Powburn Flood Risk Study

Powburn FRS

Northumberland County Council

November 2011

Draft Report

9W1520

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1 INTRODUCTION

Heavy rainfall over the Northumberland village of Powburn has led to a number of significant flood events in the last decade. The most recent flooding occurred in September 2008 which affected 1 commercial and 19 residential properties and led to an estimated £400,000 in property damage. Most flooding originated from the Pow Burn and its tributary the Crawly Dean Burn.

A previous review of the flooding problems at Powburn was undertaken for the Environment Agency following the September 2008 flood event to determine the causes and financial impacts of the flooding, as well as determine a number of potential flood management options. Consequently, and following subsequent local pressure, the Environment Agency constructed a number of small scale management schemes throughout 2010 - 2011 with the intention of reducing future flood impacts. The effectiveness of the Environment Agency works were unknown as the schemes were largely implemented without formal hydraulic assessments being completed and no formal monitoring had taken place.

Northumberland County Council has now taken a lead role in progressing the approach to future flood management at Powburn. At this first stage, Royal Haskoning has been commissioned by Northumberland County Council to provide a flood risk study for the village to determine the primary mechanisms of fluvial flooding, report on the current watercourse assets in the catchment, provide an assessment of the effectiveness of the Environment Agency flood alleviation schemes, and identify any further appropriate options that might be implemented to manage and reduce flood risk in the future. This report presents the findings and conclusions from this study.

As part of the study, an inspection of all major channel structures and the various catchment watercourses was carried out and reported to the Council in December 2010. This asset (*Powburn Interim Asset Report*) report is provided in **Appendix A**.

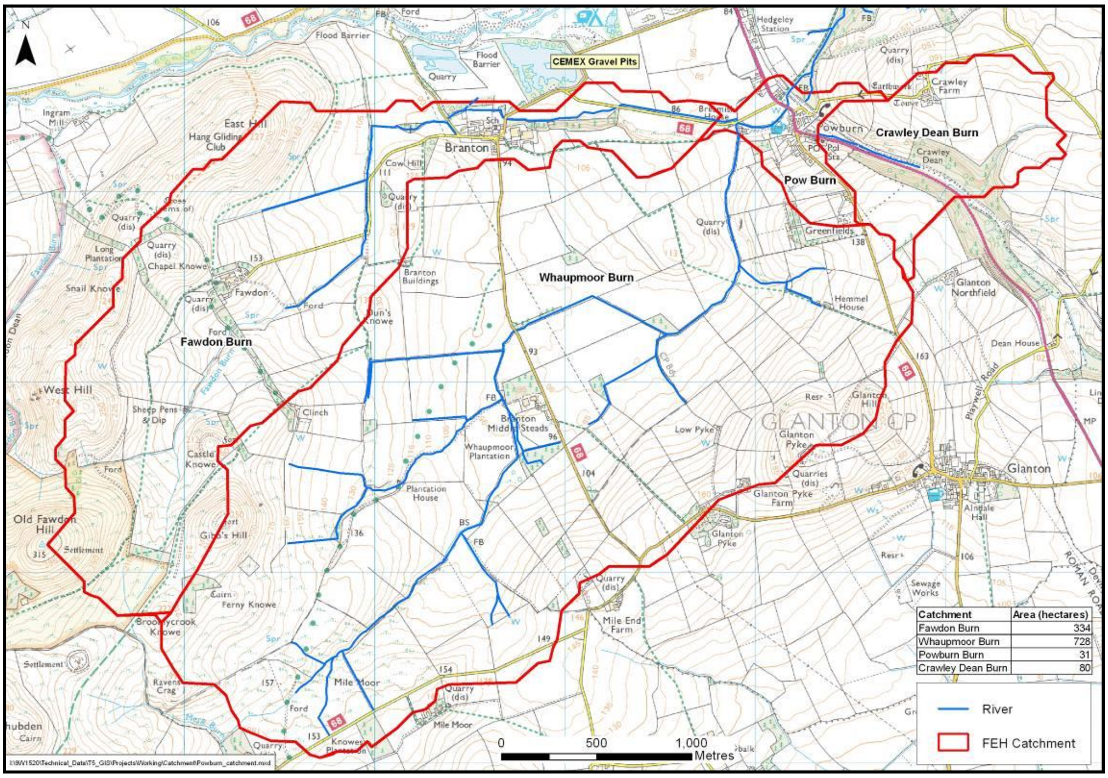
2 BACKGROUND

2.1 Catchment Description

Powburn is a small rural village in Northumberland approximately 2km south east of Morpeth. The primary watercourse which flows through the village is the Pow Burn, which is classified as an Ordinary Watercourse. The Pow Burn drains a catchment area of approximately 11km^2, comprised of three tributaries which converge just to the south of the village (Fawdon Burn (3.3km^2), Whaupmoor Burn (7.3km^2), and Crawley Dean (0.8km^2)). The catchment area is dominated by agricultural land which slopes on a steep gradient towards the north before shallowing on to the flat floodplain of the River Breamish, where the Pow Burn joins on its right bank. Minor exceptions to this are the small built up areas at Powburn, which incorporate a number of properties in the centre of the village adjacent to the Pow Burn, the new Crawley Dean housing estate, on the right bank of the Crawley Dean, and a small number of residential properties at Branton, adjacent to the Fawdon Burn.

Figure 1 provides an overview of the Pow Burn catchment and its three tributary watercourses. The following sections provide greater detail of each of these watercourses and further details of the structures are provided in the asset report in **Appendix A**.

Figure 1 – Pow Burn and Tributaries Catchment Plan



2.1.1 Whaupmoor Burn

The source of the Whaupmoor Burn is located to the south west of Powburn in steep agricultural and moor land incorporating Gibb's Hill, Mile Moor, and Glanton Pyke. The watercourse drains an area of approximately 7.3km^2 as it flows north across farmland and plantations, joined by a number of minor upland tributaries as it flows towards Powburn. The only notable infrastructure along the watercourse are a few small farm buildings dotted around the upper catchment, however these are well set back from the watercourse and do not appear to be at any risk of flooding from the channel.

Where the watercourse passes beneath the roads in the upper catchment, it is culverted for lengths of approximately 10 to 20m. The condition of these culverts appears good (although the internal condition has not been inspected and is not known), and blockage does not presently appear to cause any risk of flooding to properties.

2.1.2 Pow Burn

In the lower catchment to the south of Powburn, the Whaupmoor Burn channel gradient reduces significantly as it flows across the wide flat floodplain which defines the topography of the village. At this point, on the upstream side of the village (to the south west), the watercourse is joined on its left bank by the Fawdon Burn, and from the point of this confluence, the watercourse is referred to as the Pow Burn. The Pow Burn flows in an incised channel across farm land before flowing beneath the A697 road bridge and then through the former bridge abutments of the disused railway embankment.

The Powburn Sewage Treatment Works is located immediately downstream of the disused railway embankment adjacent to the right bank, and from here the Pow Burn flows along a very shallow gradient to discharge into the River Breamish approximately 2km to the north. Prior to joining the Breamish, approximately 200m downstream of the disused railway embankment and Sewage Treatment Works, the Pow Burn is joined by the Crawley Dean Burn on its right hand bank.

2.1.3 Fawdon Burn

The Fawdon Burn rises in the steep upland moors around Old Fawdon Hill and Castle Knowe approximately 3.3km southwest of Powburn village. The Burn has a relatively narrow and shallow channel as it flows through the small settlements at Fawdon and Branton. Upstream of Branton, the Fawdon Burn passes through a large rectangular culvert beneath the Branton to Brandon road, before dropping approximately 2m over an old weir at the site of what appears to be a former mill. Downstream of the former mill, the channel enters a stilling basin inlet structure with a culvert outlet and broad-crested concrete weir along its left bank. The limited capacity of the culvert allows excess flows to back-up in the stilling basin and then flow over the weir and into the former CEMEX gravel pits quarry to the north of Branton. The gravel pits stand full of water and are understood to have an outlet to the north which discharges directly into the River Breamish. This allows excess flows from the Fawdon Burn to bypass Powburn.

Downstream of the culvert outlet, the watercourse flows in a section of open channel for approximately 150m before passing through a triple culvert beneath the Branton Road bridge. Downstream of the bridge the watercourse flows alongside the road across very flat agricultural land towards the north. Upstream of Powburn it turns a 90° bend beneath a road bridge and joins the Whaupmoor Burn to form the Pow Burn to the south of the village.

2.1.4 Crawley Dean Burn

This tributary is located to the east of Powburn within a very steep, narrow valley between Glanton Hill and Titlington Pike. The Crawley Dean Burn flows northwest alongside the main A697 road on the southern edge of the former railway embankment within a relatively wide, heavily vegetated channel. The channel is culverted for a short section beneath a small access track, before continuing in an open channel which contains a number of sharp 90˚ bends around the perimeter of the Crawley Dean housing estate.

The channel then enters a long culverted section at the entrance of the housing estate and follows an unknown alignment until it discharges on the downstream side of the railway embankment. From here, the watercourse follows a shallow, meandering course for approximately 100m before entering the Pow Burn on its right bank approximately 200m downstream of the Sewage Treatment Works.

2.2 History of Flooding

Many parts of the North East suffered severe flooding following heavy rainfall during September 2008. At Powburn, flooding during this event resulted in inundation of a number of properties from the main Pow Burn and Crawley Dean Burn.

Flooding from the Pow Burn primarily originated from the excess flows immediately upstream of the main A697 road bridge. This section of the watercourse is very flat and heavily vegetated, as well as being constrained by the piers of the former railway bridge all of which are believed to have contributed to flows spilling onto the adjacent floodplain and affecting a number of properties.

Local residents have suggested that the small bridge over the Pow Burn which provided access to the Sewage Treatment Works, downstream of the former railway bridge, could also have contributed to the flooding. The access bridge had a rectangular section and the deck was below the top of the bank causing a restriction to flows in the Pow Burn channel. This restriction could cause the burn to back up and increase water levels in the village.

The confluence of the Pow Burn and the River Breamish is approximately 2.5km downstream of Powburn village. Levels in Powburn Village are at approximately 84mAOD, while levels at the confluence between the Pow Burn and the River Breamish are around 72mAOD. With this difference in level, flooding in Powburn Village is unlikely to be affected by backwater from the River Breamish. However, the indicative 1 in 100 year (1%AEP) floodplain does indicate that flooding from the Breamish and Pow Burn merge downstream of the Branton to Beanley Road (to the north of the village), so the River Breamish may have some influence over watercourse levels in the Pow Burn.

In addition to flooding from the Pow Burn, other flood risks have been reported from the Crawley Dean Burn, which resulted in significant flooding to the adjacent local properties on the Crawley Dean Estate. This flooding is understood to have resulted from backing up of flows at the inlet to the Crawley Dean culvert. The inlet has a vertical bar debris screen attached (which are susceptible to 'blinding', blockage), which is reported to have been blocked during the event; however it is not known if all of the risk is associated with the blockage or if there is also a lack of flow capacity within the culvert.

On the Fawdon Burn, excess flows were reported to come out of bank at the 90° bend at the confluence with the Whaupmoor Burn, resulting in flooding through the adjacent fields, affecting property on the north edge of Powburn village and exacerbating backing up of flows at the disused railway embankment.

Further risks have been reported as a result of surface water runoff from steep roads which lead down into the village. Significant flooding to property was reported following surface water flows down the steep farm track north of the village, leading to ponding of water at the bottom of the hill under the railway arch. Further surface water flooding has been seen in the village in the vicinity of The Plough Inn, as a result of flows down the Powburn to Glanton road.

Detailed investigations of these surface water issues are beyond the scope of this study, however it is important to acknowledge their existence as it is understood that they have led to internal property flooding as a result of toilets backing up due to the combined surface water / foul sewer system becoming surcharged.

2.3 Previous Studies

2.3.1 North East Flooded Communities Review (August 2009)

In 2009 the Environment Agency completed a review of the Pow Burn and its tributaries as a part of their assessment of the September 2008 flood event impacts. Included in this review was an assessment of the mechanisms of the flood event, and an initial estimate of the economic damages incurred.

At the time of the study, river flow data was not available for the catchment, so no detailed assessment on the return period (Annual Exceedance Probability) of the event was carried out. In the absence of flow data, an estimate was made based on comparisons of the flood outline with the modelled 1 in 100 years return period (1% AEP) flood map. From this comparison, it was estimated that the event was greater than a 1 in 100 years (1% AEP) event as the actual flooding was greater than that shown on the flood map. The mechanisms for flooding were identified as follows:

- The Pow Burn exceeding its channel capacity.
- The Crawley Dean Burn exceeding its culvert capacity and blockage of culverts.
- A landslip in the Crawley Dean Catchment which forced surface water to enter the Crawley Dean.

Flooding in September 2008 was concluded to have cost £400,389, based on the Multi Coloured Manual approach for estimating strategy level damages.

The report concluded that upstream storage and culvert maintenance are the preferred flood alleviation options for both watercourses, as well as some individual property protection. Subsequent to this review, the Environment Agency implemented a range of small-scale flood management schemes (in 2010) through the Local Levy programme.

3 PROBLEM

The current flooding problems within the Pow Burn catchment appear to be a result of insufficient channel and culvert capacities on the Pow Burn and Crawley Dean Burn. These issues can be attributed in part to constrictions in the Pow Burn due to development on the floodplain and old, under-sized culverts. However, the fast response time of the upper catchment also produces high flows in all three of the tributary watercourses, exerting further pressure on the downstream channel.

From assessment of the previous flooding and discussions with the local community flood group, it is apparent that flood issues with the greatest impacts are situated in two main locations:

- The Crawley Dean, and;
- Powburn village centre, downstream of the A697 bridge and at the disused railway embankment.

The following assessment of the fluvial flooding issues at Powburn is based on site and desk-based investigations and consultation with the Environment Agency. It is not known whether the schemes implemented following the September 2008 event have resolved these issues, as their behaviour and effectiveness during high-flow events has not been monitored.

3.1 Crawley Dean and Culvert

The very steep and heavily vegetated nature of the Crawley Dean has the potential to cause quite significant flood risk. The primary flood risk is to the numerous properties within the Crawley Dean housing estate to the north of the watercourse, which has resulted from backing up at the small culvert where the watercourse passes beneath the estate.

There have been historic problems with the previous vertical bar screen, which was susceptible to blockages and 'blinding'. Since the 2008 flooding, this has been replaced by an updated angled screen (as shown in the photo, **Figure 2**). Although much improved over the previous vertical screen, this still appears quite steep due to the incoming drain connection on the left side, and may still be susceptible to some blockage.

Figure 2 – Crawley Dean Culvert Entrance

3.2 Powburn Centre

The primary risk to the centre of Powburn village comes from the constricted nature of the Pow Burn channel immediately up and downstream of the A697 bridge, and the constriction caused by the bridge abutments of the disused railway bridge and embankment. During past events, flooding has emerged out of bank upstream of the A697 road bridge, leading to flooding to the adjacent properties. Flows have then become impounded behind the railway embankment (**Figure 3**) leading to backing up, increasing upstream water levels and causing further flooding in the village, as the flood waters have no means to drain away.

Figure 3 – Constricted watercourse through railway bridge piers

4 ENVIRONMENT AGENCY WORKS TO DATE

Following recent flooding events and near misses, the Environment Agency Local Levy team has installed a number of small-scale flood alleviation measures across the catchments which were recommended within the North East Flooded Communities Review for Powburn. Details of each of these measures are provided in the following sections.

4.1 Crawley Dean Burn

4.1.1 Crawley Dean In-line Storage

The Environment Agency has constructed two in-line flood storage areas on the Crawley Dean Burn, adjacent to the A697. These structures consist of earth embankments constructed from imported clay, with plastic sheet pile cut-offs. Each embankment is approximately 1m high (channel bed to crest) and the crest is reinforced with low grade armour stone.

These embankments have a flow-through pipe of 300mm diameter to allow low flows to pass through the embankment. However, during high flow events, these pipes throttle the flow and cause excess water to back-up in the in-channel storage area upstream.

It was confirmed by the Environment Agency that no as-built drawings were supplied by the contractor on completion. The structure was intended as a low design structure, and as yet is unproven and untested by significant high flow events.

The exact storage volume of the storage areas is not known, however the Environment Agency was keen to ensure that the total storage of the two storage areas did not exceed the 10,000m^3 limit of the 2010 Reservoirs Act; particularly due to the close proximity of residential property downstream.

Figure 4a – Storage embankment with 300mm diameter outlet pipe

Figure 4b – Armoured embankment crest

4.1.2 Crawley Dean Off-Line Storage

Immediately upstream of the Crawley Dean Housing Estate, the Environment Agency has installed an in-channel flow control structure (weir). This weir is made from plastic sheet piles with a timber bracing and has a hole cut into the bottom of the structure at channel bed level to allow low flows.

In addition to the weir, the Environment Agency has also constructed a low, earth embankment along the eastern edge of the Crawley Dean Housing Estate and southern edge of the field adjacent to the right bank.

The hole at the base of the weir is designed to allow low flow events to pass through the structure as normal. However, during higher order events, the weir will form a barrier to flows, causing excess water to back up in the channel behind the structure. Once the water level behind the structure reaches that of the right bank, these excess waters flow into the adjacent field where they are stored behind the newly constructed embankments.

Water stored within the storage pond is then returned back to the channel slowly via two 300mm diameter plastic pipes.

Figure 5 – In-channel weir, overflow (through fence) and storage embankment

4.1.3 Crawley Dean Estate Embankment

During construction of the housing estate, the housing developers constructed a low bund (<1m high) along the right bank of the Crawley Dean as a result of land levelling of the adjacent site. This bund was not designed as a flood defence and is reported to have been subject to seepage, resulting in flooding of the adjacent properties.

In an attempt to reduce this risk of seepage, the Environment Agency ‘topped up’ the level of this embankment with the addition of imported clay that was being used for the in-line storage embankments. It was hoped that the inclusion of clay on the back slope and crest would reduce the risk of seepage, as well as increasing the level protection.

Figure 6 – Crawley Dean Housing Estate Embankment

4.1.4 Crawley Dean Overflow Culvert

To increase the capacity of the Crawley Dean culvert during high magnitude events, the Environment Agency has installed an overflow culvert to alleviate flows within the downstream section. This allows excess flows to bypass the lower end of the main culvert, and discharges into the Pow Burn immediately upstream of the disused railway embankment. Few details of the exact depth or location of this culvert are available as there are no as built drawings available; however the culvert can be seen discharging into the Pow Burn just upstream of the disused railway embankment.

Figure 7 – Crawley Dean Overflow Culvert Outlet into the Pow Burn

4.1.5 Crawley Farm Road Surface Water Strip Drains

Although not strictly a fluvial flooding problem, surface water running down the steep road from Crawley Farm previously resulted in significant surface water flooding in the vicinity of the disused railway bridge. This surface water accumulation resulted in serious flooding to adjacent properties during past events and causes disruption to traffic flow.

In an effort to reduce the risk of surface water flooding in this location, the Environment Agency installed a series of strip drains across the road to collect the surface water flows and divert them into a ditch to the north of the railway embankment, before it is able to pond within the village.

Figure 8 - Crawley Farm Road Surface Water Strip Drains

4.2 Pow Burn and Whaupmoor Burn

4.2.1 Upper Catchment Storage (Whaupmoor Burn)

The Environment Agency has installed three large upstream off-line storage ponds to attenuate flows in the upper catchment and slow the hydraulic response to ensure that peak flows from across the catchment do not converge within Powburn village at the same time.

These storage ponds are of similar construction to those built on the Crawley Dean Burn. They each comprise a clay cored embankment with a cobble armoured crest and plastic pipe outfalls. Excess flows are diverted into the off-line storage areas with a plastic sheet pile weir similar to that on the Crawley Dean Burn, with a hole cut in the bottom to allow low flows to pass.

Figure 9 – Upper Catchment Storage Ponds

4.2.2 Pow Burn Flood Embankments

The largest flood defence implemented by the Environment Agency at Powburn is the construction of a series of 1m high flood embankments near the centre of the village. These embankments have been constructed around the perimeter of the agricultural fields which make up the floodplain upstream of the A697 road bridge, and back on to properties along the A697. At the bridge, the embankments tie into the bridge parapets and to the south the embankment ties into high ground off the A697. Off the left bank of the channel, the embankment has been extended to the north along the rear of the single property to the north of the Powburn to Fawdon Road, which prevents flows crossing the floodplain and inundating this property and the road. In doing so, the Environment Agency has had to raise a short length of the carriageway to ensure that the embankments can not be outflanked.

Figure 10 – Powburn Flood Embankments


4.2.3 Disused Railway Embankment Culverts

During the September 2008 event, flooding to properties at the north of Powburn was prolonged due to the inability of flood water to drain away quickly as a result of flows becoming trapped behind the disused railway embankment. To alleviate this problem, the Environment Agency excavated a short section of the embankment to install two 1.0m diameter concrete culverts through the embankment.

Figure 11 – New Railway Embankment Culverts

4.2.4 Sewage Treatment Works Ford

The final element of the Environment Agency's works in Powburn was the removal of the access bridge to the Sewage Treatment Works. Through discussion with Northumbrian Water, the Environment Agency was able to agree an arrangement for the installation of a new ford, which will reduce the risk of flood water backing up in this lower reach of the watercourse.

Figure 12 – New Sewage Treatment Works Ford

5 MODELLING OF ENVIRONMENT AGENCY LOCAL LEVY SCHEMES

5.1 Aim of Modelling

A 1D hydraulic model of the Pow Burn and all three tributaries has been constructed using ISIS river modelling software. The aim of this modelling was to assess the hydraulic benefits that are provided by the Environment Agency's recent flood alleviation measures and assess the magnitude of residential flood risk. By investigating two separate scenarios of the watercourse (Existing and Pre-Scheme); we have been able to assess the direct impact that the additional storage and attenuation measures have had at specific locations within the catchment.

Please note that our assessment of the Standard of Protection (SoP) provided by the Environment Agency schemes is based only on their hydraulic performance, and does not make any assumptions about their structural stability or integrity. Further details of their structural condition can be found in **Appendix A**.

All model results and schematics are provided in **Appendix B**.

5.2 Modelling Methodology

The 1D hydraulic model was constructed using the ISIS river flow modelling software based on river channel cross sections surveyed in February 2011 by Academy Geomatics. Care was taken during the design of the survey to ensure that all major channel structures were surveyed thoroughly to ensure their accurate representation within the model. The details and arrangement of each of the Environment Agency flood alleviation schemes were included into the model (weirs, storage areas, in-channel bunds).

Once the Existing model had been completed, a second model was constructed in which the recent Environment Agency works were removed, thus representing the nature of the catchment prior to the installation of the works (Pre-Schemes model). The previous Sewage Treatment Works access bridge has not been re-included for the Pre-Schemes scenario model, as the new ford was already installed prior to undertaking the survey work and exact details of the previous bridge arrangement are not known.

By comparing water levels in these two models, we have been able to establish:

- Indicative standards of protection for various locations along each watercourse, and
- The relative improvement in flood protection provided by the works implemented by the Environment Agency Local Levy Team.

5.2.1 Catchment Hydrology

Due to the lack of available flow or rainfall data, the FEH (Flood Estimation Handbook) Rainfall Runoff method was used to generate the model inflow hydrographs. With the aim of this modelling to establish an indicative level of understanding relating to the effectiveness of the Environment Agency flood defence works, this method was considered the most appropriate method to define inflows to the watercourses.

Both Existing and Pre-Schemes models were run using the same 5, 20, and 100 years inflow hydrographs, which have a critical duration of 2 hours and event durations of 4 hours.

5.3 Modelling Results

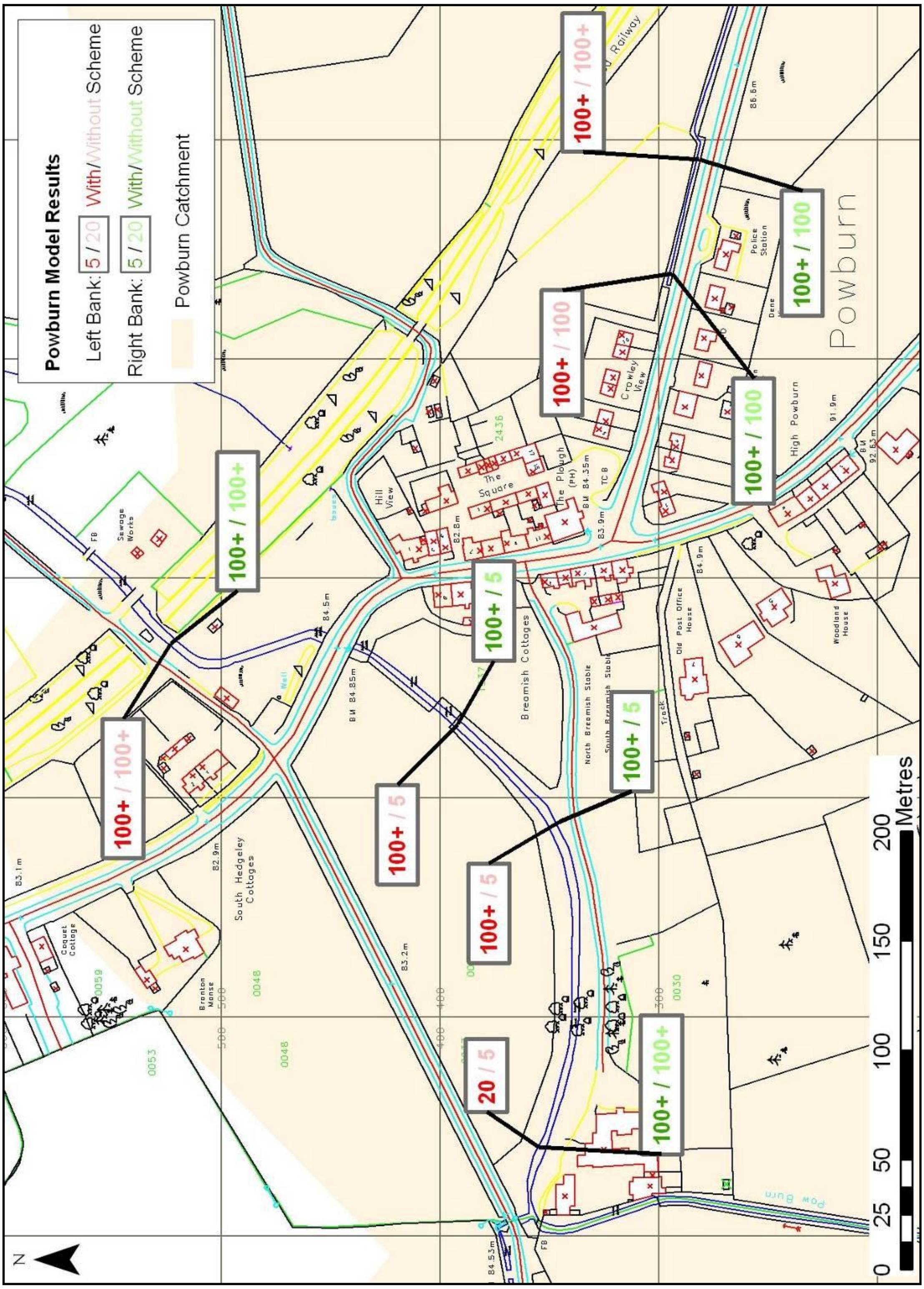
Figure 13 provides an indication of the onset of flooding (return periods) for the key flood risk areas within Powburn village, as indicated by the Existing and Pre-Schemes model scenarios. Comparative water level results from the model runs for both Existing and Pre-Schemes models are presented in **Appendix B**. Schematic plans of the model arrangements are also provided indicating the relevant model node references.

It is evident from these modelling results that there has been a clear improvement in the standard of protection to the village centre as a result of the recently installed Environment Agency schemes, particularly with the new raised flood embankment at the A697 road bridge. In the Pre-Schemes model, many of the key flood risk areas in the catchment have an onset of flooding between 5 and 20 years. However, the Existing (With Schemes) model results show that the majority of these areas will now only flood at a 100 year event or greater.

Just downstream of the Pow Burn / Fawdon Burn confluence there is one location (Node Reference: POW_F0548) where the residual onset of flooding (Post-Schemes, Existing) on the left bank is shown to remain at 20-year. Although the watercourse floods out of bank at this lower return period, the out of bank flows continue to the north-east and are contained within the new flood embankments alongside the A697 and around the Branton Manse and South Hedley Cottages properties. The 100-year water levels at the downstream model cross-sections indicate that this level of event is contained by the new embankments.

Further details of the effectiveness of the Environment Agency schemes are discussed in the following sections.

Figure 13 – Pre-Schemes and Post-Schemes (Existing) Onset of Flooding at key points within Powburn village

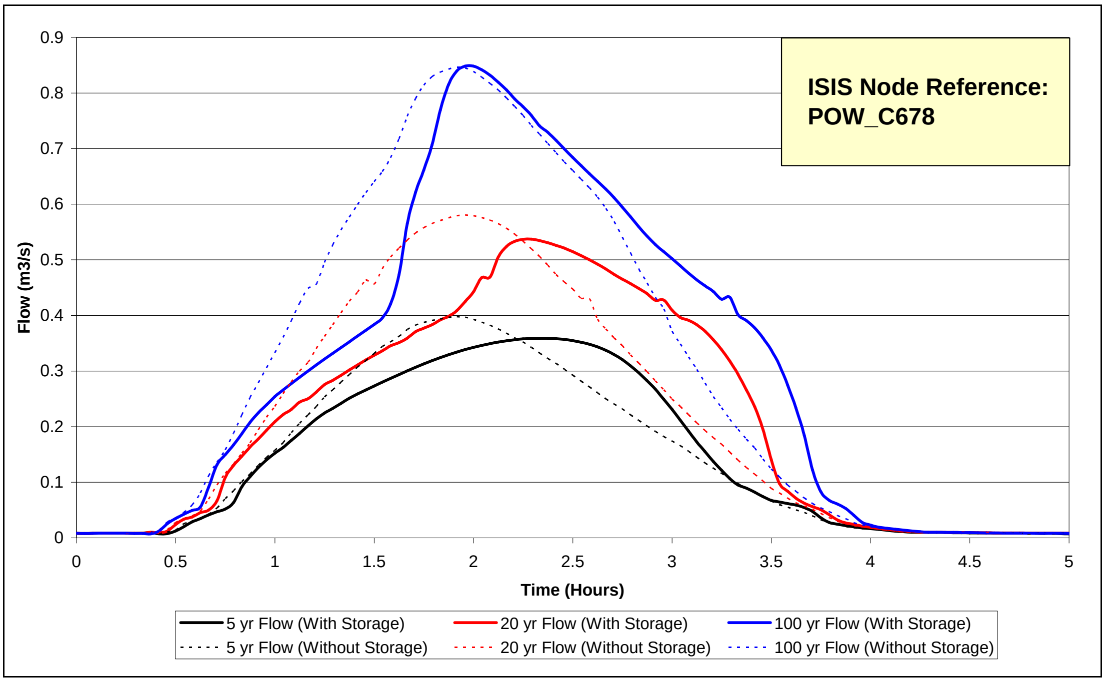


5.4 Crawley Dean Upstream Flood Storage

The two in-line flood storage ponds constructed in the upper Crawley Dean watercourse appear to be effective at all return periods, causing significant levels of backing up in the channel, and thus ultimately reducing the time to peak of the events. However, both of these storage areas are only effective at withholding flows without overtopping, for the 5 year (20% AEP) event. For the 20 and 100 year events (5% and 1% AEP), the maximum discharge over the embankments equals 0.13 and 0.43m^3/s, equivalent to 23% and 51% of the peak flow for these events.

Figure 14 illustrates the impact on the peak flows immediately downstream of the in-line storage ponds. As shown, the storage areas are effective at reducing peak flows for the 5 and 20 year events. However, overtopping occurs prior to the peak for the 100 year event, resulting in no change to the peak flow in the channel.

Figure 14 – Pre-Schemes and Post-Schemes (Existing) hydrographs from downstream of Crawley Dean In-line Storage Ponds



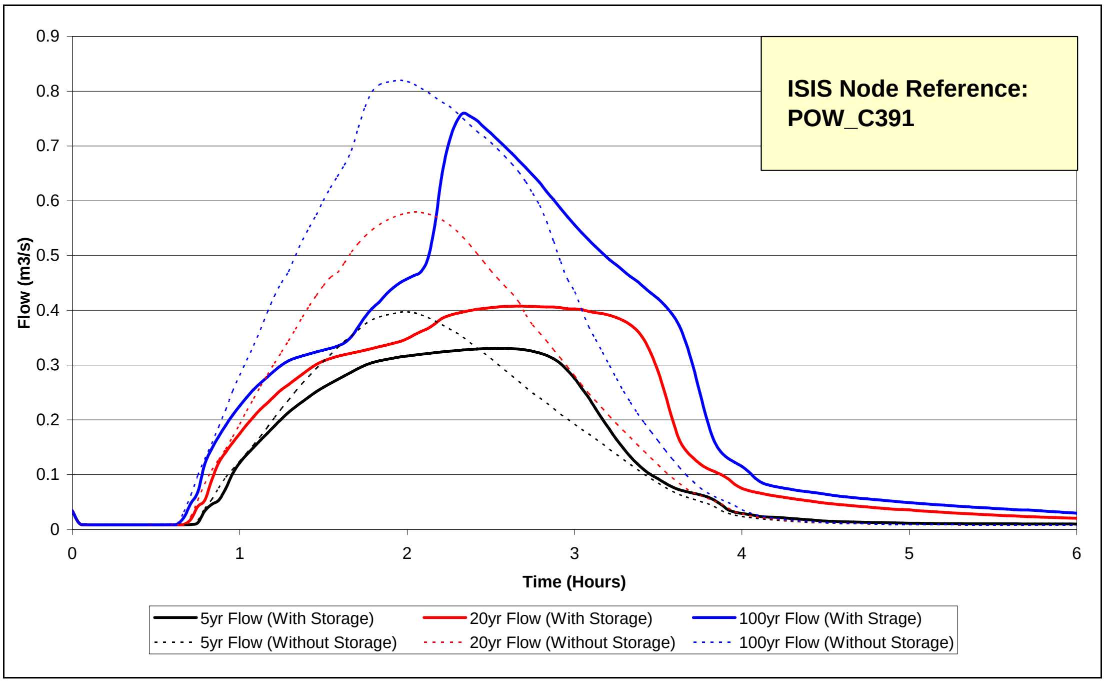
Downstream of the flood storage, halfway down the road into the village (approximately 250m from the first properties), there is an access track which crosses the Crawley Dean Burn. Here the watercourse is culverted for a short stretch. At this point (Node: POW_C691us) the 5 and 20 year event flows remain within the channel; however the extreme 100 year event spills out of bank to a depth of approximately 200mm above the left bank level for both With (Existing) and Without (Pre-Schemes) scenarios. This would likely produce flooding on to the road, and down towards the village, for these extreme events.

5.5 Crawley Dean Off-line Flood Storage

Modelling of the off-line storage pond on the Crawley Dean Burn reveals similar results to those for the upstream in-line ponds. The storage pond is effective without any overtopping for the 5 year event. For the 20 year event, the storage area fills to capacity and produces an almost negligible rate of overtopping, just 0.004m^3/s per second. However, for the 100 year event, the rate of overtopping is if far greater, with a peak overspill of 0.293m^3/s. The duration of this overtopping is also significant, lasting for almost two hours of the simulated 4 hour event.

Figure 15 illustrates the attenuation impacts of all Crawley Dean storage schemes in the reach immediately upstream of the Crawley Dean culvert. This shows that there is a reduction in the peak flow for all events with the inclusion of the Environment Agency schemes. The greatest reduction in peak flow is provided for the 20 year event, with peak flows reducing by almost a third, from 0.58m^3/s to 0.41 m^3/s.

Figure 15 – Pre-Schemes and Post-Schemes (Existing) hydrographs from upstream of Crawley Dean Culvert Inlet



5.6 Crawley Dean Overall

Generally speaking the Crawley Dean Burn remains within bank for all flows, both With (Existing) and Without (Pre-Schemes) options. The Existing model (including the Environment Agency storage schemes) shows improvement in the peak flows down through the system, and therefore reduced water levels throughout.

As discussed above, in Section 5.4, the 100 year levels for both With and Without options spill out of channel on the left bank at the access track culvert approximately halfway down the road into the village (at node: POW_C691). Flows spill on to the road for this extreme event. Downstream of the culvert the flows for the 100 year remain back within the channel banks.

Further downstream, just upstream of the Crawley Dean culvert inlet, flows used to spill out of bank, above the new embankment level alongside the properties at Crawley View, for the 100 year event prior to implementation of the Environment Agency storage schemes. With the Existing (With Schemes) situation the 100 year water level remains just within bank (by approximately 300mm at node: POW_C445).

At the inlet itself, the level of protection afforded by the low embankment in front of the houses reduces, and for the 100 year level (With options) the water level is only 100mm below the embankment crest level. Prior to the Environment Agency schemes, flows for the 100 year event used to flood over both banks, to both properties (to right) and on to the A697 road (to left).

At the Crawley Dean culvert the 20 year flows remain within capacity, and the culvert runs just above half full for the Existing (With options) model. For both With and Without options the 100 year exceeds the culvert inlet capacity, which is at about 0.46m^3/s (compared to the estimated peak catchment flow for the Crawley Dean of 0.82m^3/s). For the Existing (With options) the peak water level rises to 400mm above the culvert inlet soffit, but remains within the channel banks. For the previous Pre-Schemes (Without options) the peak water level is almost 1m above the top of the culvert inlet, and floods out of bank on both sides, as discussed above.

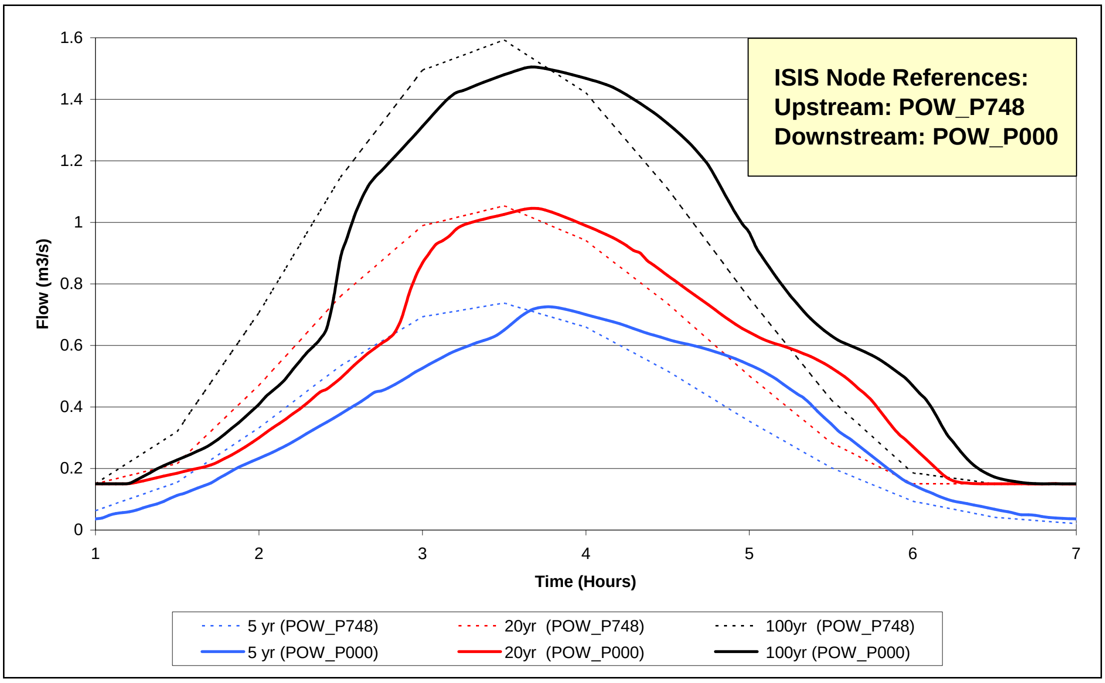
5.7 Upper catchment flood storage (Whaupmoor Burn)

To enable more efficient modelling of the catchment, the upstream flood storage arrangement on the Whaupmoor Burn has been modelled independently from the main catchment model. The model results show that the off-line storage ponds in the upper Pow Burn/Whaupmoor Burn catchment do not show the same successful reduction in peak flows as those on the Crawley Dean Burn. Results show that although the storage areas do fill and attenuate flows, they do not have the required volume to reduce the peak flows to a significant degree. In fact, the upper two storage areas become filled and overtopped by the 1 in 5 year event, while the larger third storage area, the most downstream area, is not utilised until the 100 year event.

From the available survey information, it is clear that the reason for the lower storage area not becoming utilised until the 100 year event is that the spill level into the storage area is at the same level as the in-channel bund which causes the flows to back up in the channel. As such, excess flows are able to spill over the bund and directly back into the channel, rather than being diverted into the flood storage area.

The combined effect of these three storage areas is shown in **Figure 16**. From the graph it is clear that there is no reduction in peak flow for the 5 and 20 year events, and the peak is just slightly delayed. There does appear to be a slight reduction in the peak of the 100 year event (by only 0.09m^3/s, approximately 5% decrease), which can be attributed to the activation of the third and largest storage area. For this reason the results have not been included into the main catchment model in the downstream catchment, as there are only relatively minor attenuation effects of the storage and it was felt that it was more appropriate to focus on a worse-case situation for the centre of the village.

Figure 16 – Upstream and downstream hydrographs for Post-Schemes (Existing) at the Whaupmoor Burn upper catchment storage areas



5.8 Powburn Embankments

Assessment of the effectiveness of the newly constructed embankments upstream of the A697 road bridge has been carried out by comparing the modelled water levels with the level of the new embankments.

In the case of the 'Without Embankments' (Pre-Schemes) scenario, it has been assumed that once the water spills out of bank in this lower reach, then adjacent properties begin to become flooded. The modelling results show that this area of the catchment is very susceptible to flooding, with significant out of bank flows even for the 1 in 5 year event. However, for the 'With Embankments' scenario (Existing), water levels do not exceed the level of the embankments even for the 1 in 100 year event.

5.9 Modelling Summary

As discussed above, the modelling of the Pow Burn Catchment and Environment Agency schemes has highlighted that there is a general and significant improvement in the standard of protection within Powburn as a direct result of the works carried out by the Environment Agency. The hydraulic river modelling has also aided in the identification of a number of minor issues with these schemes which are resulting in them not fulfilling their full potential. These issues are addressed in the Options Identification section (**Section 7**). The results table in **Appendix B** and **Figure 13** show the improvements that the Environment Agency schemes have had on flooding within the catchment.

6 ECONOMIC BENEFITS OF FLOOD PROTECTION

An assessment of the likely economic benefits of flood protection has been carried out using the Benefits of Flood and Coastal Risk Management (Multi-Coloured Manual, MCM) weighted Annual Average Damage approach. The number of properties at risk has been established for each of the key flood risk areas based on site investigations, documented past events and hydraulic modelling. Having established the number of properties at risk, the results of the hydraulic modelling have been used to assign each of these properties with a Standard of Protection (SoP). This SoP is then used to estimate the Average Annual Damage (AAD) which will be incurred at each of the properties. For this high level assessment, and in the absence of detailed flood water depth and property type information, the MCM Weighted Annual Average Damage (WAAD) has then been used to estimate potential maximum damages. This annual damage per property is then been multiplied over the length of the appraisal period to estimate the total economic benefits of any potential scheme. At this stage, these have been discounted to provide Present Value (PV) benefits following the guidance of the Treasury Green Book.

The damages for two appraisal periods have been calculated to provide Northumberland Council with the most flexible level of information.

- A 25 year period has been applied to assess the benefits of the recently installed Environment Agency schemes, as this is considered an appropriate design life for these structures.
- A 100 year appraisal period has also been calculated to provide an understanding of the maximum benefits that could be expected for any improved capital scheme in Powburn.

Results of the economic analysis carried out to assess the benefits of the scemes are provided in **Table 1** below. **Table 1** illustrates that the Environment Agency schemes already provide significant economic benefits to the residents of Powburn. Although these benefits may not be as high as might be expected due to the lack of apparent benefits on the Crawley Dean Burn.

Based on these calculations, the Environment Agency schemes are expected to provide over £914,441 in benefits over their design life, and if maintained for 100 years, the benefits could exceed £1.5m.

Due to these existing benefits, the total additional benefits which can be achieved from reducing the residual flood damages, over and above that which is currently in place is likely to be limited. As such, the type and scale of engineering options that are likely to gain Flood Defence Grant in Aid (FDGiA) funding are limited.

The following section provides a summary of the types of future options which could be implemented to provide further improved flood risk management for Powburn. Due to the limited economic benefits, the likelihood of achieving benefit cost ratios high enough to gain government funding is low. It is likely that contributions from third party sources (e.g. Flood Action Group, Council, and Local Levy) will need to be sought if additional flood management measures are to be installed.

Table 1 – Maximum Potential Benefits of Flood Protection in Powburn

Location	No. Properties @ Risk	Onset of Flooding		Maximum 25 Year Scheme Benefits			Maximum 100 Year Scheme Benefits		
		Before Scheme	After Scheme	Before Scheme	After Scheme	Benefits of scheme	Before Scheme	After Scheme	Benefits of scheme
Crawley Dean Estate	0	100	100	£0	£0	£0	£0	£0	£0
Powburn Centre (A697)	17	5	200	£926,031	£11,590	£914,441	£1,579,230	£19,766	£1,559,464
			Subtotal	£926,031	£11,590	£914,441	£1,579,230	£19,766	£1,559,464
			Total Benefit			**£914,441**			**£1,559,464**

7 SCHEME OPTIONS

Following a thorough review of the previous flood event reports, site visits, and hydraulic modelling of the Environment Agency schemes, we have identified a number of engineering options which could be implemented to reduce the impact of future flooding events in Powburn and the wider catchment. A full cost benefit analysis has not been carried out; however, the selection of low cost options has been based on the likely limited funding that could be available based on the simplified approach to benefits described previously in Section 6. Due to the limited amount of potential benefits, it is unlikely that any of the proposed schemes will attract the required level of FDGiA funding without significant third party contributions.

Indicative cost estimates have been derived for each of the presented options based on our previous knowledge and experience of similar schemes and construction work in other locations. The costs provided are intended as an indication rather than a definitive cost, due to the presence of significant design assumptions. As a result they are intended as outline costs only for the purposes of analysis and comparison. Each of the options would require thorough site investigation before being taken forward and detailed costs should be calculated once this process has been completed.

7.1 Option 1: Inspection and Maintenance of Environment Agency Structures

As stated previously, the overall assessment of the works conducted by the Environment Agency is that they have had significant flood risk benefits for Powburn. As such, they represent a significant asset in the flood defence infrastructure for Powburn. We would recommend regular inspection of the assets to ensure that there is an understanding of how they are holding up to flood conditions and ensure that they are maintained to a suitable operational standard. It is recommended that each structure is inspected at least every year due to the nature of their construction, and following all high flow flood events.

The cost of such inspections will be dependant on the frequency of future high flow events. However, it is not likely to be high given the distribution of assets.

7.2 Option 2: Fawdon Burn By-pass

The greatest opportunity to reduce flooding within Powburn is presented at the stilling basin and overflow weir at the CEMEX aggregate quarry near Branton. At present, approximately 30% of the flows which pass through Powburn originate from the Fawdon Burn. By lowering or removing the weir and reducing the capacity of the existing culvert, it would be possible to reduce flows in the Fawdon Burn downstream of Branton by up to 100%. A full bypass of flows is unlikely to be allowable by the Environment Agency due to the considerable environmental and ecological implications of permanently diverting a significant length of watercourse. Further flood risk considerations will also have to be considered to ensure that there are not knock-on risks being transferred to areas downstream on the River Breamish.

Discussions with the quarry landowner (CEMEX), downstream landowners/residents and the Environment Agency should be progressed to assess the required minimum flows along the Fawdon Burn and ensure that there are no objections.

Depending on the Environment Agency's requirements, this could be a very cost effective option if the weir can be completely removed and a plate affixed to the entrance of the culvert to reduce flow.

The cost of removing the weir and installing a steel plate to the culvert is likely to be in the region of £20,000, although additional costs for planning, consultations and investigations may be required.

7.3 Option 3: Improve upstream storage on Whaupmoor Burn

As highlighted in **Section 5.6**, the most downstream off-line storage area is relatively ineffective at attenuating flows in the upper catchment due to the way the in-channel structure has been constructed. With the spill level into the storage area set at the same level as the in-channel flow control structure, excess flows backing up within the channel simply flow over the structure and back down the channel, bypassing the storage. A simple and cost effective solution to this would be to lower the spill level into the storage area (or raise the level of the in-channel structure) to divert flows into the storage area prior to flowing over the in-channel structure and back into the watercourse.

Such a minor project is likely to be relatively inexpensive, requiring only a few days work. As such, the **cost for such an improvement is likely to be in the region of £5,000**.

7.4 Option 4: Large scale upstream storage

Although the small scale flood storage provided by the Environment Agency is a good start to reduce flood risk, a much greater volume of storage is likely to be required if flood flows are to be significantly reduced. We have identified an area which may be suitable for the construction of a large-scale flood storage area, although at the preliminary stage, and without ground investigation information.

Located to the east of Greenfields Plantation, a narrow valley in the undulating topography provides a potential location for the construction of a large-scale flood storage reservoir. This site has the potential to allow the construction of an embankment up to 5m high and up to 100m in length. Based on the available topographic data, this could provide storage over an area of approximately 500m^2, with storage of up to 1,250,000m^3, which would be well in excess of what would be required.

However, implementing such a large scale scheme is likely to be very expensive and as such is unlikely to achieve the required cost / benefit ratio and therefore attract funding.
Initial estimates for such a project based on recent reservoir projects suggest that the **costs could be in the region of £2 - 5 million**.

7.5 Option 5: Replacement of Crawley Farm Road Surface Water Strip Drains

The surface water strip drains installed across Crawley Farm Road are considered undersized and possibly inappropriate for the purpose that they have been intended for. Such drains are typically installed for the collection of surface water in depressions, and they are less effective when installed on steep slopes. Additionally, when small drains such as this are used, it would usually be recommended that they are installed at 45° diagonal to the road to increase the potential for surface water capture. On this steep road, it is likely that the majority of fast flows coming down the road will flow over the top and bypass the strip drains, rendering them ineffective.

To maximise the collection of surface water flows at this location, it is recommended that the strip drains be replaced with a single cattle grid or similar large scale surface water collection system at the same location. A large open grid such as this would ensure that a much greater proportion of the surface water is collected and diverted into the ditch to the north of the railway embankment, which will provide increased protection to the properties at the bottom of the hill.

As it is believed that this road is a private farm track, discussions with the land owner will need to take place to ensure that all parties are in agreement before any formal proposals are made. Furthermore, it would be recommended that the Council Highways are consulted to ensure all traffic and pedestrian risks associated with such a system are considered.

The cost of replacing the current drains with a cattle grid is likely to be in the region of £20,000.

7.6 Option 5: Preventative Maintenance / Channel Clearance on the Crawley Dean Burn

As has been shown by detailed modelling of the Crawley Dean Burn, the channel and culverts along this stretch of watercourse appear to have the capacity to discharge 100 year flows without resulting in flooding to the adjacent properties in the housing estate. However, from recent flooding events, evidence does not support this observation. The most likely reason for a lack of consistency between the modelled scenarios and those observed during previous high flow events is blockage of the Crawley Dean culvert. The vertical trash screen installed at the culvert inlet was particularly susceptible to ‘blinding’ and had a high risk of blockage. The modelling methodology which has been adopted assumes that the Crawley Dean culvert remains open throughout a flood event. Considering this scenario, we would conclude that major flooding from the Crawley Dean in recent years has been as a result of blockage of the Crawley Dean Culvert, rather than a lack of capacity.

To address this issue, we would recommend continued maintenance of the Crawley Dean Burn channel, including removal of fallen vegetation, to reduce the risk of future blockages that could result in the backing up and overtopping of the adjacent housing estate embankment.

8 CONCLUSIONS AND RECOMMENDATIONS

Following a number of significant flood events at Powburn in Northumberland including the September 2008 event, and the installation of a series of small-scale flood management measures by the Environment Agency Local Levy Team, Northumberland County Council commissioned Royal Haskoning to carry out a Flood Risk Study for the catchment.

Through a review of previous reports, site visits, discussions with third parties, and hydraulic modelling of the main watercourses in the catchment, it has been confirmed that the key flood risk areas are located upstream of the A697 road bridge and adjacent to the Crawley Dean Burn, and that there are no other areas of significant risk to property from fluvial flooding within the catchment.

Hydraulic modelling has shown that prior to the installation of the Environment Agency schemes, the standard of protection at these locations was as low as 1 in 5 years. However, the schemes implemented by the Environment Agency appear to have been successful in improving the local standard of protection to most areas, although some risks have not been resolved to as well.

As with all flood management schemes, there still remains some level of residual risk. However, with the improvement in the standard of protection to as much as 1 in 100 in some locations, the residual risks are relatively low. As such, the economic benefits which could be gained from any additional flood management works are low, and it is unlikely that such minor flood damages will attract any significant Flood Defence Grant in Aid (FDGiA) funding unless significant third party contributions are secured.

A number of small scale options have been proposed which will build on the works already completed by the Environment Agency. These include the removal of weir at the Cemex gravel pit to reduce flows in the Fawdon Burn, improvements to the Environment Agency storage areas on the Whaupmoor Burn, and large scale upstream storage.

Appendix A

Watercourse and Asset Survey Report

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Appendix B

Model Schematic and Results Tables