch in Chew Magna in the September 2012 flood.
Photograph 1.2 The view along the Batch in Chew Magna looking towards the Winford Brook (JBA Consulting, 2013)

The most recent flooding occurred in November 2016, in which the Winford Brook exceeded its banks close to the school in the centre of Chew Magna (Photograph 1.3), causing it to be evacuated although no property damage is known to have occurred (Chew Valley Gazette, 2017).

Photograph 1.3 Winford Brook in flood, November 2016 (Chew Valley Gazette, 2017)
1.4 Soil erosion

Soil erosion, the removal of topsoil by rainfall or wind, is an increasing problem in the UK with an estimated 2.2 million tonnes of topsoil lost annually (Defra, 2009). Sherrington et al. (2015) identified a problem of sedimentation in Chew Magna Reservoir from soil erosion in the catchment. Currently, sediment is periodically removed and stored on site. Due to space constraints, further accumulations of silt will have to be removed from site at considerable cost. Bristol Water are therefore interested in measures that reduce the quantity of silt entering the reservoir.

Soil erosion can have a significant impact on water quality and sediment accumulation in watercourses (Rickson, 2014), with 76% of the sediment load in UK rivers resulting from erosion of agricultural land (Collins et al., 2009). Erskine et al. (2002) found that soil erosion rate on arable land was double that of pasture. Agriculture in the Winford catchment is predominantly livestock, with some arable farming, particularly maize. The split of agriculture types, and how they have changed, is of significance to the future of erosion management in the catchment.

1.5 Research questions

With PLP already offered, and large scale engineering works largely ruled out through cost-benefit analysis by Babtie Brown & Root (2004), this project focuses on landscape-based interventions aimed at tackling the problems identified by Sherrington et al. (2015). Five principal research questions were formed at the beginning of this study and guided the research project:

- Which landscape-based surface water management interventions might be applied in the Winford Brook catchment?
- Where is surface water flowing and ponding during a storm?
- Which areas are at risk of soil erosion?
- Where might landscape-based interventions be effective in managing flows during storm events?
- What priority should these interventions be given?
2 Policy framework

Flood risk in the UK is regulated and managed through a number of policies, frameworks and documents, and it is important to understand how a scheme of landscape-based interventions aligns with local and national policy.

The Flood Risk Regulations (2009), UK legislation intended to translate the EU Floods Directive into UK law, states that the Environment Agency retains responsibility for flooding from main rivers and the sea. It places the responsibility to manage flooding from ordinary watercourses, groundwater and surface water on the Lead Local Flood Authority (LLFA).

Winford Brook is a main river managed by the EA, however the wider catchment falls across two LLFAs, Bath and North East Somerset Council (B&NES Council (2015)) and North Somerset Council (2014) have each published Local Flood Risk Management Strategies (LFRMS). All the tributaries (classed as ordinary watercourses) and most of the locations for interventions are within B&NES area so only that strategy document is discussed. Actions relevant to this study are stated below:

**LFRMS 3f** - “Identify catchments where improved land management could reduce flood risk and/or improve the water environment” (B&NES Council, 2015, p.57).

**LFRMS 3i** - “Evaluate flood reports to identify where drainage improvements or other mitigation works are possible” (B&NES Council, 2015, p.58).

This project aligns well with the LFRMS 3f as the outcome could be the identification of the Winford Brook catchment as an area where land management interventions can reduce flood risk. It will also lead onto the LFRMS 3i as mitigation works will be identified.

Chew Magna is identified as a known area of flood risk, and consequently has some location-specific objectives. One of these is to “implement source control measures to reduce surface water runoff” (B&NES Council, 2015, p.70) which could be met by retrofitting Sustainable Drainage Systems (SuDS) (discussed in 3.4.6).

Potential sources of funding for flood risk management works are also identified in the LFRMS with the primary source being the Flood and Coastal Erosion Risk Management Grant in Aid which could be supported by Local Levy funding.
LLFAs are also responsible for managing flood risk from surface water and therefore often publish a Surface Water Management Strategy (B&NES Council, 2014). However, there are no specific actions relevant to this study in addition to those already identified in the LFRMS.

Neighbourhood planning provides the community with the power to develop a vision for their neighbourhood and shape the way in which their local area develops (DCLG, 2017). Villages in the Chew Valley have produced a Neighbourhood Plan which covers the Winford Brook catchment (CVNP Steering Group, 2016). Policies in the plan include support for developments where surface water management is incorporated into the design, and developments that help to mitigate flood risk. Three policies are included in the plan relating to flood risk.
3 Landscape-based surface water management interventions

3.1 Introduction

Widespread flooding in the summer of 2007 prompted the Government to commission an independent review of the response to the emergency and lessons learned (Pitt, 2008). Recommendation 27 of what became known as the Pitt Review was that “Defra, the Environment Agency and Natural England should work with partners to establish a programme through Catchment Flood Management Plans...to achieve greater working with natural processes” (Pitt, 2008, p.130). In response Defra proposed three “Multi-Objective Flood Management Demonstration Projects” (Defra, 2013). These case studies are summarised in 3.3.

“Flood risk management is undergoing a paradigmatic change towards more integrative and ecosystem-based approach” (Rouillard et al., 2015), with focus shifting from hard engineering measures in urban areas, aimed at keeping water in channel through a town, to a catchment-based approach managing water further up the catchment.

Landscape-based interventions have many names: Natural Flood Management (NFM), Rural SuDS, Runoff Attenuation Features, “working with natural processes”, or “making space for water”. These names and phrases are used interchangeably in the literature, but the principles are the same. During a storm, ephemeral flow pathways generated by overland flow link fields and hillslopes to the stream network. Landscape-based interventions intercept these flow pathways and either store or redirect flow, delaying water in the catchment and reducing the flood peak further downstream.

The focus of this section is on interventions for flood mitigation, however in managing surface water for flooding, benefits can also be gained in soil erosion reduction and diffuse pollution control (Wilkinson et al., 2014).

3.2 Strategy for literature review

To answer the first research question: “Which landscape-based surface water management interventions might be applied in the Winford Brook catchment?”, case studies from the Defra Multi-Objective Flood Management Demonstration projects and from the EA Working with Natural Processes Evidence Base were used to produce a
list of measures that have been applied in relevant catchments, with three key case studies presented in detail (section 3.3). Evidence for their effectiveness was summarised and a final list of interventions applicable to Winford Brook defined. The wider literature was then investigated to inform a methodology for identifying locations and design criteria for those interventions (section 3.4).
3.3 Catchment scale case studies

3.3.1 Holnicote
The Holnicote Estate in Somerset is managed by the National Trust and lies across two river catchments by the Exmoor National Park (National Trust, 2015). The size of these two catchments is comparable to the Winford Brook catchment, with the Horner Water being 22 km$^2$ and the Aller 15 km$^2$. The site was chosen as one of the three Multi-Objective Flood Management Demonstration Projects and initiated in July 2009.

A raster-based inundation model developed by JBA Consulting (2016) was applied to identify areas of surface water accumulation, guiding interventions to control and store flood water. A total of 800 low earth bunds were proposed across many of the pathways and tracks in the catchment, to divert runoff onto the landscape (Hester, Rose and Worrall, 2017). The modelling also identified depressions in the ground where excavation of ponds could store excess surface runoff.

A key observation was that access routes to fields were preferential pathways for surface water and could be improved by moving gateways away from critical flow routes, directing water away from the entrance into temporary flood storage areas. This also has the benefit of retaining valuable soil within the field (Boardman, Evans and Ford, 2003).

Soil condition has a large influence on the infiltration capacity of soil and the potential for runoff generation (Newell-Price et al., 2013). Degradation due to compaction, capping or the generation of plough pans reduces the amount of rainfall that infiltrates the soil. In Holnicote, 50% of the agricultural land required remediation of soil structural condition (National Trust, 2015). Modelling investigating the sub-catchments suggested that in some cases deterioration from “good” structural condition to “severely degraded” could increase peak flow 7-9%.

A hydrological monitoring network has allowed the effectiveness of NFM interventions to be assessed. Monitoring work is ongoing, however during the wet winter of 2013/2014, no flooding was recorded in downstream villages previously prone to flooding. Modelling by Hester et al. (2017) also showed a flattening of the hydrograph and delay in the peak.

3.3.2 Pickering
Another Multi-Objective Flood Management Demonstration Project was “Slowing the Flow at Pickering” in North Yorkshire (Nisbet et al., 2011). Four floods have been experienced since 1999 and the area has been assessed for a large-scale engineering
scheme. However, as in Chew Magna, the cost-benefit analysis showed the scheme was unaffordable.

The catchment at 69 m² is larger than the Winford Brook catchment, and differs in land use, with the primary uses being forest, arable, and heather moorland. The project was extended to cover both Pickering Beck, and part of the River Seven to manage flood risk in the village of Sinnington. The aim was to deliver interventions protecting Pickering from a 1 in 25-year flood. By March 2015, a large number of measures had been implemented, including LWD dams, timber bunds, check dams, woodland planting and a large 120,000 m³ storage bund (Nisbet et al., 2015).

Modelling indicated that building LWD dams within the main channel of the Pickering Beck would be effective at retaining flood flows (Nisbet et al., 2015). The placement of these features here, rather than on tributaries, is contrary to the advice of Quinn et al. (2013) who advised that online features (including LWD dams) should not be installed where the catchment served exceeds ~1 km². This is because higher stream energy from larger watercourses could initiate scour. It was stated by Nisbet et al. (2015) that a dams built in 2012 failed during a 1 in 8-year event and a second shifted on one bank. It is possible that these were placed in an area unsuitable for LWD dams.

Timber bunds were used in the catchment to extend the concept of LWD dams to a much larger scale, with two bunds 16.5 and 57.5 m wide providing 1,260 m³ and 3,620 m³ storage respectively. Together they are estimated to delay the passage of a 1 in 100-year flood peak by approximately 18 minutes.

Based on an estimate of 100 m³/ha of soil water storage, the woodland planted in the Pickering Beck catchment was estimated to provide a total volume of 1,900 m³. The OVERFLOW model used by Odoni and Lane (2010) predicted that the impact of the woodland would be greater with increasing flow, for instance the 1 in 100-year flood peak could be reduced by 8% (compared with 4% for a 1 in 25-year flood). The large flood storage bund had the largest effect with its design capacity of 120,000 m³, reducing the risk of flooding in Pickering from 25% to 4% in any one year.

### 3.3.3 Belford

The upper Belford Burn catchment in Northumberland was the site of a partnership between Newcastle University and the EA to deliver a catchment-based flood solution for the village of Belford. At 5.7 km² it is smaller than the Winford Brook catchment, but has a similar mix of improved grassland and arable farmland (Wilkinson et al., 2010). It is a rapid-response catchment susceptible to flooding from short-duration intense
rainfall. The observed hydrograph for a storm in March 2010 that caused flooding in Belford was used to set a target for storage of 20,000 m$^3$ to attenuate the flood event.

A variety of types of feature were installed in the catchment, including large woody debris, on and offline storage ponds, and ditch management (Quinn et al., 2013). Modelling work showed the percentage reduction in flow rises with increasing storage capacity, and for the proposed 20,000 m$^3$ storage, a 30% reduction was predicted for the historic events and a 15% reduction for the 1 in 100-year event (Wilkinson et al., 2014). In one of the historic events, no attenuation effect was observed until the storage volume reached 10,000 m$^3$. This is because the capacity is reached before the arrival of the flood peak, suggesting there may be an additional critical volume of storage required before a significant peak flow reduction is observed.

Quinn et al. (2013) concluded that the effectiveness of networks of runoff attenuation features depends on the shape of the hydrograph, with the features being more effective for “flashy” short-duration flood events.

3.3.4 Summary of case studies
Evidence from the demonstration projects, and additional case studies from the Working with Natural Processes Evidence Base are summarised in Table 3.1, categorised by whether the evidence is from modelling, experiment or is anecdotal. A total of 16 case studies were examined and 18 different types of intervention identified.
### Table 3.1 Summary of case studies

<table>
<thead>
<tr>
<th>Case study</th>
<th>Interventions applied</th>
<th>Evidence for effectiveness</th>
<th>Source</th>
</tr>
</thead>
</table>
| **Holnicote** | • Runoff retention ponds  
• LWD dams  
• Woodland creation  
• Land management advice | **Empirical**  
December 2013 flood event (75 to 100-year return period)  
Effect of offline storage bunds:  
17,816 m³ storage in offline bunds  
10% reduction in peak flow  
3 min delay in peak  
**Modelling**  
1 in 5-year event  
10,619 m³ offline storage predicted  
25% reduction in peak flow  
35 min delay in flood peak | (National Trust, 2015) |
| **Pickering** | • 129 LWD dams  
• 2 large timber bunds  
• 187 heather bale check dams in moorland gullies  
• No-burn buffer zones along watercourses  
• 3.2 ha heather re-seeded  
• 19 ha riparian woodland  
• 15 ha farm woodland  
• Large flood storage bund (120,000 m³) | **Anecdotal**  
Local community believe measures implemented helped prevent near-flood in November 2012  
**Modelling**  
129 LWD dams predicted to store 1,300 m³ in 1 in 25-year event  
4,880 m³ predicted from large timber bunds, 1 in 100-year flood peak delayed by 18 mins (HEC-RAS model)  
Effect of riparian woodland and LWD dams modelled 1 in 25-year flood peak reduced by 4%  
1 in 100-year flood peak reduced by 8%  
Large flood storage bund (120,000 m³) reduces annual flood risk in Pickering from 25% to 4% | (Nisbet *et al.*, 2011)  
(Nisbet *et al.*, 2015)  
(Odoni and Lane, 2010) |
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<th>Case study</th>
<th>Interventions applied</th>
<th>Evidence for effectiveness</th>
<th>Source</th>
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<tbody>
<tr>
<td>Derwent</td>
<td>• Cattle exclusion&lt;br&gt;• Gully blocking (1284 stone dams and 834 timber dams)&lt;br&gt;• Moorland planting</td>
<td><strong>Empirical</strong>&lt;br&gt;Water table raised 38%&lt;br&gt;Overland flow production increased by 18%&lt;br&gt;Storm flow lag time increased by up to 267%</td>
<td>(Pilkington et al., 2012)&lt;br&gt;(Pilkington et al., 2015)</td>
</tr>
<tr>
<td>Belford</td>
<td>• LWD dams&lt;br&gt;• Runoff retention ponds&lt;br&gt;• Ditch management</td>
<td><strong>Modelling</strong>&lt;br&gt;Effect of retention ponds on peak flow analysed&lt;br&gt;15% reduction for 1 in 100-year event&lt;br&gt;30% reduction on historic events (1 in 5-year and 1 in 12.5-year) (FEH Rainfall-runoff methodology)</td>
<td>(Quinn et al., 2013)&lt;br&gt;(Wilkinson et al., 2010)&lt;br&gt;(Wilkinson et al., 2014)</td>
</tr>
<tr>
<td>Hills to levels Project (Somerset)</td>
<td>• 20 runoff interception features&lt;br&gt;• 14 large attenuation features&lt;br&gt;• 120 LWD dams</td>
<td><strong>Modelling</strong>&lt;br&gt;15,000 m$^3$ storage created&lt;br&gt;Peak flow reduced by 10% in 1 in 30-year event</td>
<td>(Peukert et al., 2017)</td>
</tr>
<tr>
<td>Roe and Ive</td>
<td>• Soil aeration&lt;br&gt;• 25 LWD dams</td>
<td>No data</td>
<td>(Coulthard and McIlwraith, 2017)</td>
</tr>
<tr>
<td>Water Friendly Farming (Leicestershire)</td>
<td>• Buffer strips&lt;br&gt;• LWD dams&lt;br&gt;• Soil management&lt;br&gt;• Runoff retention ponds&lt;br&gt;• Constructed wetlands</td>
<td><strong>Modelling</strong>&lt;br&gt;30,000 m$^3$ storage created in 10 km$^2$ catchment&lt;br&gt;1 in 100-year flood peak reduced by 20%&lt;br&gt;Buffer strips predicted to have reduced sediment losses by 30% (SWAT Modelling tool used)</td>
<td>(Biggs and Stoate, 2014)&lt;br&gt;(Biggs, Bonney and Stoate, 2017)</td>
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<td>Exmoor Mires Partnership</td>
<td>• Ditch blocking&lt;br&gt;• Restored wetlands</td>
<td><strong>Empirical</strong>&lt;br&gt;Reduction in peak storm discharge of 33%</td>
<td>(Angus, Lane and Brazier, 2017)</td>
</tr>
<tr>
<td>Eycott Hill</td>
<td>• Tree and scrub planting</td>
<td>No data – monitoring underway</td>
<td>(Owen, 2017)</td>
</tr>
<tr>
<td>Case study</td>
<td>Interventions applied</td>
<td>Evidence for effectiveness</td>
<td>Source</td>
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| Haltwhistle | • Change from intensive to extensive grazing  
• Creation of wetland scrapes  
• River restoration  
• Heathland restoration | Anecdotal  
Community observations suggest “tangible” benefit in winter storms of 2015/16 | (Newson, 2017) |
| Coalburn   | • River restoration  
• Erosion control  
• 10 LWD dams  
• Sediment traps  
• Tree planting  
• SuDS  
• Wetland construction | Empirical  
Initial planting increased peak flow by 15-20% and reduced time to peak by 33%  
Forest growth caused peak flow to reduce by 10-15%  
Modelling  
Reduction decreased with increasing size of event – negligible effect on 1 in 100-year event. | (Nisbet, 2017a) |
| Brackenhurst | • 10 LWD dams  
• Runoff retention ponds  
• Stream restoration  
• Woodland planting (150 ha) | Anecdotal  
Observations during Storm Angus (Dec 2016) suggest water is being held back  
Modelling  
25 fewer properties flooded in 1 in 75-year event (further data not reported) | (Labadz, Wells and Disney, 2017) |
<table>
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<tr>
<th>Case study</th>
<th>Interventions applied</th>
<th>Evidence for effectiveness</th>
<th>Source</th>
</tr>
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<tbody>
<tr>
<td>Torne</td>
<td>• Restoration of wet woodland&lt;br&gt;• SuDS retrofit in schools</td>
<td>Anecdotal&lt;br&gt;Local observation that woodland was “wet” for first time in 40 years&lt;br&gt;Modelling&lt;br&gt;4,000 m³ floodplain storage created</td>
<td>(Newborough, 2017)</td>
</tr>
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<td>Pontbren experimental study</td>
<td>• Removal of grazing&lt;br&gt;• Tree planting</td>
<td>Empirical&lt;br&gt;Soil infiltration rates found to be 67 times higher within woodland&lt;br&gt;Surface runoff reduced by 78%&lt;br&gt;Removal of grazing reduced runoff by 48%&lt;br&gt;Modelling&lt;br&gt;Predicted tree planting of 7% of 12 km² catchment could reduce severe flood (1 in 180-years) by 5%&lt;br&gt;Complete afforestation predicted to reduce flood peak by 36%</td>
<td>(Nisbet, 2017b)</td>
</tr>
<tr>
<td>River Cary model study</td>
<td>• Flood plain woodland planting (133 ha)</td>
<td>Modelling&lt;br&gt;Predicted to increase local flood storage by 71% and delay flood peak by 140 mins on 2.2 km stretch in 1 in 100-year event (HEC-RAS and River2D hydraulic models)</td>
<td>(Thomas and Nisbet, 2017)</td>
</tr>
<tr>
<td>Sussex Flow Initiative</td>
<td>• Flood plain woodland&lt;br&gt;• Hedgerows&lt;br&gt;• Shelter belts&lt;br&gt;• Runoff retention ponds&lt;br&gt;• LWD dams&lt;br&gt;• Washland meadow</td>
<td>Modelling&lt;br&gt;Addition of NFM measures could reduce flood peak by 12 m/s</td>
<td>(Manning-Jones, Williams and Southgate, 2017)</td>
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</tbody>
</table>
Analysis of the case studies shows that the majority of the evidence presented results from modelling work, with some empirical and anecdotal evidence presented (Table 3.2). Some of the case studies did not demonstrate any evidence of the effectiveness of measures implemented. The lack of empirical data is in part due to the difficulty in obtaining reliable baseline data in ungauged catchments and the long timescales required to generate long term monitoring results.

Table 3.2 Type of evidence presented

<table>
<thead>
<tr>
<th>Type of evidence</th>
<th>Number of studies</th>
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<tbody>
<tr>
<td>Modelling</td>
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<td>Empirical</td>
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</tr>
<tr>
<td>No evidence</td>
<td>2</td>
</tr>
</tbody>
</table>

The interventions that had the greatest number of studies demonstrating effectiveness were runoff retention features, LWD dams and woodland planting (Table 3.3). Buffer strips were also shown to be an effective measure for controlling soil erosion.

Table 3.3 Studies demonstrating evidence of effectiveness

<table>
<thead>
<tr>
<th>Type of intervention</th>
<th>Number of studies</th>
</tr>
</thead>
<tbody>
<tr>
<td>Runoff retention ponds</td>
<td>6</td>
</tr>
<tr>
<td>LWD dams</td>
<td>4</td>
</tr>
<tr>
<td>Woodland planting</td>
<td>4</td>
</tr>
<tr>
<td>Gully / ditch blocking</td>
<td>2</td>
</tr>
<tr>
<td>Soil management</td>
<td>1</td>
</tr>
<tr>
<td>Buffer strips</td>
<td>1</td>
</tr>
<tr>
<td>Large storage reservoir</td>
<td>1</td>
</tr>
<tr>
<td>Wetlands</td>
<td>1</td>
</tr>
</tbody>
</table>
3.4 Measures for the Winford Brook Catchment

3.4.1 Introduction
Using the information from the case studies, measures were chosen based on the strength of evidence of effectiveness in other catchments, and their appropriateness for the Winford Brook catchment. The measures selected are:

- Woodland planting
- LWD dams
- Runoff retentions ponds
- Buffer strips

The first three were chosen based on their flood mitigation potential; buffer strips were included based on their effectiveness controlling soil erosion.

Further information was drawn from the case studies and compared to literature investigating the effectiveness of each measure. A number of NFM design guides are also available:

- Scottish Environmental Protection Agency - The NFM Handbook (SEPA, 2015)
- Newcastle University - Runoff Attenuation Features guide (Newcastle University and Environment Agency, 2011)

3.4.2 Woodland creation
Afforestation has a large impact on soil and hydrology of the landscape with tree planting resulting in a more open, organic rich upper layer that allows faster infiltration and greater storage (Archer et al., 2016). Forest canopies can also reduce the amount of rainfall reaching the soil through interception (Calder et al., 2003). Woodland uses more water than other types of vegetation and so the underlying soils tend to be drier, particularly during the summer. The soils are then better able to store runoff, reducing or delaying the flood peak (Archer et al., 2013).

During a prolonged period of wet weather, forest soils may reach their capacity to store water and so not contribute to storage in a flood event (Wahren, Schwärzel and Feger, 2012). There is also variation in the volume of water intercepted by a forest canopy, with coniferous forests intercepting more rainfall than broadleaf woodland (Jost et al., 2012). This difference is more pronounced during the winter when the trees are
leafless. Interception is also reduced during high intensity rainfall, so the expected positive impact of woodland planting may not always be realised (Forestry Commission, no date).

It is generally accepted that the permeability of soils under a forest is higher than under other types of vegetation (Chandler and Chappell, 2008). However, Chandler and Chappell (2008) also note that there are surprisingly few studies that test this.

Chandler et al. (2018) highlighted the importance of land use on the effectiveness of tree planting. In woodland that was grazed, little difference was observed in infiltration rate and runoff generation potential from grazed grassland, and tree species did not have a significant effect. In un-grazed forest, soil under Scots pine was shown to have a higher infiltration rate than under sycamore. Infiltration rate of woodland that has recreational use has also been shown to be reduced, most likely due to the effect of compaction from walkers or cyclists (Millward et al., 2011). This emphasises the need to have areas where both people and animals are excluded so the full effect of the woodland can be realised.

In the Pontbren catchment a study by Marshall et al. (2014) also showed both the effect of excluding livestock from grassland and planting trees, but also demonstrated the improvement in infiltration rate was not just due to the exclusion of livestock.

There is uncertainty in the literature about the effectiveness of woodland planting to mitigate flood risk. The Centre for Ecology and Hydrology (Stratford et al., 2017) looked to address this by reviewing 71 case studies and classifying them by whether they showed a positive or negative effect on flood risk. They were further classified by whether the paper used observational or modelled data. The influence of the size of flood event was also investigated. The study found “broad support” for the conclusion that woodland planting influences flood peak (Figure 3.1).

A factor that makes this study of more interest to the Winford Brook catchment is that it looked specifically at “UK relevant” catchments, filtering out studies in areas such as India or Brazil that might skew the conclusions. The Köppen climate classification (Kottek et al., 2006) was used to define a UK-relevant catchment.
The results were less conclusive when the data was split into observational and modelling studies, with modelling showing a more positive outcome and observational studies showing an inconclusive outcome (Table 3.4).

Table 3.4 Results of CEH review by study type (Stratford et al., 2017)

<table>
<thead>
<tr>
<th>Research question</th>
<th>Type of study</th>
<th>Decrease</th>
<th>Increase</th>
<th>No influence</th>
</tr>
</thead>
<tbody>
<tr>
<td>Increasing tree cover</td>
<td>Modelling</td>
<td>23</td>
<td>0</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>Observational</td>
<td>13</td>
<td>5</td>
<td>6</td>
</tr>
<tr>
<td>Decreasing tree cover</td>
<td>Modelling</td>
<td>0</td>
<td>14</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Observational</td>
<td>0</td>
<td>7</td>
<td>9</td>
</tr>
</tbody>
</table>

When the size of flood event is taken into account, the study shows the majority of statements for small events report a decrease in flood peak, while for larger events the majority of studies reported no influence. This is supported by Wahren, Schwärzel and Feger (2012) who observed that the reduction in flood peak was highly dependent on the rainfall event characteristics, with a reduction in flood peak of 70% after afforestation for smaller floods, but only 3% in larger events.
An explanation for the difference between observational and model driven studies was put forward by Stratford et al. (2017) based on the limitations of monitoring activities. Statistical analysis of an empirical study requires monitoring over multiple locations or over an extended period which may not be practical.

A weakness of this review is that effect modifiers such as changes to landscape structure, and forest characteristics were not taken into account. Whilst this was a conscious decision of the review team, based on the lack of consistency in data reporting across studies, it could have an influence on the overall conclusions.

The proximity of the Winford Brook catchment to Bristol Airport requires consideration of how measures, in particular woodland planting, may affect bird populations. The Civil Aviation Authority (2017) defines a 13 km buffer around an airport where wildlife numbers should be monitored and airport authorities should be consulted on development within that zone that may attract wildlife.

3.4.3 Buffer strips

On arable land, fields may be left uncovered at certain times of the year. Rainfall impact on uncovered soil surfaces results in the development of a thin seal or crust of low permeability. This reduces rainfall infiltration and contributes to increased surface runoff (Fiener, Auerswald and Van Oost, 2011). Grass buffer strips (Photograph 3.1) are widely understood to reduce runoff, and control the loss of sediment and pollutants from agricultural land. By increasing the hydraulic roughness of the landscape, the velocity of runoff is reduced and sediment deposition is increased before runoff has a chance to reach a watercourse (Dillaha, Sherrard and Lee, 1986). Although less widely used, buffer strips can also be effective on grassland, providing opportunities for increased infiltration. A study in the Pontbren catchment produced evidence that runoff response is significantly affected on improved agricultural grassland when compared to grassland in a more natural state (McIntyre and Marshall, 2010).
Ngai et al. (2017) highlight a gap in the literature on the effect of buffer strips on flood risk as most studies focus on sediment trapping or pollution control. However, both processes require interception of surface runoff.

Buffer strips can take many forms, from simple grassed buffers to wooded strips (Defra, 2011a). The Environment Agency (2012) provides guidance for buffer strip design that suggests a width of 5-15 m dependent on field conditions, with steeper slopes (potentially faster flow) requiring wider strips.

Borin et al. (2005) studied the effect of wooded buffer strips on runoff and water quality over four years in northern Italy and found that a six-meter buffer strip consisting of two rows of alternating trees and shrubs reduced runoff by 78%. The age of the buffer strip was also observed to affect efficacy, with newly planted strips reducing runoff by 33%, suggesting that the full benefit is only realised after several years.

Kronvang et al. (2010 cited in Ngai et al. 2017) concluded that buffer strips are more effective when the width can be adapted according to the risk of pollution, however the approach requires a greater level of assessment and therefore cost. This may not be practical for farmers, but where a catchment is being studied using analysis of the topography, flow paths and soil type, adapting the width could allow a more efficient design and minimise the loss of agricultural land.

Borin et al. (2010) suggested that wooded buffer strips, in addition to their runoff and water quality functions, could become an active part of the farm with wood harvested every 5-7 years, providing an additional income to offset that lost by removing crops from arable land.
3.4.4 Runoff retention ponds

Runoff retention ponds (Photograph 3.2) have many different names within the literature, such as runoff attenuation feature or detention basin, and many variations in design. Here, we define a retention pond as a basin that is usually dry and designed to temporarily store surface runoff during a storm, and release it slowly over an extended period of time. Burgess-Gamble et al. (2017) stated that such features have been found to slow and store water, reducing local flood risk for small events. However, the evidence is uncertain for bigger floods at large catchment scales.

![Photograph 3.2 Retention ponds in dry (left) and storm (right) conditions (Newcastle University, 2013)](image)

To perform effectively, they should be dry at the start and then empty within 24 hours. This means that in a storm consisting of multiple rain events over a number of days, the pond can still provide some attenuation of runoff in the second or third event (Newcastle University and Environment Agency, 2011).

To reduce construction costs, natural features should be used to minimise the need for landscaping and slopes should be a maximum of 1:3 to avoid the need for bank stabilisation (Environment Agency, 2012). Overlap exists between these and infiltration basins, and where a pond is sited in an area with high soil infiltration potential it may act as an infiltration basin. When located in an impermeable area water can be returned to the catchment via a controlled outlet (SEPA, 2015). The efficiency of the retention ponds can be improved by making erosion control more effective further up the slope (Fiener, Auerswald and Weigand, 2005), reducing sediment flow into the pond, thus prolonging its life before sediment removal is required.

Retention ponds were installed on arable land north of Munich, Germany. Fiener, Auerswald and Weigand (2005) aimed to investigate their effect on soil erosion, water pollution and runoff rate. Ponds with a capacity of 220-490 m³ were shown to trap 50-80% of the incoming sediment and reduce peak runoff. During one of the largest runoff
events during the 9-year study period, peak runoff around one of the smallest ponds was reduced to a third. This is similar to the findings of Nicholson (2013) in the Belford catchment where a 30% reduction in peak flow was observed.

Mcintyre and Thorne (2013) found that greater than 1% of the catchment area was required for retention ponds in order for a significant effect on river flows to be observed. In the case of Belford this required 20,000 m$^3$ of storage (Nicholson et al., 2012).

3.4.5 Large Woody Debris Dams
LWD dams can take many forms, from natural treefall left in place to semi-engineered structures deliberately placed in a stream (Photograph 3.3).

![Photograph 3.3 LWD dam in the Pickering catchment (Forest Research, 2015)](image)

The presence of large woody debris in streams can increase hydraulic roughness (Gippel, 1995), slowing the passage of water. It can also encourage water out of bank onto the flood plain, or provide storage of flood flow behind the barrier. The effect of an individual dam is likely to be minimal, but the cumulative impact of a large number of features can be considerable (Environment Agency, 1999).
Most of the evidence on the efficacy of wood debris barriers results from modelling studies rather than observational studies. Odoni and Lane (2010) used the OVERFLOW model to show that the installation of 100 LWD dams could reduce the magnitude of a flood event by 7.5%. Other studies report a delay in the flood peak, with no impact of the magnitude (Forest Research, 2008). This is explained by the fact that water is diverted out of channel onto the flood plain where it flows around the barrier and back into the channel downstream (Nisbet et al., 2011). This is supported by Gregory, Gurnell and Hill (1985) who showed that for a 4 km river reach the flood peak could be delayed by 100 mins for lower flows but only 10 mins for higher flows that overtopped or bypassed the barrier. The effect on the magnitude of the flood peak may increase if large dams are installed, increasing the volume of water held back before they are overtopped, or water diverts around them. This storage can then contribute to a reduction in flood peak as it will release water back over a longer period of time.

Wenzel et al. (2014) took an experimental approach to investigating the effect of LWD barriers. An artificial flood wave was created on a short reach by releasing water from a storage pond. The resulting flow was equivalent to a 1 in 3.5-year flood, and the presence of LWD delayed the peak by the equivalent of 10 mins if it was upscaled to a 1,000 m reach and the peak reduced by 2.2%.

The delaying of flood peaks could contribute to flood peak synchronisation where previously unaligned hydrographs of sub-catchments become aligned, causing a larger flood peak downstream (Dixon, 2013). Conversely, previously synchronised peaks can be de-synchronised if LWD dams are introduced on one tributary, reducing the overall flood peak (Thomas and Nisbet, 2012). Differences observed in the literature between studies could be due to the wide-ranging types of LWD barriers, from coarse barriers consisting of fallen logs to more tightly constructed dams.

The presence of large woody debris in streams has been shown to impact fish movement (Dodd, Newton and Adams, 2016). Careful design of features would be needed to ensure the movement of fish and other aquatic fauna is not impeded by structures. LWD can also have a positive impact on biodiversity, sustaining refuge habitats protecting biota during pollution events and flood flows (Thomas and Nisbet, 2012).

3.4.6 Sustainable Drainage Systems (SuDS)

SuDS can often be similar in operation to natural flood management techniques and because of this NFM is sometimes called “Rural SuDS” (Environment Agency, 2012). Whilst a detailed assessment of SuDS opportunities is outside the scope of this report,
some potential measures from the literature are worth mentioning here and their use is encouraged within the Chew Valley Local Plan (CVNP Steering Group, 2016).

Ciria (2012) provides location-specific measures for retrofitting SuDS for surface water control. For out of town commercial locations, runoff is often generated from car parks and large roofs. Options to manage this include the installation of permeable parking areas, separated by swales and combined with geocellular storage to attenuate storm flow. A similar approach can also be taken on paved paths and walkways. Water storage tanks, which can be either above or below ground, can manage water from roofs and provide grey water for running toilets.

3.5 Summary

The literature provides wide-ranging evidence on the effectiveness of landscape-based interventions on flood risk and sediment control, but it also highlights some notable gaps in understanding. A frequent observation is that the majority of studies are based on modelling rather than empirical data (Burgess-Gamble et al., 2017), and where empirical studies are produced they are often less conclusive than modelling studies (Stratford et al., 2017). Scaling of effects from the plot scale to a catchment scale is often difficult due to the complex mix of land uses present: fields of different crops, livestock, buildings and infrastructure (Fiener, Auerswald and Van Oost, 2011).

In the Winford Brook catchment, LWD dams, runoff retention ponds and woodland planting offer a mix of interventions suited to different locations that together could act to reduce the flood risk in Chew Magna. Managing surface runoff for flood risk in combination with buffer strips could also provide a significant reduction in sediment reaching Chew Magna Reservoir.
4 Methodology

4.1 Introduction

The literature review contained in Section 3 addresses the first research question: “which landscape-based surface water management interventions might be applied in the Winford Brook catchment?”. The methodology now sets out how the remaining questions were answered:

- Where is surface water flowing and ponding during a storm?
- Which areas are at risk of soil erosion?
- Where might landscape-based interventions be effective in managing flows during storm events?
- What priority should these interventions be given?

The methodology starts with the identification of where surface water may be flowing in the catchment. This information is then used alongside other datasets to identify the most suitable locations in the catchment for woodland planting, buffer strips, runoff attenuation ponds and large woody debris barriers.
4.2 Data sources

Table 4.1 Data sources used in the project

<table>
<thead>
<tr>
<th>Data type</th>
<th>Data</th>
<th>Source</th>
<th>Use</th>
<th>Section</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Mapping</strong></td>
<td>OS 1:25,000 Raster</td>
<td>digimap.edina.ac.uk</td>
<td>Base mapping</td>
<td>All</td>
</tr>
<tr>
<td></td>
<td>OS 1:1,000 Raster</td>
<td>digimap.edina.ac.uk</td>
<td>Business Park boundary</td>
<td>4.10</td>
</tr>
<tr>
<td></td>
<td>OS 1:1,250 MasterMap Topography</td>
<td>digimap.edina.ac.uk</td>
<td>Identification of buildings, roads, etc</td>
<td>4.5, 4.7, 4.8</td>
</tr>
<tr>
<td><strong>Digital Terrain</strong></td>
<td>LiDAR Composite DTM England 1 m resolution</td>
<td>digimap.edina.ac.uk</td>
<td>TIN and contour layers</td>
<td>4.8</td>
</tr>
<tr>
<td><strong>Model (DTM)</strong></td>
<td>LiDAR Composite DTM England 2 m resolution</td>
<td>digimap.edina.ac.uk</td>
<td>Surface water flow paths (detailed)</td>
<td>4.4, 4.7</td>
</tr>
<tr>
<td></td>
<td>LiDAR Composite DTM England 5 m resolution</td>
<td>digimap.edina.ac.uk</td>
<td>Creation of surface water flow paths</td>
<td>4.4, 4.6</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>(whole catchment)</td>
<td></td>
</tr>
<tr>
<td><strong>Landcover</strong></td>
<td>Agricultural Land Grade</td>
<td>EA Spatial Data Catalogue - Natural England</td>
<td>Priority for woodland planting</td>
<td>4.5</td>
</tr>
<tr>
<td></td>
<td>Corine Landcover 2007 1:2,500 Vector</td>
<td>digimap.edina.ac.uk</td>
<td>Identification of field types</td>
<td>4.6</td>
</tr>
<tr>
<td></td>
<td>Corine Landcover 2015 1:2,500 Vector</td>
<td>digimap.edina.ac.uk</td>
<td>Identification of field types</td>
<td>4.6, 4.7</td>
</tr>
<tr>
<td><strong>Soil</strong></td>
<td>Soil unit dataset</td>
<td>(Quinn, 2017)</td>
<td>Identification of at-risk soil types</td>
<td>4.6</td>
</tr>
<tr>
<td><strong>Hydrology</strong></td>
<td>Catchment descriptors</td>
<td>FEH Webservice</td>
<td>Input to hydrograph generation</td>
<td>4.9</td>
</tr>
<tr>
<td></td>
<td>Tributary lags</td>
<td>(Millington, 2017)</td>
<td>Input to hydrograph convolution</td>
<td>4.9</td>
</tr>
<tr>
<td></td>
<td>Relative Runoff Generation</td>
<td>(Quinn, 2017)</td>
<td>Priority for woodland planting</td>
<td>4.5</td>
</tr>
<tr>
<td>Environmental</td>
<td>Constraints</td>
<td>4.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>------------------------</td>
<td>-------------</td>
<td>-----</td>
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<td></td>
</tr>
<tr>
<td>SSSI</td>
<td>EA Spatial Data Catalogue - Natural England</td>
<td>Constraints</td>
<td>4.5</td>
<td></td>
</tr>
<tr>
<td>Ancient Woodland</td>
<td>EA Spatial Data Catalogue - Natural England</td>
<td>Constraints</td>
<td>4.5</td>
<td></td>
</tr>
<tr>
<td>Local Nature Reserves</td>
<td>EA Spatial Data Catalogue - Natural England</td>
<td>Constraints</td>
<td>4.5</td>
<td></td>
</tr>
</tbody>
</table>
4.3 Field work

Field visits (Table 4.2) were carried out to see the areas prone to flooding and gain an appreciation of the landscape in the catchment. Later field visits were aimed at validating the analysis carried in ArcMap.

<table>
<thead>
<tr>
<th>Date</th>
<th>Objective</th>
</tr>
</thead>
<tbody>
<tr>
<td>20th January 2017</td>
<td>Orientation visit guided by Chew Valley Flood Forum</td>
</tr>
<tr>
<td>26th May 2017</td>
<td>Identification of tributary location</td>
</tr>
<tr>
<td>16th July 2017</td>
<td>Verification of landcover data</td>
</tr>
<tr>
<td>19th September 2017</td>
<td>Validation of methodology</td>
</tr>
<tr>
<td>3rd November 2017</td>
<td>Validation of updated methodology and photography of locations</td>
</tr>
</tbody>
</table>

4.4 Surface water flow

The hydrology tools within ArcMap were used to create a raster layer showing where surface water may flow in the catchment following the process in Figure 4.1. Three different resolution DTM layers were available and were chosen based on the level of detail required and the area covered. The 1 m DTM had several gaps, making it difficult to apply the hydrology tools, and only the 5 m DTM covered the entire catchment. The process below was repeated on the 2 and 5 m resolution DTMs. Breakpoints of the dimensionless flow accumulation unit were chosen to provide sufficient visual clarity to identify flow paths.

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*Figure 4.1 Flowchart showing methodology for creating the flow accumulation layer for identifying surface water pathways*

Sub-catchments were then defined based on each of the tributaries to the Winford Brook using the watershed tool in ArcMap.
4.5 Woodland Planting

The objective of woodland planting was to reduce runoff that contributes to flooding. Estimates of relative runoff generation were obtained from a NERC-funded project (Quinn, 2017). These estimates were derived by multiplying the standard percentage runoff (SPF) factor of the national soils database against the spatially varying mean annual precipitation to obtain an indication of where higher rainfall and high surface runoff due to soil properties coincide. This was used to identify locations that had the most potential for runoff generation. It is not practical to plant woodland in every location, either because of existing land uses or physical constraints. Following the methodology of Broadmeadow and Nisbet (2010), Ordnance Survey Topographic data was used to identify areas unsuitable for planting including:

- Watercourses and lakes
- Buildings
- Structures
- Roads and paths
- Existing woodland (from landcover data)
- Urban areas (from landcover data)

No rail infrastructure or MOD land which could be major constraints were identified in the catchment. The mapped constraints were then combined using the “merge” tool in ArcMap.

Agriculture is of great importance to the local economy and the removal of the highest-grade agricultural land is undesirable. Agricultural land grade was ascertained from the Agricultural Land Classification dataset from Natural England (shown in Appendix C), and the top two categories, designated as excellent or very good, were added to the constraints layer.

When the constraints layer and the relative runoff generation layers (shown in Appendix D) were combined, a map of potential areas for woodland planting was created with two categories of priority based on the highest levels of runoff potential.

The attenuation potential for woodland was estimated using the figure of 100 m³/ha used by Broadmeadow and Nisbet (2010).
4.6 Buffer strips

In section 3.4.3, buffer strips were identified as the primary measure to control runoff and soil erosion on arable land. A study by Dosskey, Qiu and Kang (2013) showed how a digital elevation model (DEM) can be used for more accurate selection of sites for placement of buffer strips to improve water quality based on the identification of flow paths, and this principle was applied here, combined with additional parameters, to evaluate the risk of soil erosion.

Arable fields were identified using the Corine Landcover dataset. A new release of this was made available early in 2017 (2015 dataset) which varied considerably from the 2007 dataset with significantly less arable land present.

A site visit was made to verify the 2015 dataset, and observed differences added to a corrected landcover layer. The fields categorised as arable were then exported as a separate layer.

The fields that would derive the most benefit from a buffer strip are those with a large surface water flow path and with a soil prone to erosion. “Soil associations at risk of wind and water erosion in England and Wales” reported in Knox et al. (2015) were used to assign an erosion risk for each soil type present. This is shown in Appendix A.

Significant flow paths or a steep slope increases the risk of erosion, so the flow accumulation layer and the slope raster derived from the DTM (Appendix B) were combined with the soil data within a weighted overlay in ArcMap. Figure 4.2 shows the scores that were applied in order to create the overlay, with the soil type and slope scoring system based upon the study by Knox et al. (2015) and the soil erosion risk assessment methodology from Defra (2011b).

Other factors can affect soil erosion risk such as rainfall erosivity and crop cover (Zhang, O’Neill and Lacey, 1996), however these have not been used in this study as the rainfall erosivity can be assumed to be similar over the area of the catchment. Information on crop cover could be incorporated, but the objective of this piece of work is to highlight priority fields for measures to be applied. By using information on the type of crop currently in each field, the risk map produced becomes time dependent and only applicable while that crop is present. If crop type changes, the risk of erosion in that field could change considerably, making the risk map obsolete. In studies comparing sites across geographically remote locations, rainfall erosivity should be incorporated.
Runoff retention ponds were discussed in 3.4.4 as a method for storing runoff in the landscape, delaying and reducing the magnitude of the flood peak. The surface and hydrology tools within ArcMap were used to identify potential locations for these features, following a methodology similar to that applied in the Holnicote where JBA Consulting’s JFLOW 2D raster-based inundation model was used (National Trust, 2015). This highlighted areas where ponding of surface water would naturally occur and identify flow pathways connecting these areas with the drainage network.

The curvature tool within ArcMap reveals the shape of the landscape from the DTM layer. Two outputs were obtained from the tool: profile curvature parallel to the direction of slope (Figure 4.3) and planform curvature perpendicular to the direction of slope (Figure 4.4). A combination of these allows natural hollows in the landscape to be identified.
Figure 4.3 Profile curvature (ESRI, 2016)

Figure 4.4 Planform curvature (ESRI, 2016)

Figure 4.5 outlines the methodology used within ArcMap, the output being a polygon layer of potential sites with a 2 m resolution.

Figure 4.5 Flow chart showing methodology for identifying hollows in the landscape

Gently sloping or flat areas are best suited for locating retention ponds. Information on the slope was therefore combined with the landscape hollows. The outline methodology for this is shown in Figure 4.6.
For a retention pond to be useful it must receive runoff and so the location of significant surface water flow paths was required. The flow accumulation data generated earlier was used to show the areas in the catchment that received the highest flows, the outline methodology for this is shown in Figure 4.7.

Natural hollows and areas of gentle slope were combined, and locations within 25 m of a significant flow paths were identified. Diversion of watercourses into attenuation ponds is possible, but not considered in this study, therefore fields that contained only fluvial flow paths were eliminated. The constraints layer used in Figure 4.5 to show locations unsuitable for woodland planting was modified to remove the constraint of high-grade agricultural land and applied again to remove locations unsuitable for retention ponds. High grade agricultural land should be considered for retention ponds due to the potential for sediment capture that could help preserve that land. Figure 4.8 shows how the layers created above are combined to produce the location of sites most suitable for retention ponds.
It is not practical to install a retention pond in every site identified. Polygons representing all the fields that contained a potential retention pond site were extracted, and the area calculated using the geometry tool in ArcMap. Fields less than 5,000 m² were discounted as the location of a retention feature could make those fields unproductive or impractical to farm. The assumption was made that taking 1% of each field in the case of grassland, and 0.5% in the case of arable, would have a negligible effect on the productivity of that field, and that area could be set aside as a retention pond. A mean depth of 1 m across the area was applied to give an approximate volume of water that could be stored in each field.

The ponds studied by Fiener, Auerswald and Weigand (2005) were between 30 and 260 m³/ha with water depths between 1.08 and 1.44 m. By the method above, this would result in 0.3% to 2.6% of each field being taken.

A walkover study of a number of the sites was performed to verify that the natural basins identified in ArcMap showed the same characteristics in reality (Figure 4.9).
4.8 Large Woody Debris Dams

Sites for LWD dams were chosen based on where water could be impounded without encroaching on buildings identified using the OS MasterMap. The hillshade tool was applied to the 1 m DTM raster to allow a better visualisation of the landscape and guide the placement of LWD dams.

The 3D analysis tools within ArcMap were then used to calculate the volume of water that could be stored behind each LWD dam using the process shown in Figure 4.10. A 0.5 m contour interval was chosen, which allowed a representative volume to be created behind a dam of between 1 and 1.5 m in height.
Figure 4.10 Flow chart showing process for calculating volume behind a LWD dam

Figure 4.11 shows the creation of a polygon behind a linear feature representing a LWD dam located at the site of Photograph 4.2 demonstrating a close match.

Figure 4.11 Polygon created behind a LWD dam in ArcMap and photograph of the location
4.9 Rainfall runoff analysis

Catchment descriptors were extracted from the Flood Estimation Handbook using the FEH Webservice (Centre for Ecology and Hydrology, 2017). Descriptors for the Winford Brook catchment and individual sub catchments are shown in Table 4.3.

Where an area was not covered by a defined catchment, a quasi-catchment was used utilising the catchment descriptors for the overall Winford catchment, and the remaining area of the catchment.

Table 4.3 Catchment descriptors from the FEH Webservice

<table>
<thead>
<tr>
<th>Catchment Descriptors</th>
<th>Winford Brook</th>
<th>North Farm</th>
<th>Bithams</th>
<th>Littleton Court</th>
<th>Primrose</th>
<th>Felton</th>
<th>Powdermill Farm</th>
</tr>
</thead>
<tbody>
<tr>
<td>SAAR 61-90 (mm)</td>
<td>955</td>
<td>909</td>
<td>934</td>
<td>965</td>
<td>970</td>
<td>979</td>
<td>964</td>
</tr>
<tr>
<td>URBEXT 2000</td>
<td>0.0181</td>
<td>0.0026</td>
<td>0</td>
<td>0.0048</td>
<td>0.0077</td>
<td>0.0329</td>
<td>0</td>
</tr>
<tr>
<td>DPLBAR (km)</td>
<td>4.97</td>
<td>1.35</td>
<td>1.23</td>
<td>1.5</td>
<td>1.25</td>
<td>2.77</td>
<td>2.2</td>
</tr>
<tr>
<td>DPSBAR (m per km)</td>
<td>73.6</td>
<td>97.8</td>
<td>99.7</td>
<td>102.8</td>
<td>108</td>
<td>57.3</td>
<td>68.9</td>
</tr>
<tr>
<td>PROPWET (mm)</td>
<td>0.35</td>
<td>0.35</td>
<td>0.35</td>
<td>0.35</td>
<td>0.35</td>
<td>0.35</td>
<td>0.35</td>
</tr>
<tr>
<td>BFIHOST</td>
<td>0.692</td>
<td>0.625</td>
<td>0.681</td>
<td>0.662</td>
<td>0.7</td>
<td>0.761</td>
<td>0.679</td>
</tr>
</tbody>
</table>

The descriptors were used as input in the ReFH2 software released by the Centre for Ecology and Hydrology (CEH) and used to generate hydrographs.

Rainfall depth, peak flow and the occurrence of property damage in the 2012 floods is reported by JBA Consulting (2013b). Three separate floods in November were shown to cause property damage with flows ranging from 7.1 m³/s to 7.6 m³/s as measured at Chew Magna Reservoir. A flood a few days prior to this had a flow of 5.3 m³/s and did not cause property damage. The November floods were provisionally estimated to have a return period of 1 in 10-years. Whilst there is some uncertainty in the magnitude of the peak flows, and on the estimated return period, a reasonable assumption could be made that reducing the peak flow from approximately 7.1 m³/s to 5.3 m³/s in a 1 in 10-year event could avoid property damage. This represents a 25% reduction.

The storm duration used in the hydrograph for the overall catchment was applied to each individual sub-catchment, which allowed a consistent rain event to be applied across the whole study area. By multiplying the flow rate by the timestep, the volume of
water at each timestep was calculated. This allowed an estimate of the volume required to reduce the flood peak by 25%.

The 1 in 10-year total flow data was extracted from each sub-catchment, and summed for each timestep to produce a combined hydrograph. In order to account for the distance upstream of each tributary, data was taken from the hydraulic model for the Winford Brook (Millington, 2017). Channel geometry, slope and roughness allowed a velocity to be calculated resulting in an estimated time for the flood wave from each sub-catchment to reach the outfall in Chew Magna (Table 4.4). The effect of implementing measures in one sub-catchment on the overall hydrograph could be then be observed.

Table 4.4 Lag times applied to each sub-catchment

<table>
<thead>
<tr>
<th>Sub-catchment</th>
<th>Lag time (mins)</th>
</tr>
</thead>
<tbody>
<tr>
<td>North Farm</td>
<td>0</td>
</tr>
<tr>
<td>Bithams</td>
<td>132</td>
</tr>
<tr>
<td>Littleton Court</td>
<td>160</td>
</tr>
<tr>
<td>Primrose</td>
<td>182</td>
</tr>
<tr>
<td>Felton</td>
<td>182</td>
</tr>
<tr>
<td>Powdermill Farm</td>
<td>169</td>
</tr>
<tr>
<td>Quasi catchment</td>
<td>0</td>
</tr>
</tbody>
</table>

The effect of implementing measures on the hydrograph was assessed by the hydrograph data for the appropriate sub-catchment. The effect of a rainfall event arriving from different directions was also considered.

4.10 SuDS retrofit

The volume of runoff generated by the Winford Business Park was calculated by taking the area of impervious hard-standing and roofs, and using the catchment descriptors for a point in the centre of the business park extracted from the FEH webservice to generate a hydrograph for the same storm applied to the rest of the catchment. The volume of runoff generated then becomes a target for SuDS measures to attenuate.
5 Results

5.1 Results of flow accumulation

The flow accumulation tool was applied to a DTM model and the result for the 5 m DTM is shown in Figure 5.1.

Figure 5.1 Map showing the output of the flow accumulation tool
5.2 Sub-catchments

Sub-catchments were identified using the watershed tool in ArcMap and are displayed in Figure 5.2.

5.3 Landcover data

Figure 5.3 and Figure 5.4 show the changing landcover in the Winford Brook catchment from 2007 to 2015, with corrections applied to the 2015 dataset to bring it up to date. A significant change from arable to grassland has been observed during this time.
Figure 5.3 2007 Landcover map for the Winford Brook catchment

Figure 5.4 2015 Landcover map for the Winford Brook corrected through fieldwork in July 2017.
5.4 Identification of Woodland sites

Figure 5.5 shows the locations within the catchment where woodland planting could be targeted. The high impact area has the greatest potential for reducing runoff through storage and infiltration.

Table 5.1 shows the potential volume of water that could be stored by each category of woodland based on 100 m$^3$/ha. This is further broken down in
Table 5.2 by sub-catchment.

**Table 5.1 Potential storage for woodland planting areas**

<table>
<thead>
<tr>
<th>Potential Impact</th>
<th>Area (ha)</th>
<th>Potential Storage (m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low Impact</td>
<td>736.8</td>
<td>73681</td>
</tr>
<tr>
<td>Medium Impact</td>
<td>415.3</td>
<td>41532</td>
</tr>
<tr>
<td>High Impact</td>
<td>93.5</td>
<td>9353</td>
</tr>
</tbody>
</table>
### Table 5.2 Potential storage for woodland planting areas by catchment

<table>
<thead>
<tr>
<th>Sub-catchment</th>
<th>Low Impact (ha)</th>
<th>Medium Impact (ha)</th>
<th>High Impact (ha)</th>
<th>Potential Storage (m$^3$)</th>
<th>Potential Storage (m$^3$)</th>
<th>Potential Storage (m$^3$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>North Farm</td>
<td>46</td>
<td>50</td>
<td>12</td>
<td>4590</td>
<td>5007</td>
<td>1179</td>
</tr>
<tr>
<td>Bithams</td>
<td>36</td>
<td>29</td>
<td>21</td>
<td>3559</td>
<td>2922</td>
<td>2142</td>
</tr>
<tr>
<td>Lane End</td>
<td>13</td>
<td>3</td>
<td>2</td>
<td>1301</td>
<td>315</td>
<td>236</td>
</tr>
<tr>
<td>Littleton Court</td>
<td>79</td>
<td>73</td>
<td>11</td>
<td>7898</td>
<td>7310</td>
<td>1104</td>
</tr>
<tr>
<td>Primrose</td>
<td>21</td>
<td>41</td>
<td>8</td>
<td>2112</td>
<td>4097</td>
<td>801</td>
</tr>
<tr>
<td>Monarch</td>
<td>6</td>
<td>7</td>
<td>0</td>
<td>567</td>
<td>703</td>
<td>25</td>
</tr>
<tr>
<td>Felton</td>
<td>407</td>
<td>26</td>
<td>38</td>
<td>40728</td>
<td>2635</td>
<td>3831</td>
</tr>
<tr>
<td>Powdermill Farm</td>
<td>94</td>
<td>79</td>
<td>0</td>
<td>9441</td>
<td>7865</td>
<td>0</td>
</tr>
<tr>
<td>Littleton Farm</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

Much of the high impact area is steep-sloped, rough grassland (Photograph 5.1) and was not being used for grazing at the time of a site visit in September 2017.

*Photograph 5.1 High priority woodland area within the Littleton Court sub-catchment (Pardoe, 2017)*
5.5 Buffer strips

Figure 5.6 shows the risk of soil erosion in the arable fields in the Winford Brook catchment based upon the vulnerability of the underlying soil. There are no soils in the catchment that have the category of high or very high risk. The fields at moderate risk represent the highest priority fields for location of buffer strips.

The cluster of arable fields in the east of the catchment within the North Farm sub-catchment have the highest priority for the placement of buffer strips.
5.6 Runoff Retention Ponds

Figure 5.7 shows locations within the catchment that may be suitable for retention ponds, with sites located evenly north and south of Winford Brook.

Once smaller fields (< 5,000 m²) were eliminated, the volume of potential storage in each of the remaining fields was calculated based on 0.5% of an arable field and 1% of a grassland field being converted to a retention pond. The total for each sub-catchment is presented in Table 5.3 below. The Littleton Court sub-catchment north of the Winford Brook could provide the largest capacity for attenuation.
### Table 5.3 Potential storage volumes in identified fields

<table>
<thead>
<tr>
<th>Sub-catchment</th>
<th>Arable Fields</th>
<th>Storage potential (m³)</th>
<th>Grassland Fields</th>
<th>Storage potential (m³)</th>
<th>Total storage (m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>North Farm</td>
<td>12</td>
<td>2349</td>
<td>13</td>
<td>2350</td>
<td>4699</td>
</tr>
<tr>
<td>Bithams</td>
<td>3</td>
<td>312</td>
<td>20</td>
<td>5350</td>
<td>5662</td>
</tr>
<tr>
<td>Lane End</td>
<td>0</td>
<td>0</td>
<td>3</td>
<td>868</td>
<td>868</td>
</tr>
<tr>
<td>Littleton Court</td>
<td>0</td>
<td>0</td>
<td>35</td>
<td>12051</td>
<td>12051</td>
</tr>
<tr>
<td>Primrose</td>
<td>0</td>
<td>0</td>
<td>19</td>
<td>3768</td>
<td>3768</td>
</tr>
<tr>
<td>Monarch</td>
<td>0</td>
<td>0</td>
<td>2</td>
<td>165</td>
<td>165</td>
</tr>
<tr>
<td>Powdermill Farm</td>
<td>3</td>
<td>318</td>
<td>26</td>
<td>4376</td>
<td>4694</td>
</tr>
<tr>
<td>Littleton Farm</td>
<td>3</td>
<td>391</td>
<td>7</td>
<td>1574</td>
<td>1965</td>
</tr>
<tr>
<td>Wider Catchment</td>
<td>6</td>
<td>1067</td>
<td>45</td>
<td>9293</td>
<td>10360</td>
</tr>
<tr>
<td>Catchment Total</td>
<td>27</td>
<td>4437</td>
<td>170</td>
<td>39795</td>
<td>44232</td>
</tr>
</tbody>
</table>

The wider catchment figure represents the area not covered by defined catchments.
5.7 Instream features

Figure 5.8 shows an example of the locations of 16 LWD dams within the North Farm catchment representing a potential storage volume of 2,038 m$^3$.

The potential storage volume of water within each sub-catchment is reported in Table 5.4. The largest potential for storage is the Littleton Court sub-catchment. Monarch and Felton sub-catchments did not have a watercourse suitable for installation of a LWD dam, however opportunities for small features such as ditch-blocking placed on known flow paths may offer some attenuation.
Table 5.4 Potential storage from LWD dams by sub-catchment

<table>
<thead>
<tr>
<th>Sub-catchment</th>
<th>Total Volume (m³)</th>
<th>No. of Dams</th>
<th>Vol. / Dam (m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>North Farm</td>
<td>2038</td>
<td>16</td>
<td>127</td>
</tr>
<tr>
<td>Bithams</td>
<td>2216</td>
<td>19</td>
<td>117</td>
</tr>
<tr>
<td>Lane End</td>
<td>705</td>
<td>9</td>
<td>78</td>
</tr>
<tr>
<td>Littleton Court</td>
<td>3999</td>
<td>22</td>
<td>182</td>
</tr>
<tr>
<td>Primrose</td>
<td>3584</td>
<td>17</td>
<td>211</td>
</tr>
<tr>
<td>Monarch</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Felton</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Powdermill Farm</td>
<td>1343</td>
<td>15</td>
<td>90</td>
</tr>
<tr>
<td>Littleton Farm</td>
<td>614</td>
<td>6</td>
<td>102</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>14499</strong></td>
<td><strong>104</strong></td>
<td><strong>-</strong></td>
</tr>
</tbody>
</table>
5.8 Opportunities for SuDS

The Winford Business Park (shown in Figure 5.9) in the centre of the catchment covers an area of 12,809 m² and drains directly into the Winford Brook.

Figure 5.9 Winford Business Park site boundary
© Crown Copyright and Database Right 2017. Ordnance Survey (Digimap Licence).

Table 5.5 shows the runoff generated by the business park in a 1 in 10-year storm and therefore the reduction in runoff that could be achieved. A higher design standard (e.g. 1 in 100-year) would be applied to provide attenuation for larger events.

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Runoff generated in 1 in 10-year event</strong></td>
<td>173 m³</td>
</tr>
<tr>
<td>Potential rainfall harvesting from rooftops</td>
<td>58 m³</td>
</tr>
<tr>
<td>Left to mitigate</td>
<td>115 m³</td>
</tr>
<tr>
<td><strong>Runoff generated in 1 in 100-year event</strong></td>
<td>519 m³</td>
</tr>
<tr>
<td>Potential rainfall harvesting from rooftops</td>
<td>174 m³</td>
</tr>
<tr>
<td>Left to mitigate</td>
<td>345 m³</td>
</tr>
</tbody>
</table>
5.9 Summary of interventions

The volume of storage from each type of intervention is summarised in Table 5.6 and shows that runoff retention ponds have the greatest potential for storage of runoff in the catchment.

*Table 5.6 Summary of potential storage by sub-catchment*

<table>
<thead>
<tr>
<th>Sub-catchment</th>
<th>Woodland (m$^3$)</th>
<th>Runoff retention ponds (m$^3$)</th>
<th>LWD Barriers (m$^3$)</th>
<th>Total storage (m$^3$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>North Farm</td>
<td>1179</td>
<td>4699</td>
<td>2038</td>
<td>7916</td>
</tr>
<tr>
<td>Bithams</td>
<td>2142</td>
<td>5662</td>
<td>2216</td>
<td>10020</td>
</tr>
<tr>
<td>Lane End</td>
<td>236</td>
<td>868</td>
<td>705</td>
<td>1809</td>
</tr>
<tr>
<td>Littleton Court</td>
<td>1104</td>
<td>12051</td>
<td>3999</td>
<td>17154</td>
</tr>
<tr>
<td>Primrose</td>
<td>801</td>
<td>3768</td>
<td>3584</td>
<td>8153</td>
</tr>
<tr>
<td>Monarch</td>
<td>25</td>
<td>165</td>
<td>0</td>
<td>190</td>
</tr>
<tr>
<td>Felton</td>
<td>3831</td>
<td>0</td>
<td>0</td>
<td>3831</td>
</tr>
<tr>
<td>Powdermill Farm</td>
<td>0</td>
<td>4694</td>
<td>1643</td>
<td>6337</td>
</tr>
<tr>
<td>Littleton Farm</td>
<td>0</td>
<td>1965</td>
<td>614</td>
<td>2579</td>
</tr>
<tr>
<td>Wider Catchment</td>
<td>34</td>
<td>10360</td>
<td>0</td>
<td>10394</td>
</tr>
<tr>
<td><strong>Catchment Total</strong></td>
<td><strong>9352</strong></td>
<td><strong>44232</strong></td>
<td><strong>14799</strong></td>
<td><strong>68383</strong></td>
</tr>
</tbody>
</table>
5.10 Rainfall runoff results

The 1 in 10-year hydrograph for the overall Winford catchment is shown in Figure 5.10. A 7.5-hour storm was applied with a timestep of 30 minutes. The same rainfall event was applied to all the hydrographs generated.

A combined hydrograph (Figure 5.11) was produced based on the total flow from each of the sub-catchments in response to the same rainfall event. Appropriate lags were applied to each sub-catchment. Peak flow in this case is 4.3 m$^3$/s.

![Figure 5.10 1 in 10-year hydrograph for the Winford Brook catchment](image)

![Figure 5.11 Combined hydrograph produced from the sub-catchments](image)
6 Discussion

6.1 Introduction

At the beginning of the project the following research questions were defined:

- Which landscape-based surface water management interventions might be applied in the Winford Brook catchment?
- Where is surface water flowing and ponding during a storm?
- Which areas are at risk of soil erosion?
- Where might landscape-based interventions be effective in managing flows during storm events?
- What priority should these interventions be given?

Section 3 summarised the evidence for the efficacy of different landscape-based interventions and identified four measures to apply in the Winford Brook catchment: woodland planting, buffer strips, runoff retention ponds and LWD dams.

Landscape-based interventions have been shown to be effective in many situations (Wilkinson et al., 2014), but evidence suggests that its effect is reduced for larger flood events (Nisbet et al., 2011). It was therefore decided to focus on the 1 in 10-year storm in the Winford Brook catchment (Figure 5.10).

The hydrograph for the Winford Brook catchment predicts that during a 1 in 10-year storm a total of 247,697 m$^3$ of water passes through the village of Chew Magna. Analysis of the data in the report investigating the 2012 flooding suggests that a reduction in flood flow of 25% could avoid property flooding in a 1 in 10-year event (JBA Consulting, 2013b). This equates to 61,924 m$^3$ of storm water that needs to be attenuated to reduce the flood peak. This could be achieved either by temporary storage further up the catchment or by manipulation of the timing of the hydrographs from each of the sub-catchments.
6.2 Woodland planting

Locations where woodland planting could help attenuate surface water flows is shown in Figure 5.5, and are categorised as high, medium and low impact based on the potential for runoff generation on that land. Much of the high impact area falls on an area of low grade agricultural land which is steeply sloping, and currently is a mixture of rough grassland not currently in use and improved grassland used for grazing cattle (Photograph 5.1). This may offer significant opportunities to plant woodland without impacting so heavily on farm profitability. If a payment for ecosystem services approach was taken, farmers could be compensated for the loss in land.

Studies have shown that planting trees in strips or clumps can also offer almost the same benefits as those planted in continuous forests (Broadmeadow and Nisbet, 2009). It is possible therefore that a high proportion of benefits could be achieved with a reduced area of planting.

Where land is taken for woodland or other measures, care must be taken that the stocking density does not increase significantly between features as this could result in a higher degree of compaction (McIntyre and Marshall, 2010), and therefore higher runoff generation offsetting the benefits of the features installed.

If all the high impact land was used for woodland planting a potential 9,352 m$^3$ of flood storage could be provided, 15% of that required. Recreational and biodiversity benefits can also be gained from the creation of woodland.

6.3 Buffer strips

Priority areas for placing buffer strips were identified based on the risk of soil erosion (Figure 5.6). The highest priority areas are found in the North Farm sub-catchment and these fields may benefit from thicker buffer strips to control sediment. Other measures to control runoff entering those fields should be considered to help minimise surface water flow paths. For example, ploughing perpendicular to contours has been observed in the catchment (Figure 6.1), which can increase surface runoff (Boardman et al., 2009).
Sedimentation in Chew Magna Reservoir was identified by Sherrington et al. (2015) as one of the primary problems in the catchment. However, the North Farm sub-catchment feeds into the Winford Brook downstream of the reservoir so cannot contribute to sedimentation there.

Soil erosion is higher on arable land than grassland (Kibblewhite, Chambers and Goulding, 2016). Figure 5.3 and Figure 5.4 show the changing landcover in the Winford Brook catchment from 2007 to 2015 and highlight the shift in agriculture from arable to pasture. This could suggest that erosion is lessening and its resulting sedimentation in the reservoir is a decreasing problem contrary to the findings of Sherrington et al. (2015). A more likely explanation is that there is another more significant source of sediment in the catchment.

A site visit in September 2017 identified locations where cattle were gaining access to the watercourse (Photograph 6.1), and evidence of soil erosion around watering points, both of which could be significant sources of sediment and explain why sedimentation remains a problem in Chew Magna Reservoir despite the reduction in arable land.
Funding for fencing watercourses may be available under a catchment-sensitive farming scheme (Natural England, 2014), and could significantly reduce that source of sediment from the catchment. Watering points for cattle can also be better designed to reduce soil erosion (River Restoration Centre, 2013).
6.4 Runoff retention ponds

Figure 5.7 identifies locations that may be suitable for runoff retention ponds. These represent natural hollows in the landscape close to predicted surface water flow paths. Throughout the catchment, a total area of 823,734 m² was identified as suitable, however conversion of this area of land would be very disruptive to agriculture. In some smaller fields this could result in the loss of the entire field. The approach was therefore taken that smaller fields (less than 5,000 m²) were eliminated and where a field had the potential for runoff retention, a standard figure of 0.5% for arable and 1% for grassland would be used from each field. Assuming a mean depth of 1 m once full, this gave a total storage across the catchment of 44,232 m³. Quinn et al. (2008) suggested a higher figure of 5-10% of farmland could be taken for retention features, however this figure may result in greater resistance from landowners.

Although the map in Figure 5.7 provides a starting point for locations, careful design is required to ensure that the ponds fill during a storm (Environment Agency, 2012). A search distance of 25 m was applied during the methodology so that natural hollows in the landscape can be linked to surface water flows and some groundwork may be required to divert flows into ponds.

The Littleton Court sub-catchment offers the greatest opportunity for storage (12,051 m³). Areas outside a defined sub-catchment, particularly south of the Winford Brook, also provide a significant contribution (10,360 m³).

6.5 Large woody debris barriers

104 sites were identified for the placement of LWD barriers and a total storage of 14,499 m³ was estimated. In the Pickering case study (Nisbet et al., 2015), 100 dams were installed, but the estimated storage totalled only 1,300 m³, with a range of storage between 0.1 m³ and 110 m³. This is quite different to the volume of storage in the Winford catchment where a mean of 117 m³ per barrier was calculated. Many different designs of LWD dam could be applied that behave differently, and the dams modelled in the Winford catchment have more in common with the timber bunds described by Nisbet et al. (2015) designed to store a larger volume of water.

This study assumes a semi-engineered structure aimed at retaining a large volume behind it and locations were chosen on the potential to impound water. The fact that the dam is “leaky” and water will flow between gaps has been ignored and whilst the
theoretical volume stored behind the barrier may not change significantly, the rate at which the storage fills may be slower, altering the downstream flow.

The potential for each sub-catchment to store water is shown in Table 5.4 and varies based on the stream geometry. For example, there were 19 locations in the Bithams sub-catchment and 17 in the Primrose sub-catchment, however the watercourse within Primrose with a more deeply incised channel has greater potential to impound water and so has a much higher volume stored behind each barrier, and along with the Little Court sub-catchment provides the greatest opportunities for water storage.

In areas where there is either no watercourse, or it is unsuitable for impounding large volumes of water, ditch or gully blocking could act to slow surface water offering similar benefits. The effect of this has not been accounted for.

The studies presented in 3.3.4 widely report a delay in the flood peak from LWD barriers, however their effect on the magnitude of flood peak is less certain (Environment Agency, 2017). Thomas and Nisbet (2012) suggest a delay of 2-3 minutes per barrier which is supported by the experimental work of Wenzel et al. (2014). If this were applied to the sub-catchments delays to flood peaks of up to 44 minutes may be observed (Table 6.1).

Table 6.1 Potential delays to flood peak due to LWD barriers

<table>
<thead>
<tr>
<th>Sub-catchment</th>
<th>No. of barriers</th>
<th>Potential delay to flood peak (mins)</th>
</tr>
</thead>
<tbody>
<tr>
<td>North Farm</td>
<td>16</td>
<td>32</td>
</tr>
<tr>
<td>Bithams</td>
<td>19</td>
<td>38</td>
</tr>
<tr>
<td>Lane End</td>
<td>9</td>
<td>18</td>
</tr>
<tr>
<td>Littleton Court</td>
<td>22</td>
<td>44</td>
</tr>
<tr>
<td>Primrose</td>
<td>17</td>
<td>34</td>
</tr>
<tr>
<td>Monarch</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Felton</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Powderrmill Farm</td>
<td>15</td>
<td>30</td>
</tr>
<tr>
<td>Littleton Farm</td>
<td>6</td>
<td>12</td>
</tr>
</tbody>
</table>

The potential negative consequences of the synchronisation of flood peaks after implementation of LWD barriers is identified by Dixon (2013), and Burgess-Gamble et al. (2017) highlight the shortage of evidence in this area and suggest caution when implementing these measures. This is addressed in more detail in 6.7.
6.6 Other measures

Retrofitting SuDS in a location such as Winford Business Park could provide some attenuation of runoff and provide a benefit to businesses in the form of rainwater harvesting offsetting part of the cost. For a noticeable benefit to flood peaks, similar schemes would need to be applied to other businesses in the area, and to properties within the village of Winford.

Highway drainage has not been discussed in this report, but opportunities may be present for modifications to the highway drainage system to contribute to a reduction in flood risk. An example is near Littleton Farm where the outfall from highway drainage is directly into the Winford Brook. Redirection of high flow into an offline storage bund could provide some attenuation of flood flows.

The Bristol and Avon Streams area was designated as a target area for catchment-sensitive farming by Natural England in 2015 (Bristol Avon Catchment Partnership, 2016). Since then, funding has been available for farmers to implement schemes aimed at minimising soil erosion and nutrient pollution from their land, namely phosphate. So far, the majority of grants have been for measures such as concreting yards and improvements to roofing, i.e. those with the largest immediate benefit to the farmer (Sherrington et al., 2015). Farmers should be incentivised to take up other options such as livestock fencing in order to contribute to a reduction in soil erosion.

6.7 The effect on the hydrograph

The hydrograph for the Winford Brook catchment was compared to a combined hydrograph formed by convolution of the individual sub-catchments and a quasi-catchment representing the area not covered by defined sub-catchments. A difference was observed between the two, with the combined hydrograph having a higher peak and slower response (Figure 5.11). This is likely to be because the catchment descriptors for the overall catchment were applied to the area of the quasi-catchment. In reality, the quasi catchment has two distinct areas: Chew Magna, which would have a rapid response to rainfall, and an area of wider catchment which is not well connected to the watercourse, with a slower response. The combination of these two should result in a quicker overall response but a reduction in the peak, as the peak of the quasi catchment is flatter. Separating the two components would serve to reduce this difference.
The shape of the individual hydrograph for each sub-catchment will depend on the characteristics of that sub-catchment (topography, soil condition, etc). NFM measures by their nature aim to modify the response of the hydrograph, delaying or reducing the flow of water to the watercourse. NFM measures that delay the flood peak in one hydrograph may cause it to synchronise with another peak, increasing the peak of the overall hydrograph (Pattison et al., 2014).

The baseline hydrograph was based on the same rainfall event being experienced in every sub-catchment. In reality, the rainfall is likely to start from one side of the catchment and move across the landscape, so the sub-catchments will experience a different start time, and potentially a different duration for the rainfall. A scheme of measures designed to produce a particular response in the hydrograph could therefore produce an unexpected negative result under certain conditions.

A rainfall event starting in Felton and moving very slowly east could cause all the of the sub-catchment peaks to align, increasing the overall peak by 11% from the baseline Figure 6.2. In that scenario, any delay from NFM measures in any one sub-catchment would have a positive effect on reducing the flood peak, although if the same delay was produced in all sub-catchments, the peak will not change. Rainfall from the Felton direction is more likely due to the prevailing south westerly wind.

![Hydrograph showing worst case scenario of alignment in all peaks](image)

*Figure 6.2 Hydrograph showing worst case scenario of alignment in all peaks*

With rainfall applied evenly, or coming from Chew Magna, a 1-hour delay in any one of the Bithams, Littleton Court or Powdermill sub-catchments individually could increase
the flood peak by approximately 1.5%. The North Farm sub-catchment has the largest individual effect, increasing the peak by 3% as shown in Figure 6.3. This is due to its position directly north of the village and feeding into the Winford Brook close to the outfall of the catchment.

![Figure 6.3 Effect of a 1-hour delay in the North Farm hydrograph](image)

This analysis does not take into account reductions in the magnitude of the peak from water storage, which may be significant where woodland planting is increasing the contribution of throughflow vs overland flow, and retention ponds are storing a significant volume of water over 24 hours.

### 6.8 Summary

Of the interventions examined in this report, runoff retention ponds provide the largest opportunity to store water further up the catchment with a potential 44,232 m³ across the catchment. LWD have the potential to store approximately 15,000 m³ and whilst their potential to reduce flood peaks is uncertain, there is a significant opportunity to delay the flood peak. Woodland planting is the most disruptive of the interventions to current land use and therefore the least likely to be implemented, however there is a potential to attenuate up to 9,300 m³ of flood water. Overall, the Littleton Court sub-catchment has the greatest potential to affect the flood peak downstream with 17,154 m³ of storage potential.
Buffer strips can reduce soil erosion, but other interventions such as contour ploughing, livestock fencing and modifications to cattle watering areas are required to make an impact on sediment generation in the catchment.

In order to reduce the flood peak in a 1 in 10-year flood event by 25%, 61,924 m$^3$ of water needs to be retained in the catchment. Table 5.6 shows that the total volume if all the interventions were implemented is 68,383 m$^3$, exceeding the target figure. This suggests that it is possible for NFM measures to attenuate a 1 in 10-year flood by a magnitude significant enough to reduce flood risk to properties. However, it should be recognised that in order to reach that storage volume, three types of interventions spread throughout the catchment were required.

Consideration of the schedule for implementing measures in each of the sub-catchments is needed to avoid synchronisation of peak flows. For instance, implementing a scheme of LWD dams in the North Farm sub-catchment in isolation, could cause an increase in the flood peak in Chew Magna. A safer system would be to implement a small number of measures simultaneously in each sub-catchment.
### 6.9 Limitations

<table>
<thead>
<tr>
<th>Topic</th>
<th>Limitation</th>
<th>Resolution</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Woodland planting</strong></td>
<td>Opportunities for riparian woodland/reconnecting with the floodplain have not been considered</td>
<td>Further study of opportunities along Winford Brook to encourage out of bank flow</td>
</tr>
<tr>
<td></td>
<td>Assumption of 100 m³/ha for woodland depends on species and maturity. If trees or shrubs already exist on site, full additional benefit may not be realised</td>
<td>Include a reduction factor in the calculation to reduce the assumed volume based on average existing landcover</td>
</tr>
<tr>
<td><strong>Runoff retention ponds</strong></td>
<td>Assumption is all ponds are empty and operating at capacity; silt will reduce capacity</td>
<td>Base the assumed volume on a mean volume over time, considering the rate of sediment build-up and the maintenance period</td>
</tr>
<tr>
<td></td>
<td>Felton sub-catchment was not looked at in detail as there were few watercourses, and it was not covered by 2 m DTM. Opportunities may exist here for measures</td>
<td>Extend study to cover this area using 5 m DTM</td>
</tr>
<tr>
<td><strong>LWD Dams</strong></td>
<td>Shallow structures are hard to model accurately. DTM has 1 m resolution and max height of dam should be between 1 and 1.5 m</td>
<td>Some uncertainty needs to be accepted, and a range of volumes quoted</td>
</tr>
<tr>
<td><strong>Soil erosion</strong></td>
<td>Erosion risk on grassland was not considered</td>
<td>Repeat soil erosion risk work adding in proximity to</td>
</tr>
<tr>
<td>Runoff modelling</td>
<td>Hydrograph from quasi-catchment does not represent the area accurately</td>
<td>Treat urban area separately and adjust catchment descriptors accordingly</td>
</tr>
<tr>
<td>----------------------------------</td>
<td>-----------------------------------------------------------------------</td>
<td>-----------------------------------------------------------------------</td>
</tr>
<tr>
<td></td>
<td>The effect of storm water storage is difficult to model using a rainfall runoff approach</td>
<td>A more detailed hydraulic modelling approach is required</td>
</tr>
<tr>
<td></td>
<td>Timestep of 30 mins was taken from 1 in 10-year design storm for overall Winford Brook catchment and applied to all. A shorter timestep would allow more precision when applying lags to sub-catchments</td>
<td>Re-run ReFH2 method using shorter timestep</td>
</tr>
</tbody>
</table>

watercourse as an additional factor
7 Conclusion and recommendations

Significant opportunities for the implementation of surface water management interventions exist within the catchment and have been identified in this report.

The report focuses on catchment woodland, buffer strips, retention ponds and large woody debris dams, but other measures such as land management changes and retrofit SuDS are also briefly discussed.

- A reduction in peak flow of 25% in a 1 in 10-year storm would require storage of approximately 61,924 m$^3$ of surface water. The results show that this could be achieved with the implementation of a widescale scheme of NFM measures.
- Of the identified measures, runoff retention ponds offer the largest opportunity for storage of surface water with a potential 44,232 m$^3$ of storage if 1% of the area in suitable grassland fields and 0.5% in arable fields is set aside for this purpose.
- LWD dams offer a potential for approximately 14,500 m$^3$ of flood water storage along the tributaries to the Winford Brook and offer significant opportunities to delay the flood peak.
- Woodland planting within the catchment could have a significant role to play, but could be the hardest to implement at a scale that could make a difference as it involves the conversion of a large area of agricultural land.
- No single measure is enough to provide protection; a combination of measures must be applied.
- The timing of flood peaks from the sub-catchments that feed the Winford Brook contribute to the overall flood peak experienced in Chew Magna, and there is a risk that if measures are implemented in the wrong places, or in the wrong order, further synchronisation of the flood peaks may occur, making the situation in the village worse.
- Buffer strips offer an opportunity to manage soil erosion on many of the arable fields in the catchment by intercepting runoff and trapping sediment. Changes in farming and land management practices can also make a significant contribution, such as preventing livestock access to watercourses, and contour ploughing.
- By slowing surface water flow, offering opportunities for infiltration and intercepting sediment, water pollution from contaminants such as phosphate
fertilizer can be reduced. This could reduce the need for expensive phosphate removal treatment downstream.

- There are a number of funding opportunities for a scheme of measures in the catchment which include a payment for ecosystem services approach in partnership with Wessex Water or Bristol Water; future changes to the common agricultural policy, or implementation of funds raised through the community infrastructure levy.
8 Notes for future implementation

It is clear from the literature that more empirical evidence is required on effectiveness of NFM at a catchment scale. Implementing a catchment-wide scheme along the Winford Brook would provide a useful case study to address this but would require the installation of gauges to monitor the response of the river. Ideally, data would be collected for several years prior to installation of the measures in order to allow a baseline to set. This raises a difficult ethical question of whether it is justifiable to delay installing a measure that may prevent property damage for the sake of a scientific study. Installation of some gauging along the Winford Brook should therefore be considered as early as possible, before funding for measures is obtained, to allow some data to be collected.

Brexit is a very divisive and controversial topic; however, it may offer an opportunity to redefine the Common Agricultural Policy and there is discussion on whether future payments could be linked to the implementation of ecosystem services such as flood management (Guardian Online, 2016).

It is important that once measures are implemented they are properly maintained to ensure they remain effective, for example inspection of leaky dams, and de-silting of retention ponds. This may be simple if the measure has been funded as part of a catchment-sensitive farming scheme, but less so if the measure has been installed by local volunteers and responsibility is not clear.

In the Belford case study a demonstration was set up prior to full scale implementation in order to persuade regulators and landowners of the suitability and benefits of the scheme (Wilkinson et al., 2014). A similar approach of engagement, particularly with landowners, may be required to persuade landowners across the catchment to allow the installation of features on their land.
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10 Photographic Credits


Appendix A – Soil units categorised by erosion risk

Analysis from a NERC Innovation Project: Co-creating railway flood resilience – applying the science of blue-green-grey infrastructure NERC NE/M008274/1
12 Appendix B – Slope raster
13 Appendix C – Agricultural land grade

14 Appendix D – Relative runoff generation


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