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Malton, Norton and Old Malton Flood Study

Final Report

North Yorkshire County Council

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Malton, Norton and Old Malton Flood Study

Final Report

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Executive Summary

Arup have been appointed by North Yorkshire County Council to identify an initial business case for options to prevent flood risk to the towns of Malton, Norton and Old Malton. This report summarises that work, identifying a range of potential options and their relative economic and technical merits. Options presented in this report do not represent a final decision to be implemented; rather the report identifies the likely front running options, as well as the work required to bring these to an implementation phase.

Significant flooding occurred in Malton, Norton and Old Malton in November 2012. The areas most significantly affected were as follows:

- Castlegate, Sheepfoot Hill and Railway Street, Malton;
- Welham Road, Church Street and St Nicholas Street, Norton;
- Old Malton Road and Town Street, Old Malton.

The combination of existing defences and operational response ensured that the level of property flooding that occurred was relatively low – only 20 properties suffered internal flooding. However, the impact upon the community was significant. This report was commissioned by North Yorkshire Council (NYCC) and sets out an initial business case for investment in additional measures to reduce local flood risks in the above three locations.

Flood risk in Malton, Norton and Old Malton is currently managed through operation and maintenance of: the River Derwent flood defences (including associated drainage outfall non-return valves, flood gates and land drainage pumping stations), highway/land drains and the combined sewer network, including sewerage pumping stations. Flood warning, emergency preparedness, planning and response measures are used to manage the residual risk (which is primarily that associated with surface water flooding). Should all these activities cease, the Net Present Value (NPV) cost of the flood damages that would occur over the next 100 years is estimated to be just under £30m if current flood management activities all ceased.

The primary cause of the flooding problems experienced in 2012 is ‘flood-locking’, whereby gravity drainage systems cannot discharge to the river as a result of high river levels. Surface water flooding generally coincides with flows in the River Derwent that exceed $80m^3/s$, which corresponds broadly with the threshold at which gravity drainage becomes impeded. There have been seven occasions when a flow of greater than $80m^3/s$ has occurred in the River Derwent, Malton since 2003, when the Main River flood defences were constructed. In 2012 this flow was exceeded for ten days and this required a major operation to over-pump the flood defences using temporary pumps. The related problems this causes can be summarised as follows:

- Whilst local surface water flooding may not affect as many properties as would flood from the River Derwent, sewer flooding from the overloaded combined sewer network makes it particularly unpleasant for the residents and businesses affected;
- Flood warnings in Malton are based on river levels and hence flood warning response to surface water and groundwater is reactive. Knowing when and

where temporary surface water pumps need to be deployed has to rely on anecdotal and eyewitness accounts;

- The residual risk of surface water flooding in Malton, Norton and Old Malton is potentially too high for the emergency response procedures developed by the Multi-Agency group to fully make sense as a long-term solution, if an economically viable investment now could save costs in the longer term;
- Relying on temporary pumping in emergencies is not an ideal arrangement because:
  - the pumps are not absolutely guaranteed to be available when required;
  - there are no formal ‘well’ points connected into the drainage systems in which to deploy them;
  - the arrangements still result in disruption to local residents and the local transport network.
- High groundwater levels cause infiltration into the combined sewer network, which reduces the network capacity for wastewater and stormwater, especially during flood-locked periods.

In assessing potential options to reduce flood risk to businesses and communities in Malton, Norton and Old Malton, the appraisal has been guided by the following overriding objectives:

- To reduce flood risk in a manner which represents best value for money in the short, medium and long term;
- To adopt solutions that are socially and environmentally acceptable to local people and statutory authorities, which respect the heritage setting and avoid disruption to local residents and businesses where possible.

Engineering judgement and experience, coarse economic baseline assessment and an understanding of the catchment and flood mechanisms from data and models were used to assess viable measures with regard to their technical and economic viability, their social/environmental impacts and their level of resilience. The shortlisted options for each of the three sites can be described generically as follows:

Option 1: Under this purely theoretical scenario, all spending on activities and infrastructure to reduce flood risk would cease. This allows the benefits afforded by existing spending to be identified and is the baseline required for appraising schemes in line with national guidance;

Option 2: Maintain existing levels of support;

Option 3: Improve local flood warning procedures, construct permanent pumping chambers, in which to deploy the temporary pumps, and reduce the residual risk with property level protection measures. In Norton this option also involves optimising the operation of the existing Mill Beck pumping station and formalising a pipe-crossing of the railway line through which water can be pumped when necessary**;**

Option 4: As above, but with wider rationalisation of the drainage systems. In Old Malton this would involve diverting Riggs Road drain. In Norton, this option would involve upgrading Mill Beck Pumping Station, further optimisation of the performance of an existing sewer pumping station, creating a high level overflow and constructing a small floodwall. In Malton, this option involves groundwater control measures in Castlegate.

Option 5: As above, but with installation of permanent pumps within the pump chambers, with associated telemetry and control systems.

Table 1 summarises initial estimates of the whole life costs and benefits of the five options above for each site, together with an indication of the local partnership funding (PF) contributions required in order to secure central government Flood and Coastal Erosion Risk Management Grant in Aid (FCERM GiA). The "Residual Damages" presented are those flood damages that would still be expected to be incurred after the implementation of an option. Residual damages are presented because the Benefits of an option are calculated from the avoided Residual Damages resulting from the implementation of the option. The Costs have been estimated by a Quantity Surveyor from a specification of the measures contained under each option. The Benefit Cost Ratio (BCR), amongst other factors contained within the Environment Agency Partnership Funding Calculator, is used to calculate the costs eligible for funding by Flood and Coastal Erosion Risk Management Grant In Aid (FCERM GiA). The costs that are not met by FCERM GiA would need to be met by Partnership Funding (PF).

It is notable that the costs of some options reduce for options that on face value involve a greater level of civil engineering intervention. This is because Property Level Protection is used to reduce the residual risk in Options 3, 4, 5. Increased levels of collective protection measures reduce the need for property level protection, and this means that costs do not increase consistently.

Table 1: Summary data for the options considered in Malton, Norton and Old Malton (monetary values in GBP to nearest £1000).

	Malton Options				
	M1	M2	M3	M4	M5
Residual Damages (£)	10,189,000	4,527,000	1,901,000	1,868,000	1,556,000
Benefits (£)	-	5,662,000	8,288,000	8,321,000	8,633,000
Costs (£)	-	42,000	1,311,000	1,104,000	1,091,000
BCR		134.7	6.32	7.54	7.92
Costs eligible for FCERM GiA (£)			724,000	726,000	744,000
PF contribution required (£)			587,000	377,000	347,000

	Norton Options				
	N1	N2	N3	N4	N5
Residual Damages (£)	15,428,000	12,047,000	5,410,000	5,168,000	4,774,000
Benefits (£)	-	3,381,000	10,017,000	10,259,000	10,654,000
Costs (£)	-	42,000	2,278,000	2,176,000	2,545,000
BCR		80.4	4.40	4.71	4.19
Costs eligible for FCERM GiA (£)			1,007,000	1,020,000	1,042,000
PF contribution required (£)			1,271,000	1,156,000	1,503,000

	Old Malton Options				
	OM1	OM2	OM3	OM4	OM5
Residual Damages (£)	3,759,000	2,671,000	1,276,000	506,000	485,000
Benefits (£)	-	1,087,000	2,482,000	3,252,000	3,274,000
Costs (£)	-	84,000	1,004,000	746,000	1,150,000
BCR		12.9	2.47	4.36	2.85
Costs eligible for FCERM GiA (£)			388,000	431,000	432,000
PF contribution required (£)			616,000	315,000	718,000

It can be concluded that there is a very good economic case for investment in proposals to reduce flood risk in Old Malton, Malton and Norton. However, none of the options identified would be wholly fundable from central government FCERM Grant in Aid.

Table 2 shows what the situation would be should: a) the three schemes be combined, b) further appraisal work identify 20% additional benefits and c) further refinement of the designs/costs show that a 20% optimism bias (rather than 40%) is likely to be sufficient. This represents a ‘best case scenario’.

Table 2: Summary data for a ‘best case scenario’ combined scheme (monetary values in GBP to nearest £1000).

	Combined scheme (Benefits up 20%; Costs down 20%)				
	1	2	3	4	5
Residual Damages (£)	29,375,000	19,245,000	8,587,000	7,543,000	6,814,000
Benefits (£) + 20%	-	12,156,000	24,946,000	26,199,000	27,073,0000
Costs (£) - 20%	-	135,000	3,674,000	3,221,000	3,829,000
BCR		90.4	6.79	8.14	7.07
Costs eligible for FCERM GiA (£)			2,351,000	2,420,000	2,469,000
PF contribution required (£)			1,323,000	800,000	1,360,000

This scenario indicates that, depending on the option selected, combined scheme costs could feasibly be between £3.2m and £3.8m. Between £0.8m and £1.4m of these costs would need to be secured from sources other than FCERM GiA (i.e. from partnership funding). The most promising likely sources of such funding are:

- Funds within the Multi-Agency Flood Group organisations, as well as other organisations, individuals and local businesses with vested interests in the reduction of flood risk;
- Key local businesses including landowners and property developers affected or those with a financial interest in the area;
- Local residents and community groups benefitting from the proposals.

Other potential options include, for example, Local Enterprise Partnership - European Strategic and Investment Fund (ESIF), Regional Flood and Coastal Committee (RFCC) Local Levy funding, Community Infrastructure Levy and/or setting up a Business Improvement District.

The recommended next steps are as follows:

- Consultation with stakeholders, potential contributors and affected parties;
- Preparation of Partnership Funding calculations, factoring in the likely contributions;
- Discussions with the Environment Agency with a view to developing a full Project Appraisal Report (PAR) and application for FCERM GiA, making best use of this report, which contains all the essential elements of such an application.

Development of a full PAR will however involve refinement of scheme analysis, designs, cost and benefit calculations, as well as discussion with the individuals and organisations affected by the proposals. It is also strongly recommended that a geotechnical desk study, topographical survey, site investigation, including physical location of site services, as well as any archaeological/ecological surveys required be undertaken to inform the outline designs.

1 Introduction

1.1 Purpose of this report

This report was commissioned by North Yorkshire Council (NYCC) and sets out an initial business case for investment in measures to reduce local flood risks in three locations in Old Malton, Malton and Norton that were affected by flooding in November 2012.

1.2 Study Objectives

The objective of the current study is to develop potential solutions, including an assessment of the costs of implementation and the benefits that could be realised from each option. In short, the information needed by any community, organisation or partnership to put together a bid for funding. To realise these objectives, North Yorkshire County Council, as Lead Local Flood Authority, set the following tasks for this study, in collaboration with the Multi-Agency Flood Group:

- develop a conceptual understanding of the flood mechanisms;
- develop hydraulic models that represent the mechanisms identified;
- map the spatial extent of the areas likely to be affected if no action is taken;
- identify the economic consequences of not acting to reduce flood risk;
- identify a long list of potential actions that could be taken in the short, medium and long term
- develop a shortlist based on a range of technical, environmental and economic criteria;
- identify a likely preferred option for each of the three areas;
- prepare indicative designs and costs for these options;
- present the results in the form of a coarse benefit:cost analysis and initial business case;
- identify the work required to develop; a full application for funding, if the analysis shows that such funding is likely to be forthcoming.

The emphasis is on the need at this stage to only provide a coarse assessment of economic viability, with indicative costs and indicative designs. Any elements required for development of a more detailed understanding must be identified to NYCC. The scale and detail of the approach was to be appropriate to the potential benefits.

This report adopts the format of a Project Appraisal Report (PAR) for a Flood and Coastal Erosion Risk Management (FCERM) simple change project for local authorities, with the aim of minimising any work required to develop a funding application for Flood Defence Grant in Aid (FDGiA), should NYCC decide to proceed with such an application.

2 Background

2.1 History and wider context

Old Malton, Malton and Norton are on the River Derwent in North Yorkshire, sixteen miles north east of York. All three communities, which form a single conurbation straddling the river, had a long history of flooding from the River Derwent, but were particularly badly affected in 1999 and 2000. These floods hit the national headlines and prompted a visit from the Deputy Prime Minister, John Prestcott. The Regional Flood Defence Committee requested that the Environment Agency fast-track a project to reduce flood risk in the town. The c. £9m Malton Flood Alleviation Scheme was completed in 2002. The defences comprised a combination of earth embankments (at Old Malton) and floodwalls (through the town centre) to prevent flooding from the river. Pumps were installed at the outfalls of two Internal Drainage Board watercourses (that are now Main River).

The River Derwent flood defences significantly reduce the risk of direct flooding by river water. However, in November 2012 significant flooding occurred in Malton, Norton and Old Malton. The areas most significantly affected were as follows:

- Castlegate, Sheepfoot Hill and Railway Street, Malton;
- Welham Road, Church Street and St Nicholas Street, Norton;
- Old Malton Road and Town Street, Old Malton.

These areas and their key features are shown in Figures 1 to 3.

The combination of existing defences and operational response ensured that the level of property flooding that occurred was relatively low. However, the impact upon the community was significant.

While the individual rainfall events at the peak of flooding in November 2012 were not particularly remarkable in themselves, they followed a period of unusually prolonged wet weather. River levels in November 2012 were elevated for an extended period, such that the drainage systems connected to the river had no means of gravity discharge, and it was not until February that emergency pumps were finally removed from the area.

Localised ponding of surface water behind the flood defences has occurred on several occasions since 2003, but was most significant in 2012. Whilst only 20 houses flooded this was largely due to the mobilisation of temporary pumps. The two main river tributary pumps were at full capacity for several days.

A post project review of Malton FAS commissioned by the Environment Agency in 2013 concluded as follows:

"*River flooding was the principal issue of concern in Malton and this issue was addressed effectively by the scheme on a very tight programme. The fact that the surface water flooding issues do not appear to have been adequately addressed was primarily due to this fast-tracking of the project. Those responsible for land drainage (IDB and LA), road drainage (HA and LA) and sewerage (the Water Utility company) had made no provision within their forward plans to investigate and address the surface water risks in Malton in tandem. Their investment* *programmes were not aligned with the Environment Agency's timescales for fast-track delivery*".

The above issues reflect the problems with the management of surface water and local flood risks across England identified by Sir Michael Pitt in his review of the 2007 floods. Particularly relevant extracts from his key conclusions and recommendations on this subject are outlined below:

"Surface water flooding is complex and affected by many factors, such as the capacity of the sewerage/drainage system, saturated ground and high river levels that prevent the system from discharging. The responsibilities for certain drainage assets remain unclear, a situation that frustrated the public during the summer 2007 floods. This lack of transparency in ownership and the complexity involved could be reduced by having a single national organisation with an overarching responsibility for all types of flooding" *Recommendation 2: The Environment Agency should progressively take on a national overview of all flood risk, including surface water and groundwater flood risk, with immediate effect.*

"With no clear coordination and structure, the Review has found that responses to local flood risk are piecemeal and not necessarily prioritised. Each of the organisations with a responsibility for certain assets tends to carry out maintenance and improvement works independently, as there is currently little incentive to do otherwise. This results in investment decisions being made in isolation, which at best leads to inefficiencies and at worst actually increases the risk of flooding". *Recommendation 14: Local authorities should lead on the management of local flood risk, with the support of the relevant organisations.*

Pitt's recommendations had a major influence on the Floods and Water Management Act, 2010. This legislation extended the EA's role to include provision of a strategic overview role in relations to all sources of flood risk (rather than just flooding from rivers and the sea). The legislation also created Lead Local Flood Authorities – which are either County Councils or Unitary Authorities. This legislation is now beginning to re-shape how flood risk is managed across England and has impacted on arrangements in Malton/Norton as outlined below.

2.2 Current approach to flood risk management

In Malton and Norton, the Environment Agency therefore now has a national strategic overview role. Responsibility for the surface water, groundwater and land drainage systems still lies with multiple parties. However, North Yorkshire County Council now fulfils the local role of Lead Local Flood Authority, coordinating local flood risk management activities.

Flood risk in Malton, Norton and Old Malton is primarily managed through operation and maintenance of the following infrastructure:

- Main River flood defences (including associated drainage outfall non-return valves, flood gates and pumping stations on Mill Beck and Priorpot Beck);
- highway and land drainage systems;
- combined sewer network, including pumping stations.

In addition to the above, the following activities help to prevent new risks developing and ensure that the residual risks are also managed:

- development control through the planning process: both the Environment Agency and NYCC (in their capacity as Lead Local Flood Authority and as Highway Authority) are consulted on the development of Local Plans and on applications for new development by Ryedale District Council as the planning authority;
- flood warning, emergency preparedness, planning and response measures to manage the residual risk (which is primarily that associated with surface water flooding, but also to deal with a scenario involving very extreme flooding should this threaten to overtop the Main River flood defences).

A Multi-Agency Flood Group was formed after 2012 as a commitment by the relevant risk management authorities to look at ways in which the residual risks might be further reduced and more actively managed. The group consists of representatives from

- Environment Agency,
- North Yorkshire County Council (in the capacity of Lead Local Flood Authority, Highway Authority and Emergency Planning Unit),
- Ryedale District Council,
- Yorkshire Water Services, and
- Vale of Pickering Internal Drainage Board.

This group has developed a formal emergency response plan based on the lessons learnt from the 2012 event and designed specifically to reduce risks associated with the mechanisms responsible for the flooding that occurred in 2012. This plan makes provision for improved warnings and deployment of temporary pumps. Progress has also been made with implementing a pipe crossing to allow surface water to be pumped through the York-Scarborough railway line, something that was achieved using an informal arrangement in 2012.

3 Problem definition and objectives

3.1 Outline of the problem

Details of the flood mechanisms responsible for causing the problem are provided in Appendix A. The primary mechanism is 'flood-locking', whereby gravity drainage system cannot discharge to the river due to high river levels. Surface water flooding generally coincides with flows in the River Derwent that exceed $80m^3/s$, which corresponds broadly with the threshold at which local drainage systems cannot discharge by gravity to the River Derwent. There have been seven events when a flow of greater than $80m^3/s$ has occurred on the River Derwent since 2003. The problems this causes can be summarised as follows:

- Whilst local surface water flooding may not affect as many properties as would flood from the River Derwent, sewer flooding from the overloaded combined sewer network makes it particularly unpleasant for the residents and businesses affected;
- Flood warnings in Malton are based on river levels and hence flood warning response to surface water and groundwater is reactive. Knowing when and where temporary surface water pumps need to be deployed has to rely on anecdotal and eyewitness accounts;
- The residual risk of surface water flooding in Malton, Norton and Old Malton is potentially too high for the emergency response procedures developed by the Multi-Agency group to fully make sense as a long-term solution, if an economically viable investment now could save costs in the longer term;
- Relying on temporary pumping in emergencies is not an ideal arrangement because:
    - the pumps are not absolutely guaranteed to be available when required;
    - there are no formal 'well' points connected into the drainage systems in which to deploy them;
    - the arrangements still result in disruption to local residents and the local transport network.
- High groundwater levels cause infiltration into the combined sewer network, which reduces the network capacity for wastewater and stormwater, especially during flood-locked periods.

3.2 Consequences of walking away

Defining the consequences of this highly theoretical scenario helps to identify the benefits of all the activities that are currently undertaken to reduce flood risk. If all current flood management activities ceased, the impacts on these communities would be very significant.

Existing measures to reduce flood risk include: raising awareness, flood forecasting and warning, development control, community support, emergency pumping and maintenance of all existing land drainage, urban drainage and flood defence systems.

During past flood events, it is likely that many more properties would have experienced flood damage without the operation of the existing flood defences on the River Derwent, and without the implementation of the emergency flood response plans, including the temporary pumping arrangements. The Main River defences only work if the floodgates and pumps are operated and the walls and banks, outfalls and non-return valves are maintained. Figures 1-3 show the areas that would be at direct risk of flooding under this scenario for varying levels of annual probability. The Annual Average Value of the resulting flood damages are estimated to be £4m now, rising to £10m per year by 2080, if peak river flows increase in line with current climate change projections. The Present Value cost of the flood damages over the next 100 years, discounted at the appropriate rates for projects of this kind, is estimated to be just under £28m. So continued investment of public money in managing these risks makes good sense.

3.3 Strategic issues

In managing flood risk in one location, consideration should always be given to mitigation of any potential impacts elsewhere, as well as opportunities to take advantage of delivery efficiencies. Surface water flooding is an issue across many communities in North Yorkshire. The problems are generally quite isolated and localised, but this does not make them any less distressing for those affected. NYCC is keen to ensure that their approach is fair and equitable across the County. The Council is also considering delivery mechanisms for solutions to high priority problems of this kind across the County that take advantage of economies of scale.

3.4 Key constraints

The key constraints on the project are outlined below:

Funding: The key constraint on this project is primarily financial. Flood damage assessment, and hence investment prioritisation, is conventionally based on internal property flooding, risk to life and transport infrastructure disruption. The impacts of contamination by sewer water are more challenging to quantify and are not conventionally included in the appraisal of flood management schemes.

Flood mechanism complexity: Local surface water /ground water flood risks are highly localised and complex and limited information is available with which to calibrate and verify hydraulic models. Analysis, modelling and design costs are constrained by the scale of the problem and so expert judgement is critical.

Local businesses and tourism: The towns of Malton and Norton attract visitors throughout the year due to the market town feel, proximity to North York Moors, Castle Howard and the Yorkshire and Cleveland Heritage coast and a range of other attractions. There is a diverse and growing range of businesses in Malton and Norton, all of which will be sensitive to traffic disruption if road or rail closures are proposed as part of any scheme.

Built heritage/archaeology: there are approximately 254 different listed buildings across both town centres. The majority are located in Malton Town Centre with several also within Old Malton. The Roman Fort is a scheduled monument as is the adjacent Malton Castle. Old Malton Priory Church is also a scheduled monument. The area also has numerous archaeological features. Any proposals would need to take account not just of these protected heritage assets, but also of the historic setting of the town and its aesthetic appeal.

Ecology: The Derwent is a special area of conservation (SAC) and runs through the centre of the two towns acting as the boundary between Malton and Norton. It should be noted that the river section within the main urbanised area of Malton and Norton is not a designated SAC, though it is through Old Malton. The same area of SAC is also a SSSI, including the fish ponds at Old Malton. Norton Ings is a designated Site of Importance for Nature Conservation (SINC) and is located behind Commercial Street, Norton.

Contaminated land: Contamination with heavy metals, asbestos, ash fill, sulphates, hydrocarbons (PCB's, PAH) and solvents is always a possibility when working on or near railways, which will be an issue in Norton. Careful consideration will also need to be given to avoiding utilities, as well as former land uses, in areas where new infrastructure is proposed.

3.5 Project Objectives

In assessing potential options to reduce flood risk to businesses and communities in Malton, Norton and Old Malton, the appraisal has been guided by the following overriding objectives;

- To reduce flood risk in a manner which represents best value for money in the short, medium and long term;
- To adopt solutions that are socially and environmentally acceptable to local people and statutory authorities, which respect the heritage setting and avoid disruption to local residents and businesses where possible.

4 Long list of options

The following long list of measures has been derived based on an understanding of the flood mechanisms, and discussions with key stakeholders and the community. The long list has not been restricted by any technical, practical, funding or any other constraints identified in section 3.4. Each measure is provided with a high level description stating its intended effect.

Table 3: Option longlist

No.	Option	Time to implement *(Short / medium / long term)*	Description
1	**Maintenance**		
1.1	Flood defence maintenance	Short term and Long term	Maintenance, repair or replacement where necessary of all existing flood defences along the River Derwent. Flap-valve maintenance is particularly important to ensure the current River Derwent defences are operating effectively, and river water is not flowing back through the defences.
1.2	Land drain maintenance	Short term and Long term	De-silting and vegetation clearance of land drainage systems to maximise both storage capacity (ability to temporarily store floodwater) and conveyance capacity (ability to move/transport floodwater).
1.3	Urban drainage system maintenance	Short term and Long term	Verification of drainage network connectivity and enhanced schedule for clearance of road gullies. Removal of any pipe blockages as they are identified.
2	**Surface Water/Land drainage Pumping (effective for flood events up to and above 1:30 years return period)**		
2.1	Temporary pumping arrangements	Short term	Implementation of the existing Emergency Pumping Plan by the OFERG (Operational Flood Emergency Response Group), using the locations for temporary pumps already identified, phasing the installation in three stages depending on identified water level or flood triggers. This does not include the permanent Mill Beck Pumping Station which continues to operate as planned.
2.3	Formalised/ improved pump chambers (sumps)	Short term	Construction of chambers/well points that temporary pumps can be mobilised to, and deployed, as identified in the Emergency Pumping Plan.
2.4	Network Rail pumping agreement	Short term	An agreement with Network Rail to install a temporary pump line across the railway in Norton to permit the pump hoses from Church Street to cross the railway and discharge to the River Derwent as occurred in 2012.

2.5	Network Rail underpumping arrangement	Medium term	Installation of two permanent ducts passing under the railway line, engineered to meet Network Rail requirements, at Church Street that would be used for pumping during a flood event.
2.6	Modify use of CSO	Medium term	An existing Combined Sewer Overflow from Norton Church Street to the River Derwent would be used to provide an alternative route for pump lines beneath the railway line. Modification to the pipe and chamber could enable temporary pumps to be connected with a permanent or easily installable emergency pump line to the river.
2.7	Permanent land drainage pumps	Medium term	Installation of permanent pumps (or upgrading in the case of the Mill Beck Pumping Station) to ensure that flows from the Mill Beck and Riggs Road Drain and surface water collecting behind defences have a permanent, pre-installed discharge mechanism. Such provision would reduce the reliance on additional temporary pumps or remove this need altogether. These pumps could be designed with associated local storage volumes, wherever there is space (for example in Old Malton).
2.8	Optimise Mill Beck Pumping Station on/off levels	Short term	Further optimise the levels at which Mill Beck Pumping Station operates to improve the ability of the Combined Sewer Overflow (CSO) to Mill Beck to continue to discharge.
3	**Modify urban drainage network (designed for flood events up to 1:30years return period)**		
3.1	Separation of foul and surface water in flooded area only	Long term	Local sewers draining these locations would become less at risk of foul flooding, as surcharging would be restricted to the surface water system.
3.2	Separation of foul and surface water in wider catchment	Long term	This would reduce the total amount of flow entering the existing combined system, reducing the loading on existing the system and its frequency of flooding. It would provide the same benefits as the above against surcharging.
3.3	Sewer rehabilitation to reduce infiltration-inflow	Medium term	In areas where high groundwater levels are noted, measures (sewer lining, joint sealing or sewer replacement) would be taken to reduce groundwater leakage into sewers, thereby reducing the hydraulic loading on the system.
3.4	Reconfigure CSOs	Short term	Combined sewer overflows (CSOs) provide a mechanism for foul or foul-contaminated surface water flooding. Excess sewer flows can discharge into the Riggs Road Drain, Mill Beck or directly to the River Derwent through CSOs, but so too can surcharged watercourses flood back into the combined sewers through CSOs causing further surcharging and flooding elsewhere. Reconfiguring CSO operation levels would help to a) manage and where possible maximise network storage and b) reduce the likelihood of floodwater backflow through CSOs.

3.5	Add capacity at existing Sewer Pumping Stations	Long term	Permanent Sewer Pumping Stations that remove combined sewage flows from the catchments would be upsized to increase the pumping rate and thus outflow from flood affected areas. This may need to be coupled with measures to either contain or treat the greater volumes of contaminated water at the Waste Water Treatment Works, or additional emergency overflow mechanisms from each Sewer Pumping Stations to the River Derwent.
4	**Diversion**		
4.1	Norton	Medium term	Auxiliary overflow diversion from the Welham Road area in the vicinity of Norton Sewer Pumping Station.
4.2	Norton – Priorpot Beck	Long term	A large contributing upper catchment area of the Mill Beck system, and parts of the urban catchment in the east of Norton, would be diverted into Priorpot Beck, which already has a permanent pumping station to tackle flood locking by the River Derwent. This measure would need to ensure that the diversion does not cause or worsen flood risk in the Priorpot Beck catchment and would need to consider options such as attenuation or upsizing the existing Priorpot Beck pumping station.
4.3	Divert RRD downstream of A64	Medium term	High flow would be diverted from Riggs Road Drain or the A64 drainage through a reconfiguration of the land drainage network. Baseflow would be maintained in all watercourses under normal conditions, and watercourses would be adapted to mitigate any potentially negative impacts. This would need to be evaluated for additional flood impacts elsewhere, and compensation where appropriate for landowners. It could be undertaken as an environmental wetland creation / restoration and amenity project, if landowners were amenable and appropriately compensated. Diverting downstream of the A64 would capture more of the contributing flow and is therefore preferable
4.4	Divert RRD upstream of A64	Medium term	High flow would be diverted from Riggs Road Drain or the A64 drainage through a reconfiguration of the land drainage network upstream of the A64. Baseflow would be maintained in all watercourses under normal conditions, and watercourses would be adapted to mitigate any potentially negative impacts. This would need to be evaluated for additional flood impacts elsewhere, and compensation where appropriate for landowners. It could be undertaken as an environmental wetland creation / restoration and amenity project. Diverting upstream of the A64 would capture less of the contributing flow than option 4.3 above.
5	**Control of flow paths**		
5.1	Malton – surface water	Medium term	Castlegate would be fitted with surface water interceptors, road side drainage or other such features to ensure water is diverted into locations which either have capacity to accommodate flood water or to ensure that pumping efforts are effectively able to remove the water. In particular, diverting flow to certain areas may enable more effective removal of flood water.

5.2	Malton – ground water	Medium term	Properties in Castlegate affected by groundwater discharge from the base of the Castle Hill would be modified with flowpath control features (e.g. french drains) to ensure water is able to pass around the properties to areas suitable for pumping, rather than through the ground floors of the properties.
5.3	Norton carpark runoff control	Medium term	Reported overland flow causing flooding to properties would be controlled or improved, features to attenuate runoff put in place, either located in the car park or to divert floodwater away from the properties.
5.4	Old Malton reinstate the Cut	Medium term	The Riggs Road Drain would be reconnected back into the Cut and the open section of the Cat Well as it was historically, removing the outfall to the River Derwent and reinstating the old outfalls.
5.5	Old Malton soffit connection between Cat Well and Riggs Road Drain	Medium term	The top of the Riggs Road Drain culvert, where it passes beneath the Cut, would be removed connecting it directly to the Cut and Cat Well. This may provide a preferable connection into Cat Well from the Riggs Road Drain to facilitate pumping when the system is flood-locked by the River Derwent.
5.6	Old Malton road runoff	Short term	Reports indicate a mechanism of flooding from the overwhelming of road gullies and the underlying drainage system at the western end of the B1257 after storms, with quick runoff along the road to the bottom of Town Street. Road camber or runoff interception gullies or an interceptor arrangement would be used to divert flow south via the sports fields for infiltration and discharge to the Cut.
6	**Property level protection**		
6.1	Resistance and resilience	Short term	These measures would include tanking (exclusion of flow from property basements and ground floors including provision of flood doors, and blocking air vents); through flow (reinstatement or creation of drainage routes through buildings which would reduce build-up of water upstream of properties); and resilience (measures to reduce the impacts of the flooding on personal and property damage, and improve the ability and speed of recovery after flooding). These measures can also include waterproof plastering, elevating electrical sockets, easy to wash down hard flooring.
7	**Flood Warning**		
7.1	Broughton groundwater and/or local telemetry	Short term	Analysis of telemetry at the Broughton borehole would allow a more confident determination of the threshold of groundwater level and groundwater flooding in Malton – possibly linked formally to a local flood warning system, allowing time for authorities and residents to take action.

7.2	Local telemetry groundwater or wet well pump alarms	Short term	Telemetry would be installed at other known flood trigger points to automate / provide warning for local residents and emergency procedures to reduce reliance on reports or local observations.
8	**Flood Storage**		
8.1	Flood storage on Mill Beck	Long term	Opportunities to attenuate water in the Mill Beck catchment, such as in the millpond, further upstream in the Yorkshire Wolds, or within the urban area, would help to reduce the peak flow where designed with respect to synchronicity of flow peaks. Options would include engineered attenuation reservoirs, or small, dispersed attenuations features and Natural Flood Management techniques.
8.2	Flood storage on Riggs Road Drain	Long term	Attenuation in the Riggs Road Drain catchment to the north or to the west would help to reduce the peak flows into Old Malton and maximise infiltration losses. This would help to reduce the floodwater during smaller return period events, or reduce the peak flows sufficiently to match the maximum pumping capacities available downstream.
8.3	Flood storage in Malton	Long term	Storage in an alternative location for floodwater from which pumps could operate, with potentially less disruption to fewer properties.
9	**Development control**		
9.1	Development control	Long term	Several new developments are proposed, especially in the Norton and Old Malton areas. Development control would ensure that new developments keep runoff rates and volumes to greenfield values. Other opportunities for enhancements would be explored with developers.
10	**Derwent modifications**		
10.1	Kirkham Sluices	Short term	Investigations by the Environment Agency and previous modelling studies suggest that the operation or removal of Kirkham Sluices downstream on the River Derwent can reduce river levels in Malton by a small amount (<0.10m). This would be used to reduce the duration or onset of flood-locking.
11	**Flood walls**		
11.1	Formalisation of defences at sewer pumping station in Norton.	Medium term	This asset (and flood routes originating in its location) are currently protected by sandbags. Permanent defences in this location would increase confidence in the level of protection provided. The alignment of the sandbagging at present isolates Norton from the land to the west – re-aligning to maintain connectivity here would increase the available flood storage (and therefore the resilience) of Norton.

5 Option shortlisting

5.1 Shortlisting process

The shortlisting process and results are described in detail in Appendix I and summarised as:

- an internal workshop with the Arup project team to review the initial long-list of measures;
- selection of the short-list of technically feasible and economically viable measures for reducing flood risk in Malton, Norton and Old Malton; and
- short-listed options then taken forward for appraisal.

Engineering judgement and experience, coarse economic baseline assessment and an understanding of the catchment and flood mechanisms from data and models have been used to assess each of the long-listed measures with regard to four criteria. Relevant measures were independently assessed for each of the three main locations where flooding is a problem.

A scoring threshold of 8 was selected to ensure a manageable number of options is shortlisted for detailed appraisal. For each area, engineering judgement has been used to combine appropriate measures into three option scenarios beyond the walk away (do nothing) and sustain existing level of support options. Improvement options would involve successive increases in expenditure to reduce the risk of floods occurring. Except where indicated each of these options incorporates all measures outlined in the preceding option.

5.2 Malton

The options shortlisted for Malton are as follows:

5.2.1 Walk away M1

Under this purely theoretical scenario, all spending on activities and infrastructure to reduce flood risk would cease. This allows the benefits afforded by existing spending to be identified and is the baseline required for appraising schemes in line with national guidance.

5.2.2 Sustain existing level of support M2

This option would involve continuing with all existing measures to reduce flood risk, including awareness raising, flood forecasting and warning, development control, community support, emergency pumping and maintenance of all existing land drainage, urban drainage and flood defence systems.

5.2.3 Improvement Option M3

Improved flood warning measures – Analysis of telemetry at the Broughton borehole would allow a more confident determination of the threshold of groundwater level and groundwater flooding in Malton. This would be linked formally to a local flood warning system, allowing authorities and local residents and businesses time to take action. Telemetry would be installed at other known flood trigger points to automate the warnings for the Emergency Pumping Plan and reduce reliance on reports or local observations.

Constructed chambers for deployment of temporary pumps – Construction of chambers/well points that temporary pumps could be mobilised to, and deployed, as identified in the Emergency Pumping Plan.

Local Property Level Protection measures – These measures would include tanking (exclusion of flow from property basements and ground floors including provision of flood doors, and blocking air vents); through flow (reinstatement or creation of drainage routes through buildings which would reduce build-up of water upstream of properties); and resilience (measures to reduce the impacts of the flooding on personal and property damage, and improve the ability and speed of recovery after flooding). These measures could also include waterproof plastering, elevating electrical sockets, hard easy to wash down flooring.

5.2.4 Improvement Option M4

As per M3, with Property Level Protection reduced as appropriate, plus:

Control of surface water flowpaths – Castlegate would be fitted with surface water interceptors, road side drainage or other such features to ensure water is diverted into locations which either have capacity to accommodate flood water or to ensure that pumping efforts are effectively able to remove the water.

Control of surface flowpaths from groundwater emergence – Properties in Castlegate affected by groundwater discharge from the base of the Castle Hill would be modified with flowpath control features (e.g. french drains) to ensure water is able to pass around the properties to areas suitable for pumping, rather than through the ground floors of the properties.

5.2.5 Improvement Option M5

As per M4, plus:

Upgrade to permanent land drainage pumps within each sump – Installation of permanent pumps to ensure that surface water collecting behind defences has a permanent, pre-installed discharge mechanism. Such provision would reduce the reliance on additional temporary pumps or remove this need altogether. These pumps could be designed with associated local storage volumes, wherever there is space.

5.3 Norton

5.3.1 Walk away N1

Under this purely theoretical scenario, all spending on activities and infrastructure to reduce flood risk would cease. This allows the benefits afforded by existing spending to be identified and is the baseline required for appraising schemes in line with national guidance.

5.3.2 Sustain existing level of support N2

This option would involve continuing with all existing measures to reduce flood risk, including awareness raising, flood forecasting and warning, development control, community support, emergency pumping and maintenance of all existing land drainage, urban drainage and flood defence systems.

5.3.3 Improvement Option N3

As per N2, plus:

Improved flood warning measures – Telemetry would be installed at other known flood trigger points to automate the warnings for the Emergency Pumping Plan and reduce reliance on reports or local observations, and provide warnings to local residents and businesses.

Constructed chambers for deployment of temporary pumps – Construction of chambers/well points that temporary pumps could be mobilised to, and deployed, as identified in the Emergency Pumping Plan.

Network Rail under-pumping arrangement – Installation of two permanent ducts passing under the railway line at Church Street that would be used for pumping during a flood event.

Further optimise Mill Beck Pumping Station on/off levels – Optimise the levels at which Mill Beck Pumping Station operates to improve the ability of the Combined Sewer Overflow (CSO) to the Mill Beck to continue to discharge.

Local Property Level Protection measures – These measures would include tanking (exclusion of flow from property basements and ground floors including provision of flood doors, and blocking air vents); through flow (reinstatement or creation of drainage routes through buildings which would reduce build-up of water upstream of properties); and resilience (measures to reduce the impacts of the flooding on personal and property damage, and improve the ability and speed of recovery after flooding). These measures could also include waterproof plastering, elevating electrical sockets, hard easy to wash down flooring.

5.3.4 Improvement Option N4

As per N3, with Property Level Protection reduced as appropriate, plus:

Upgrade Mill Beck PS – Increased pump capacity to ensure that flows from the Mill Beck and surface water collecting behind defences have a permanent, pre-installed discharge mechanism. Such provision would reduce the reliance on additional temporary pumps or remove this need altogether.

Add capacity at existing Sewer Pumping Stations – Permanent Sewer Pumping Stations that remove combined sewage flows from the catchments would be upsized to increase the pumping rate and thus outflow from flood affected areas. This may need to be coupled with measures to either contain or treat the greater volumes of contaminated water at the Waste Water Treatment Works, or additional emergency overflow mechanisms from each Sewer Pumping Stations to the River Derwent.

Auxiliary overflow diversion – Ground levels to the east would be modified to divert flood water from Welham Road area along this route, providing an additional escape route.

Formalisation of defences at sewer pumping station – In combination with the above to reduce the risk of ponding surface water flooding the SPS, and so reducing the risk of sewer-related flooding affecting properties in and around Derwent Terrace.

5.3.5 Improvement Option N5

As per N4, plus:

Permanent land drainage pumps – Permanent new pump station at Church Street to ensure surface water collecting behind defences has a permanent, pre-installed discharge mechanism. This would tie in with the railway under-pumping arrangements and under-road ducts. Such provision would reduce the reliance on additional temporary pumps or remove this need altogether.

5.4 Old Malton

5.4.1 Walk away OM1

Under this purely theoretical scenario, all spending on activities and infrastructure to reduce flood risk would cease. This allows the benefits afforded by existing spending to be identified and is the baseline required for appraising schemes in line with national guidance.

5.4.2 Sustain existing level of support OM2

This option would involve continuing with all existing measures to reduce flood risk, including awareness raising, flood forecasting and warning, development control, community support, emergency pumping and maintenance of all existing land drainage, urban drainage and flood defence systems.

5.4.3 Improvement option OM3

As per OM2, plus:

Urban drainage system maintenance – Enhanced clearance of road gullies and removal of any pipe blockages as identified.

Improved flood warning measures – Telemetry would be installed at other known flood trigger points to automate the warnings for the Emergency Pumping Plan and reduce reliance on reports or local observations, and provide warnings to local residents and businesses.

Constructed chambers for deployment of temporary pumps – Construction of chambers/well points that temporary pumps could be mobilised to, and deployed, as identified in the Emergency Pumping Plan.

Local Property Level Protection measures – These measures would include tanking (exclusion of flow from property basements and ground floors including provision of flood doors, and blocking air vents); through flow (reinstatement or creation of drainage routes through buildings which would reduce build-up of water upstream of properties); and resilience (measures to reduce the impacts of the flooding on personal and property damage, and improve the ability and speed of recovery after flooding). These measures could also include waterproof plastering, elevating electrical sockets, hard easy to wash down flooring.

5.4.4 Improvement option OM4

As per OM3, with Property Level Protection reduced as appropriate, plus:

Diversion of Riggs Road Drain – Diversion of high level flows from Riggs Road Drain south of A64 to the east, reconfiguring the field drain network flowing to the River Derwent. Baseflow would be maintained in Riggs Road Drain. Land drains within this catchment would be adapted to mitigate any potentially negative impacts.

5.4.5 Improvement option OM5

As per OM4, plus:

Permanent land drainage pumps – Installation of permanent pumps to ensure that flows from the Riggs Road Drain and surface water collecting behind defences have a permanent, pre-installed pumped discharge mechanism. Such provision would reduce the reliance on temporary pumps or remove this need altogether. It may also obviate the need for any property level measures.

The key component of all of the above options and sketches showing their general arrangement are included in Appendix I.

6 Initial appraisal

6.1 Social and environmental impacts

An initial assessment of the environmental impacts of the shortlisted options is provided in Appendix H. In general, none of the works outlined is likely to have an unacceptable social or environmental impact. The impacts would be very positive in terms of the health and wellbeing of local residents currently exposed to the flood hazard.

Traffic disruption during construction is likely to be a key issue of concern. Any works and working methods during construction would need to minimise any disruption caused to key access routes.

A geotechnical desk study of each specific site will be required and this may identify the need for ground investigations to assess the soils and scope for contaminants to be present.

The River Derwent downstream of the site is designated a SSSI and SAC and consequently a Habitat Regulation Assessment Screening may be required. In addition it is probable that consultation with Natural England may be required in relation to potential impacts on the SSSI and their mitigation.

The proposed diversion of Riggs Road Drain would need to be very sensitively designed to retain a flow through the existing gardens, whilst diverting flood flows in flood conditions.

Any works taken forward would be screened for their Environmental Impact Assessment and Equalities Impact Assessment requirements, and regulatory duties would be followed.

6.2 Economic impacts, cost and benefits

The following section presents the results of the costs and benefits of the options in each of the three areas. The following should be noted:

- Residual flood damages are the flood damages that still occur after the implementation of an option. These were derived from Arup's in-house flood damage calculation tool, which implements the methods of the FHRC Multi Coloured Manual.

- The Benefits of an option are the damages avoided through the implementation of that option.

- The costs have been estimated by a Quantity Surveyor from a specification of the measures. Costs also include 40% for appraisal optimism bias – this adjustment must be explicitly accounted for in appraisals to counters any over-optimism of estimated capital costs, works duration, operational costs and delivery of stated benefits, and has been calculated in accordance with Defra and HM Treasury Green Book guidance. The infrastructure has been assumed to constitute non-standard civil engineering works, based on the Supplementary Green Book Guidance for Optimism Bias. Allowances have also been made for design, planning and environmental appraisal, surveys, site supervision and contract administration, whole life operation and maintenance costs and compensation payments.

- The Benefit Cost Ratio, and other factors contained within the Environment Agency Partnership Funding Calculator, give a guide to the costs eligible for FCERM Grant in Aid.

- The remainder is the contribution that would be required from Partnership Funding (PF) for the scheme to be eligible for FCERM Grant in Aid.

The various assumptions, and a break-down of the capital costs, are included in Appendix G.

Table 4 summarises the Present Value whole life costs and benefits associated with the improvement options identified for each area, together with an indication of the local partnership funding (PF) contributions required in order to secure central government Flood and Coastal Erosion Risk Management Grant in Aid (FCERM GiA).

It is notable that the costs of some options reduce for options that at face value involve a greater level of civil engineering intervention. This is because Property Level Protection is used to reduce the residual risk in Options 3,4,5. Increased levels of collective protection measures reduce the need for property level protection, and this means that costs do not increase consistently.

Table 4: Summary data for the options considered in Malton, Norton and Old Malton.

	Malton Options				
	M1	M2	M3	M4	M5
Residual Damages (£)	10,189,000	4,527,000	1,901,000	1,868,000	1,556,000
Benefits (£)	-	5,662,000	8,288,000	8,321,000	8,633,000
Costs (£)	-	42,000	1,311,000	1,104,000	1,091,000
BCR		134.7	6.32	7.54	7.92
Costs eligible for GiA (£)			724,000	726,000	744,000
PF contribution required (£)			587,000	377,000	347,000

	Norton Options				
	N1	N2	N3	N4	N5
Residual Damages (£)	15,428,000	12,047,000	5,410,000	5,168,000	4,774,000
Benefits (£)	-	3,381,000	10,017,000	10,259,000	10,654,000
Costs (£)	-	42,000	2,278,000	2,176,000	2,545,000
BCR		80.4	4.40	4.71	4.19
Costs eligible for GiA (£)			1,007,000	1,020,000	1,042,000
PF contribution required (£)			1,271,000	1,156,000	1,503,000

	Old Malton Options				
	OM1	OM2	OM3	OM4	OM5
Residual Damages (£)	3,759,000	2,671,000	1,276,000	506,000	485,000
Benefits (£)	-	1,087,000	2,482,000	3,252,000	3,274,000
Costs (£)	-	84,000	1,004,000	746,000	1,150,000
BCR		12.9	2.47	4.36	2.85
Costs eligible for GiA (£)			388,000	431,000	432,000
PF contribution required (£)			616,000	315,000	718,000

Tables 5 to 8 below provide additional information designed to illustrate the impact of combining the schemes, reducing costs and increasing benefits – all of which may or may not be possible, depending on the outcome of more detailed appraisal.

Table 5: Results showing the impact of combining all three schemes (Malton, Norton and Old Malton) into a single project, with costs and benefits merged.

	Malton, Norton and Old Malton combined				
	1	2	3	4	5
Residual Damages (£)	29,375,000	19,245,000	8,587,000	7,543,000	6,814,000
Benefits (£)	-	10,130,000	20,788,000	21,833,000	22,561,000
Costs (£)	-	168,000	4,593,000	4,026,000	4,786,000
BCR		60.3	4.53	5.42	4.71
Costs eligible for GiA (£)			2,120,000	2,178,000	2,218,000
PF contribution required (£)			2,473,000	1,848,000	2,568,000

Table 6 shows what the situation would be with a combined scheme should further appraisal work identify 20% additional scheme benefits and also that a 20% optimism bias (rather than 40%) is likely to be sufficient. This is a best case scenario that would need to be verified using additional investigation. This scenario indicates that, depending on the option selected, combined scheme costs could feasibly be between £3.2m and £3.8m. Between £0.8m and £1.4m of these costs would need to be secured from sources other than FCERM GiA (i.e. from partnership funding).

Table 6: Results showing the impact of a sensitivity analysis on the combined scheme scenario shown in Table 5.

	Malton, Norton and Old Malton combined (Benefits up 20%; Costs down 20%)				
	1	2	3	4	5
Residual Damages (£)	29,375,000	19,245,000	8,587,000	7,543,000	6,814,000
Benefits (£) + 20%	-	12,156,000	24,946,000	26,199,000	27,073,000
Costs (£) - 20%	-	135,000	3,674,000	3,221,000	3,829,000
BCR		90.4	6.79	8.14	7.07
Costs eligible for GiA (£)			2,351,000	2,420,000	2,469,000
PF contribution required (£)			1,323,000	800,000	1,360,000

Table 7 shows the situation should the works in Norton and Malton be combined, but the proposals in Old Malton, which are the least cost-beneficial, be removed from the combined scheme.

Table 7: Results for Malton and Norton combined.

Table 7	Malton and Norton Only				
	1	2	3	4	5
Residual Damages (£)	25,617,000	16,574,000	7,311,000	7,036,000	6,329,000
Benefits (£)	-	9,043,000	18,306,000	18,580,000	19,287,000
Costs (£)	-	84,000	3,589,000	3,280,000	3,636,000
BCR		107.6	5.10	5.66	5.31
Costs eligible for GiA (£)			1,731,000	1,747,000	1,786,000
PF contribution required (£)			1,857,000	1,533,000	1,850,000

Table 8 shows the situation should Norton and Malton be combined (as above), and further appraisal work identify 20% additional scheme benefits and also that a 20% optimism (rather than 40%) bias is likely to be sufficient. This again is very much a best case scenario. Under this alternative 'best case scenario' costs would lie in the range £2.6m-£2.9m; between £0.7m and £0.9m of which would need to be secured from partnership funding sources. Under this scenario though, the flooding problem in Old Malton would remain unaddressed.

Table 8: Results for Malton and Norton combined only, with a best case scenario change to the costs and.

	Malton and Norton Only (Benefits up 20%; Costs down 20%)				
	1	2	3	4	5
Residual Damages (£)	25,617,000	16,574,000	7,311,000	7,036,000	6,329,000
Benefits + 20% (£)	-	10,851,000	21,967,000	22,296,000	23,145,000
Costs - 20% (£)	-	67,000	2,871,000	2,624,000	2,908,000
BCR	-	161.4	7.65	8.50	7.96
Costs eligible for GiA (£)			1,935,000	1,953,000	2,000,000
PF contribution required (£)			936,000	671,000	908,000

7 Conclusions and recommendations

7.1 Conclusions

It can be concluded that there is a very good economic case for investment in proposals to reduce flood risk in Old Malton, Malton and Norton. FCERM Grant in Aid could be applied for subject to technical approvals and submission of a Project Appraisal Report (PAR). However, none of the options identified would be wholly fundable from central government FCERM Grant in Aid, even if optimistic assumptions are made about implementation costs and the benefits achieved. All options will require partnership funding to be secured locally.

The most promising sources of such partnership funding are likely to be as follows:

- Funds within the Multi-Agency Flood Group organisations, as well as other organisations, individuals and local businesses with vested interests in the reduction of flood risk;
- Key local businesses including landowners and property developers affected or those with a financial interest in the area;
- Local residents and community groups benefitting from the proposals.

Other potential options include, for example, Local Enterprise Partnership - European Strategic and Investment Fund (ESIF), Regional Flood and Coastal Committee Local Levy funding, Community Infrastructure Levy and/or setting up a Business Improvement District.

7.2 Next steps

The recommended next steps are as follows:

- Consultation with stakeholders, potential contributors and affected parties;
- Preparation of Partnership Funding calculations, factoring in likely contributions;
- Discussions with the Environment Agency with a view to developing a full Project Appraisal Report (PAR) and application for FCERM GiA, making best use of this report, which contains all the essential elements of such an application.

A PAR is a technical report, written to demonstrate that a proposed scheme is technically and economically viable, and is the most appropriate option. The granting of FCERM Grant in Aid will be subject to the acceptance of a successful PAR, and other sources of funding may also be contingent on this acceptance. A full PAR requires a high level of robustness in its key conclusions, and as such, its development will involve refinement of the work presented in this report.
These refinements would be undertaken alongside discussions with the statutory authorities and non-statutory organisations, businesses and / or individuals potentially affected by the proposals.

It is also recommended that further studies and surveys, including, but not limited to, the following are undertaken:

- a geotechnical desk study to help identify the ground conditions in the area,
- topographical survey to refine the ground elevations, the location of physical features, and dimensions of key hydraulic features,
- site investigation, including physical location of site services,
- archaeological/ecological surveys to complement the initial environmental desktop study.
- monitoring of flows and water levels to help refine hydrological and hydrogeological estimates

This baseline data will help identify any further physical constraints and the associated environmental impact assessments to comply with the Environmental Impact Assessment Regulations. The more detailed information will be fed back into

- scheme analysis,
- designs,
- cost and benefit calculations.

All of this will give more robust understanding for the PAR. This work will also involve appointment of a Principal Designer under the revised 2015 Construction and Design Management Regulations.

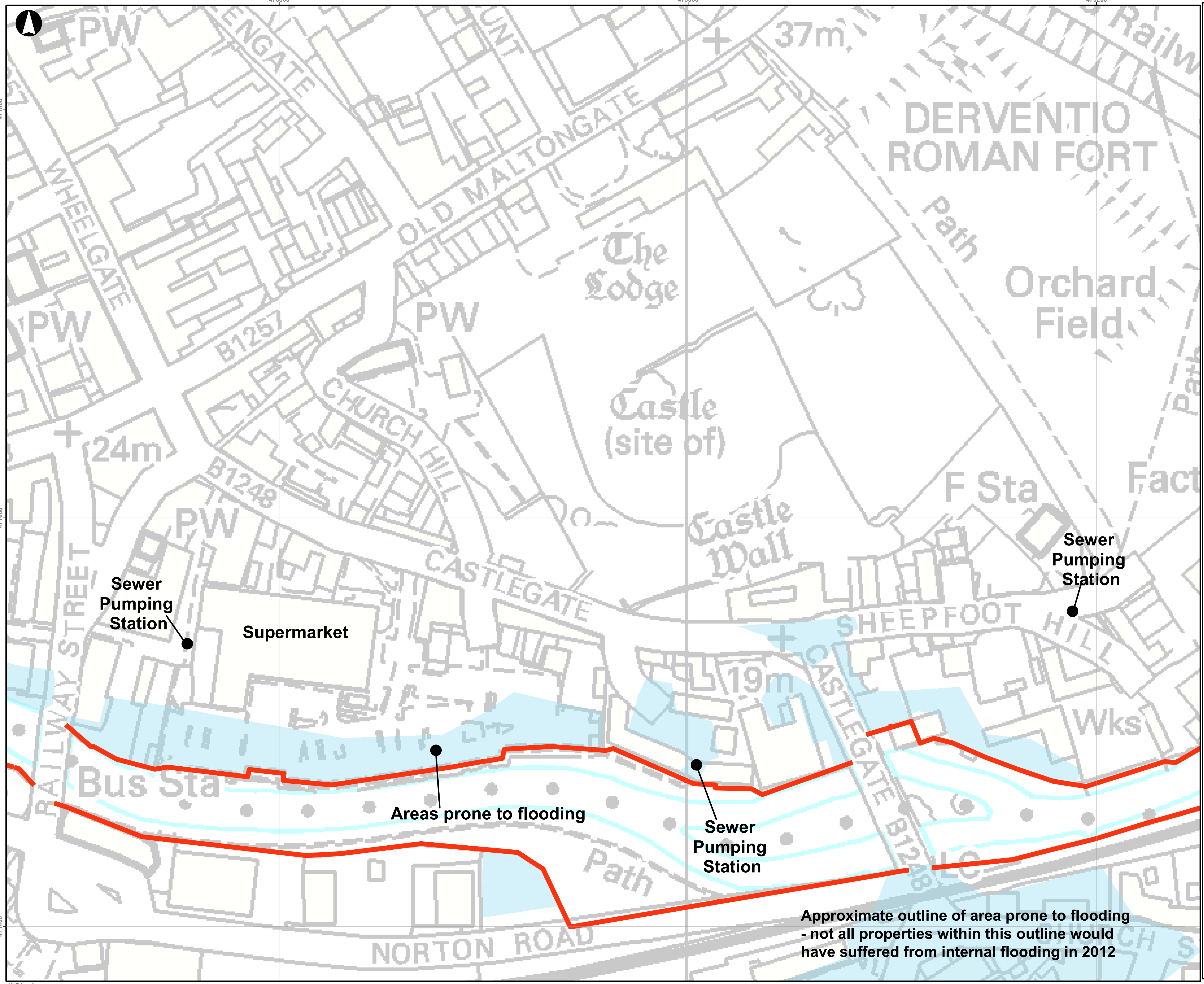
Figures

Figure 1 Malton Key Plan

Figure 2 Norton Key Plan

Figure 3 Old Malton Key Plan

A3



Legend

Existing flood defences

Approx. outline of Nov 2012 flood. Not all properties within this outline would have suffered from internal flooding.

Issue	Date	By	Chkd	Appd
P0	2015-07-02	AB	LB	WM

Metres
0 20 40 80

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Client
North Yorkshire County Council

Job Title
Malton and Norton Flooding Study

Key Plan - Malton

Scale at A3
1:1,750

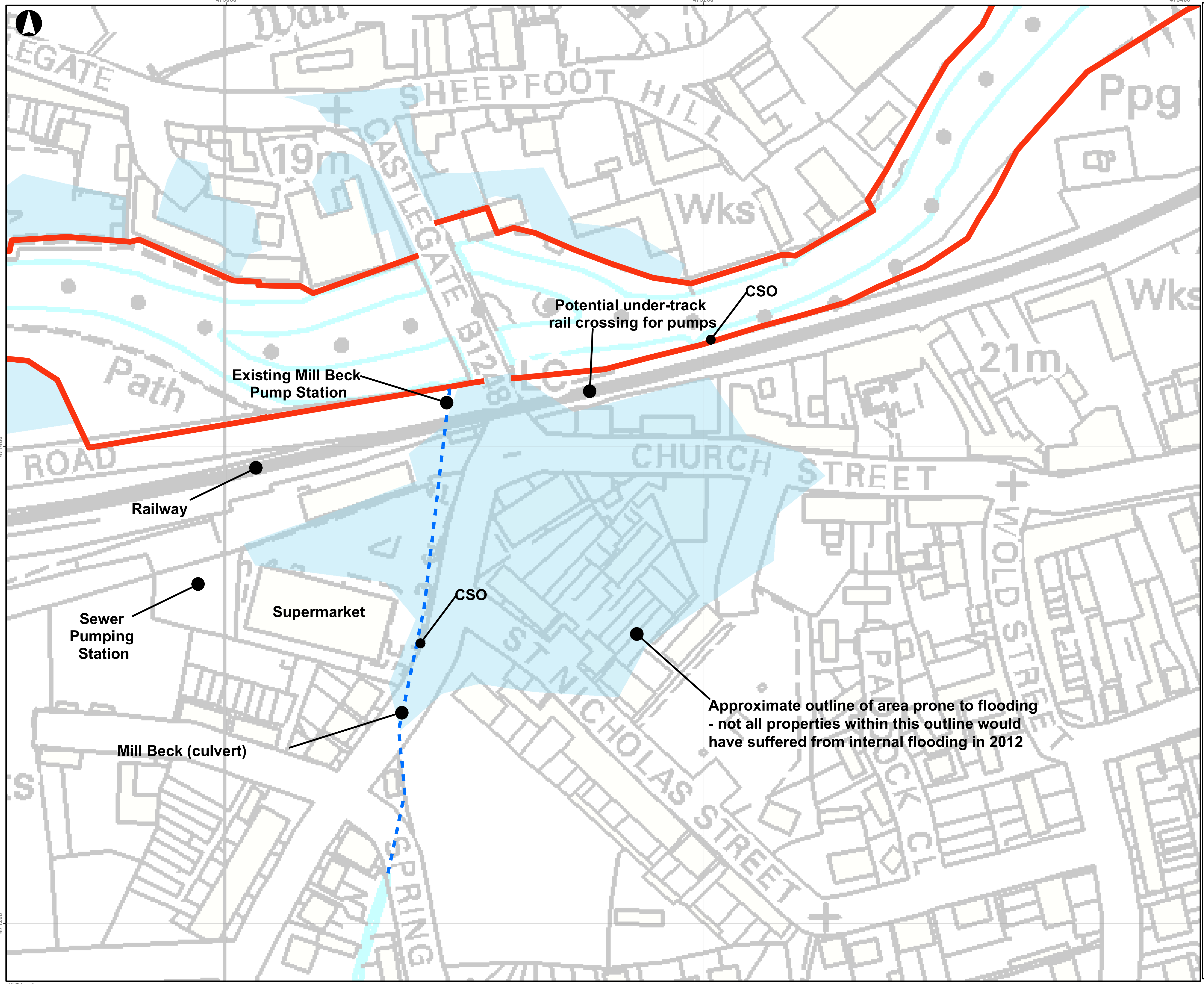
Job No	Drawing Status
239474-00	**Preliminary**

Drawing No	Issue
001	**P0**

MXD Location

02/07/2015 12:06:44

A3



MXD Location

Legend

- Culverts
- Existing flood defences
- Approx. outline of Nov 2012 flood. Not all properties within this outline would have suffered from internal flooding.

Issue	Date	By	Chkd	Appd
P0	2015-07-02	AB	LB	WM

Metres
0 20 40 80

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Client
North Yorkshire County Council

Job Title
Malton and Norton Flooding Study

Key Plan - Norton

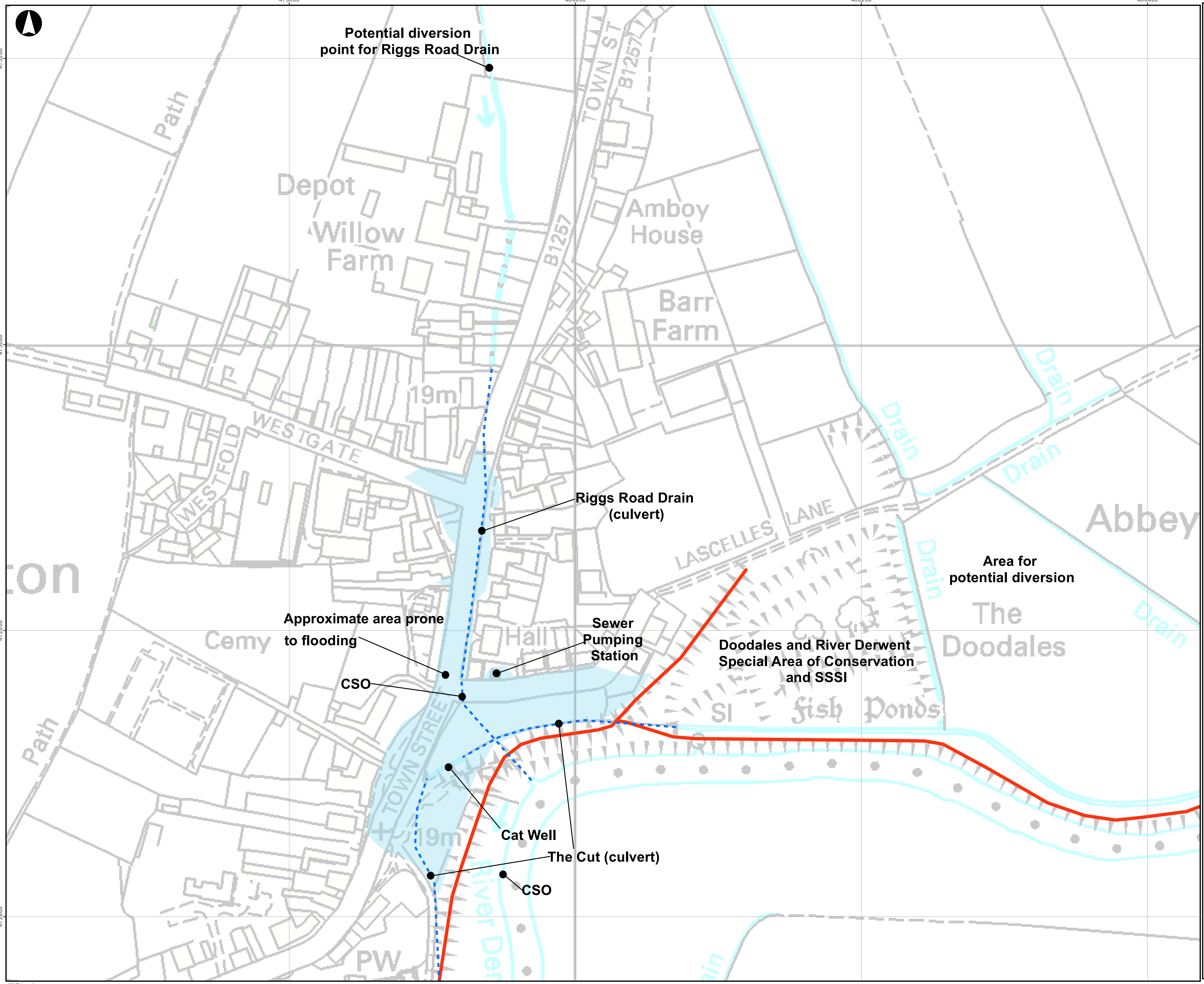
Scale at A3
1:1,500

Job No	Drawing Status
239474-00	Preliminary

Drawing No	Issue
002	P0

02/07/2015 12:59:26

A3



Legend

- Culverts
- Existing flood defences
- Approx. outline of Nov 2012 flood. Not all properties within this outline would have suffered from internal flooding.

P0	2015-07-02	AB	LB	WM
Issue	Date	By	Chkd	Appd

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North Yorkshire County Council

Job Title
Malton and Norton Flooding Study

Key Plan - Old Malton

Scale at A3
1:2,500

Job No	Drawing Status
239474-00	**Preliminary**

Drawing No	Issue
003	**P0**

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MXD Location

Appendix A

Flood History

File Note

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Project title	Malton and Norton Flooding Study	Job number	239474-00
cc		File reference	
Prepared by	Adam Broadhead	Date	25 March 2015
Subject	Appendix A - Flooding History and Mechanisms		

1 Flood history

A full record of the flood history of Malton, Norton and Old Malton is presented in Table 1 overleaf. This has been drawn from information provided in previous studies, supplemented by information from the community and stakeholders. For each event, indicative dates, locations affected, and possible flood mechanisms have been identified.

Table 1: History of flooding in Malton, Old Malton and Norton

Date	Malton	Norton	Old Malton	Primary likely flood mechanism	Description	Source
1866	Y	Y	Y	Derwent overtopping	Widespread flooding	Riggs Road Drain Report
1878	Y	Y	Y	Derwent overtopping	Flooding in Old Malton and Malton, snow melt	Riggs Road Drain Report
1892	Y	Y	Y	Derwent overtopping	Flooding in Malton and Norton, probably also Old Malton.	Riggs Road Drain Report
Sep-31	Y	Y	Y	Derwent overtopping	Widespread flooding in Old Malton, Malton and Norton, Derwent overtopping	Riggs Road Drain Report
1947	Y	Y	Y	Derwent overtopping	Flooding in Malton and Norton, probably also Old Malton.	Riggs Road Drain Report
1960	Y	Y	Y	Derwent overtopping	Flooding in Malton and Norton, probably also Old Malton.	Riggs Road Drain Report
1963	Y	Y	Y	Derwent overtopping	Flooding in Malton and Norton, probably also Old Malton.	Riggs Road Drain Report
December 1978	?	Y	Y	?	Flooding of houses along Welham Rd, St Nicholas Street, Church Street	Mill Beck Final Report
1982	Y	Y	Y	Derwent overtopping	Flooding in Malton and Norton, probably also Old Malton.	Riggs Road Drain Report
Feb-91	?	?	Y	Derwent overtopping	Large scale flooding to farmland north of Old Malton	Priorpot Beck Report
7-9 Mar-99	Y	Y	Y	Derwent overtopping	Flooding of houses along Welham Rd, St Nicholas Street, Church Street, and Springfield Garth. Widespread flooding in Old Malton Town Street and adjacent properties as far north as Willow Farm, Westgate Road and adjacent properties, washlands east of Old Malton. Main flooding from Derwent Flooding of large areas of agricultural land and significant number of residential, industrial and commercial properties, lasting 5 days. Groundwater flooding Malton and Norton	Mill Beck Final Report Riggs Road Drain Report Priorpot Beck Report
7-9 November 2000	?	Y	Y	Derwent	Flood patterns in Priorpot similar to those in March 1999 but water levels reported a few inches higher Flooding of houses along Welham Rd, St Nicholas Street, Church Street, and Springfield Garth Widespread flooding in Old Malton Town Street and adjacent properties as far north as Willow Farm, Westgate Road and adjacent properties, washlands east of Old Malton. Main flooding from Derwent	Priorpot Beck Report Mill Beck Final Report Riggs Road Drain Report
August 2002	?	?	?		Flood gates reported closed.	Ian Cooke, EA

Table 1: History of flooding in Malton, Old Malton and Norton

Date	Malton	Norton	Old Malton	Primary likely flood mechanism	Description	Source
Jan-03	?	?	Y		Flooding vicinity of Cat Well and Royal Oak. Derwent did not overtop banks. Flooding primarily from Riggs Drain	Riggs Road Drain Report
2003					**Completion of Flood Alleviation Scheme** **Malton SOP 50 yr** **Norton SOP 50 yr** **Old Malton SOP 200 yr**	
Feb-04	?	?	Y		Flooding vicinity of Cat Well and Royal Oak. Derwent did not overtop banks. Flooding primarily from Riggs Drain Groundwater flooding. Flood gates reported closed.	Riggs Road Drain Report Ian Cooke, EA
May-05	?	?	?		Flooding of Priorpot Scarborough Road, lasting 2 days	Priorpot Beck Report
2005	?	?	?		Stated 170 properties flooded, but no further details. Flood gates reported closed.	Derwent Catchment Management Plan. Ian Cooke, EA
2007	?	Y	?		A resident (name redacted) on St Nicholas Rd reported flooding almost to back gardens. Flood gates reported closed.	Community Ian Cooke, EA
22-23rd January 2008	Y	Y	Y	Flood-locking, long duration rain, groundwater	Reported groundwater flooding in Castlegate after days of heavy rain, with Derwent noted to be high, reported to be flood-locking drainage outfalls, particularly from 23rd to 24th at Castlegate, Sheepfoot Hill and Kings Mill Flats. Fire Service starts pumping Chandlers Wharf. Other pumps deployed. Old Malton at the Gannock water pumped from flooded beck over defences in Derwent (Cat Well? Riggs Road Drain?) on 22nd January overnight to 23rd. Norton flooding starts evening of 22nd, St Nicholas Street and Welham Rd gardens flooded by foul sewer surcharging. Residents claimed and EA confirmed 1 pump at Mill Beck PS not working, and 2 temporary ones deployed.	http://knowledge-controversies.ouce.ox.ac.uk/RyedaleFloodResearchGroup/photographs/MaltonFloodsJanuary2008/malton23rdjanuary200841.html http://www.gazetteherald.co.uk/news/2004482.residents_hold_their_breath_as_waters_rise/ http://www.maltonmercury.co.uk/news/local/residents-race-against-floods-in-malton-s-castlegate-1-916032
September 2008	?	?	?		Flood gates reported closed.	Ian Cooke, EA

Table 1: History of flooding in Malton, Old Malton and Norton

Date	**Malton**	**Norton**	**Old Malton**	**Primary likely flood mechanism**	**Description**	**Source**
2008	?	Y	?	Penstock failure	Flooding occurred when CSO to Mill Beck was not shut off before the Mill Beck penstock for the PS was closed. Probably referring to January event.	Yorkshire Water, discussions in meeting.
November 2009	?	?	?		Flood gates reported closed.	Ian Cooke, EA
February 2010	?	?	?		Flood gates reported closed.	Ian Cooke, EA
Sep-12	N	N	N		River Derwent high, but within defences. Observed Mill Beck outfall submerged. (https://www.youtube.com/watch?v=2p2wWkvJArg&feature=player_detailpage#t=66). No surcharging of drains in Norton at this time.	Internet search (youtube) Community
27-30 November 2012	Y	Y	Y		River Derwent high. Above level of Mill Beck outfall. Water being pumped over defences at Chandlers Wharf. Flood water in yard to west of Castlegate Bridge pumped and flooded up to tree near driveway. https://www.youtube.com/watch?v=bvJoTPj0Y08&feature=player_detailpage#t=82 Resident (name redacted) on St Nicholas Rd reported flooding to within 2 inches of floor level. Approx rate of rise 2inches / hour at peak, but probably already influenced by pumping at this point in time.	Internet search (youtube) Community
20-27 December 2012	N	N	N		High flows on Derwent – flooding might have been expected to Malton, Norton, Old Malton. It is expected that flooding didn’t reoccur due to high alertness following Nov 2012.	Derwent gauge record.
29 Jan 2013	N	N	N		Rye out of bank nr A169. Pumps deployed at Old Malton and Norton. Snowmelt mechanism	https://www.youtube.com/watch?v=cbVdLmgiddw

Table 1: History of flooding in Malton, Old Malton and Norton

Date	**Malton**	**Norton**	**Old Malton**	**Primary likely flood mechanism**	**Description**	**Source**
February 2014	Y	?	?	Flood locking	"In February 2014 we experienced further flooding issues at Castlegate/Chandlers Wharf. This was reported by the resident at no 104 Castlegate, Malton YO17. This was caused by high river levels in the river Derwent. Over-pumping was set up for a week to reduce the levels in the sewer. This incident prompted an investigation to look at sources of infiltration in to the sewers in this area."	Malton and Norton Flood Procedure, YW (based on Emergency Pumping Plan document)
7-8 November 2014	?	?	Y	Drainage exceedance	Surface runoff ponding on Old Malton from top of hill, spilling from ponding in Town Street towards Lascelles Lane, no surcharging from sewers or drains. This situation then remained close to flooding over the Christmas period.	Community
3 May 2015	?	?	Y	Rapid runoff, blocked gullies	Surface runoff ponding on Old Malton from top of hill, spilling from ponding in Town Street towards Lascelles Lane, but no surcharging reported or noted in photographs and videos from sewer or drains.	Report, photos and videos from Mark Saunders, EA
Annually	?	?	?	Priorpot Beck	Flooding to gardens downstream of Priorpot Bridge on Scarborough Road	Priorpot Beck Report, dated 2001
Frequent 1-2 yr floods	?	Y	?		Flooding along Welham Road and within the foundations of adjacenet terraced houses (8, 10, 12, 14, 16, 18)	Mill Beck Final Report, dated 2005
2-3 times a year	?	?	Y	RRD	Minor flooding, ponding near the Old Oak Hotel after heavy rainfall events. RRD backs up when Derwent high, and surface water flowing down Westgate and Town Street ponds at bottom.	Riggs Road Drain Report, dated 2005

2 Flood mechanisms

2.1 Direct flooding from the River Derwent

Until 2003, this simple mechanism occurred whenever the flows in the River Derwent exceeded the capacity of the channel through the town. Following construction of the Main River flood defences in 2003, no direct flooding from the River Derwent has occurred. Flooding from the Derwent could however still occur as a result of the following:

- Failure to close the flood gates in the flood defences or penstocks, which are fitted to larger gravity outfalls;
- Failure of flap valves;
- Overtopping due to a design exceedance flood. The reported standard of protection from the River Derwent FAS is a 50 year return period for Malton and Norton, and a 200year return period for Old Malton.

2.2 Flood locking

The main flood mechanism experienced in the November 2012 event across Malton, Norton and Old Malton is the River Derwent rising above the level of the gravity drainage outfalls through the main river flood defences. Most of the outfalls had, or have since been fitted with, effective flap valves that prevent the River Derwent leaking through into the town, although a risk remains that they could fail or be ineffective. Watercourses, surface water drains and sewers cannot discharge to the River Derwent unless pumped away, and this phenomenon is referred to as "flood-locking". Water backs up and collects behind the defences in the lowest points, until river levels recede and gravity drainage can resume. The duration that the River Derwent remains high affects the volume of surface water that accumulates. There are some recorded events where river levels have exceeded drainage outfalls for as long as 10 days.

It is notable that most flood incidents following the construction of the 2003 River Derwent Flood Alleviation Scheme seem to coincide with flows in the River Derwent in excess of $80m^3/s$ (a return period of ~ 4 years according to the Malton Data Improvements Study), and this corresponds broadly with the threshold at which local water courses and drainage systems cannot discharge to the Derwent.

2.3 Drainage exceedance

Another general flood mechanism is when localised storms, within the Malton, Norton and Old Malton catchments, result in peak flows through drainage systems that exceed their capacity to convey floodwater. In the case of open watercourses and land drains, this causes localised bank overtopping. In the case of road drainage systems, sewers and/or culverted watercourses, this can cause surcharging at manholes or gulley pots, with consequent overland flow and ponding at low points. This has been reported to occur in Old Malton, when the River Derwent level was not particularly high. Where combined sewers surcharge through the above mechanisms, there is the likelihood of foul contamination of floodwaters. This was reported in the November 2012 event.

2.4 Groundwater flooding

A flood mechanism affecting Malton and Norton (and possibly also Old Malton) is groundwater emergence following extended wet periods. Springs reactivated following the extended wet period during the November 2012 event, with groundwater collecting in Castlegate, Malton. Sites here have a long history of groundwater flooding, with a number of historic natural springs in the area.

2.5 Area specific mechanisms

2.5.1 Malton

Malton has no distinct watercourse draining to the River Derwent. Instead, it has a number of surface water drain and sewer outfalls, and combined sewer overflows (CSO) outfalls. The sewers are generally combined, and pumped to treatment from several sewer pumping stations (SPS) sited at the lowest points behind the defences. Overland flowpaths drain through the urban area and water collects in the low points behind the defences. Groundwater is specifically known to discharge at properties on Castlegate, and Yorkshire Water have reported infiltration-inflow of their surface water sewer in this location, by flows of 20-30 l/s, even during dry weather conditions.

2.5.2 Norton

The Mill Beck flows through Norton, culverted between Welham Road and its outfall to the River Derwent. The Mill Beck drains a moderately urbanised catchment, with a large agricultural, highly permeable catchment in its upper reaches. Consequently, groundwater discharges through springs, some of which have been buried in the lower reaches of this catchment. Although the River Derwent did not overtop the flood defences, seepage through the walls was reported, which is reported to have been dealt with by the Environment Agency.

Unlike in Malton and Old Malton, the Mill Beck has a permanent pumping station at its outfall. When the River Derwent exceeds a given threshold, a penstock is closed and flow is diverted to the pumps. The pumps operate with a start water level of 16.7mOD,[1] which is the same level as the soffit of the upstream culvert on the Mill Beck.

Norton is served by a combined sewer network that drains a large urban area, draining by gravity to the main Pumping Station, Welham Road North (located to the west of LidL). A CSO connects the drainage system to the Mill Beck culvert at the south east corner of LidL. Since the operation of the Mill Beck pumping station would automatically mean that water levels in the Mill Beck will exceed the level of the CSO, the CSO is closed off by a penstock before the Mill Beck / Derwent penstock is closed. In 2008, this didn’t occur, and flooding ensued due to the Mill Beck entering the combined sewer system.

Reports indicate that both surface water ponding and foul sewer surcharging occurred in the November 2012 event. The pattern of flooding from the November 2012 event provided by Yorkshire Water’s Flood Mitigation Plan[2], indicates flooding around Church Street and houses to the south of Church Street, and is reported to have come out of the sewers in this vicinity. Flow from the sewer goes from Church St, along Welham Road and passes around LidL to its south to reach the Welham Rd North Pumping Station. The CSO to the Mill Beck is located at LiDL, and would have been shut off by closing a penstock in the 2012 event. The Flood Mitigation Plan notes

[1] Malton Norton Data Improvements Study

[2] Malton & Norton Flood Mitigation Plan (“Malton Norton flood procedure ARUPS docx”), provided by Yorkshire Water, 7th April 2015

that Yorkshire Water have issues with their sewers when the Derwent water level exceeds 2.5m AND there has been increased rainfall for a prolonged period in the catchment. The plan also notes that the river can be over 3m without any issues, suggesting that backflow from the Derwent or Mill Beck are not so much of an issue as the lack of discharge to the Mill Beck via the CSO. Arup note however that, the fact that Yorkshire Water have been able to establish this operational understanding within a relatively short period of time (12years since the construction of the Derwent flood alleviation scheme), does suggest that issues are a relatively common event.

It is notable that the Flood Mitigation Plan's drawings of November 2012 do not show flooding on Welham Road around the junction of St. Nicholas Street (and there was no flooding reported at this location). As this location is lower than Church Street, it suggests that the 2012 event may have been influenced by localised blockage in the vicinity of Church Street.

The stated capacity of the Welham Rd North Pumping Station is 0.10m^3/s, however the subsurface storage on the drainage system is estimated to be relatively small (~400m^3). In a flood locked scenario, flows that exceed the pumping station capacity by as little as 60 l/s, would take approximately 2 hours to start causing flooding to roads, or 15 hours to cause flooding comparable to November 2012. Given the durations for which flood-locking can and has occurred, flow exceedence does not need to be as high as this value to cause flooding.

Understanding of the November 2012 event is to some extent limited by pumps deployed during the event. It is understood (from an early draft of the Malton and Norton pumping Plan) that 2-3 6"pumps may have been deployed on Church St, which suggests a pumping capacity of approx. 200 – 300 l/s. However, that such a capacity was deployed is not an immediate indicator of the peak flow values in November 2012 (as identified, it is as much the gradual accumulation of volume that can cause flooding as the peak flow).

2.5.3 Old Malton

The Riggs Road Drain watercourse flows through Old Malton, culverted through the town until its flap-valved outfall to the River Derwent. It drains a large area to the north of predominantly flat agricultural land. It also drains an area of the A64. The culvert through Old Malton, as well as the culverted sections carrying the Riggs Road Drain beneath the A64, may pose conveyance constraints.

Anecdotal evidence suggests that high inflows enter a tributary of the Riggs Road Drain as it passes under the A64. Hydrological analysis suggests that the A64 itself presents a relatively small area, and even though it is highly impermeable it should not present a significant proportion of the overall flow in the Old Malton catchment. However, the A64 is in a cutting as it passes through Malton, and it is considered plausible that its drains intercept ground water, as well as run-off from two catchments that might otherwise have taken a more circuitous route to Old Malton, and possibly wouldn't have discharged to Old Malton before its construction.

Overland flow from combined and separate sewer catchments and greenfield areas also drain to Old Malton. Reports indicate the Riggs Road Drain surcharged through road gullies and a CSO chamber during the November 2012 event. A short distance upstream of its outfall to the Derwent, the Riggs Road Drain culvert flows below an artificial watercourse / drain called the Cut, which is partially culverted and runs parallel to the River Derwent throughout this area – complex interactions and draining / surcharging between the two are suggested.

Overland flow routes being unable to drain effectively to either the Riggs Road Drain or the open section of the Cut – called the Cat Well – are also reported, causing localised ponding during heavy rainfall. Groundwater flooding has been suggested in this area. It is probable that the predominantly combined sewer network in Old Malton is affected by infiltration-inflow in such events, and was also surcharged in the November 2012 event.

3 What was the significance of the November 2012 flood event?

In the November 2012 event, the peak flow was $126.5m^3/s$, a 48yr event. The $80m^3/s$ threshold was exceeded for 5 days.

Perhaps of more significance to this study is the understanding of the rainfall magnitudes. The probability of a given rainfall event is relative to both the depth of rainfall and the duration of an event. Fast responding systems (small or steep catchments, or urban drainage systems) are sensitive to short duration storms. Slow responding systems are sensitive to long duration storms.

The rainfall that fell during the flood-locked period is notable in that it appears that, considered against all potential durations, it was generally of less significance than a 1-year return period storm.

What the event demonstrates therefore is that, if the local drainage systems can not discharge freely to the Derwent, it does not take a significant magnitude of rainfall to result in flooding.

It should however be noted that a wet summer meant that groundwater levels had been rising steadily and when the period of rainfall immediately preceding the flood-locked period is also considered, the 3.5 day rainfall accumulation was approximately a 6 year return period. There were no particularly intense peaks during this period, so drainage systems would have coped with such an event, but this accumulation would have increased catchment wetness, and raised ground water discharges, such that rates of run-off were more significant during the flood-locked period.

Sewer systems in theory drain the largely impermeable areas of catchments and should not therefore be as subject to increases in percentage run-off due to antecedent rainfall as rural catchment. However any groundwater captured by a sewer system would be expected to increase in the circumstances.

DOCUMENT CHECKING (not mandatory for File Note)

	Prepared by	Checked by	Approved by
Name	Adam Broadhead	Luke Ballantyne	Will McBain
Signature			

Appendix B

Past Studies

Contents

B1 Overview of studies and models in the study area

Study	Year	Author	Hydrology	Hydraulics	Issues
Section 105 C30/92 Survey River Derwent at Foulbridge, Malton and Scrayingham	1999	Kennedy and Donkin	Gauge at Malton, Gringorten to estimate return period of 18 floods. FSR regional growth curve to scale to 1% and 0.5% AEP.	HEC-RAS	Downstream boundary assumed Normal, and results sensitive to boundary.
Priorpot Beck Flood Risk Mapping Phase 2	2001	JBA	Ungauged FEH donor catchments.	HEC-RAS Steady, unsteady. D/S BDY Derwent tailwater levels.	Pumpstation not included. Limited calibration. Not applicable to study scope
Dales Area Floodplain Mapping Phase 2 Studies 2004 – Lower Derwent	2005	JBA	Gauged, FEH statistical plus ungauged FEH rainfall runoff tributaries.	HEC-RAS D/S BDY spring neap tide hydrograph on Ouse.	Uncertain cross-section data.
SFRM Phase 2 Mill Beck – S105	2005	Atkins	Ungauged. FEH pooling groups for rural area. Rational Method for	ISIS and Infoworks D/S BDY fixed Derwent level. Free discharge and backwater,	Highly urbanised and permeable catchment adds uncertainty

			urban areas.	pump and no pump scenarios.	to hydrology.
Dales Area Floodplain Mapping Phase 1 Studies – Riggs Road Drain Old Malton	2005	JBA	Ungauged. IH124 for QBAR, regional growth curve for other return periods.	No model. Estimates hydraulic capacity, no pumps, assumes free discharge.	Only 1.9km2 catchment from OS50k. Only 1300m2 A64 runoff. CDs estimated from nearby.
Malton Data Improvements	2009	Halcrow	Derwent – gauged, FEH statistical AMAX. Priorpot and Mill Beck – ungauged, FEH statistical catchment descriptors and donor adjustment, ReFH for hydrograph shape.	Updates existing. ISIS Tuflow (Old Malton to Buttercrambe) ISIS (Mill Beck and Priorpot Beck Pumping on tributaries. With and without defences. Test Kirkham Sluice operation.	1D only on tributaries due to steepness.
Malton, Norton and Old Malton Case Study Investigation	2013-4	Jacobs	N/A	N/A	High level investigation and summary of 2012 flood event, mechanisms, sources and actions.

B2 Section 105 C30/92 Survey River Derwent at Foulbridge, Malton and Scrayingham

See overview summary MDI_AppendixB_Model_Information_Sheets.pdf in Malton Data Improvements Model reports.

This model covers the River Derwent from Old Malton to south of Malton.

A key limitation was the sensitivity of the River Derwent to the downstream boundary, and the water slope was assumed as normal.

Calibration was a comparison of observed and modelled flood extents.

B3 Priorpot Beck Flood Risk Mapping Phase 2

See overview summary MDI_AppendixB_Model_Information_Sheets.pdf in Malton Data Improvements Model reports.

This model is outside the Malton and Norton Flood Study area, but offers similar hydrological characteristics to the Mill Beck and catchments in our study area. The FEH methods used for design inflows may be relevant.

Limitations of the study were limited calibration data.

B4 Dales Area Floodplain Mapping Phase 2 Studies 2004 – Lower Derwent

See overview summary MDI_AppendixB_Model_Information_Sheets.pdf in Malton Data Improvements Model reports.

This model is outside the Malton and Norton Flood Study area, but later models of the River Derwent build on this work downstream of Malton, which is important because the River Derwent is sensitive to downstream boundary conditions.

Limitations include concerns over changes to channel cross-sections from bed level accretion.

B5 SFRM Phase 2 Mill Beck – S105

See overview summary MDI_AppendixB_Model_Information_Sheets.pdf in Malton Data Improvements Model reports.

This model covers the Mill Beck Norton catchment, testing combinations of flood-locking by the River Derwent and pump operations on flood risk.

Limitations include the design inflow estimation using FEH methods, given high urbanisation and high permeability in the catchment.

B5.1 Model schematisation

1D ISIS model of Mill Beck 1.1 km from weir upstream of Fish Hatchery to River Derwent. 12 bridges, 1 culvert, 1 sluice, 4 weirs.

Inflow boundary represented as FEH unit in ISIS.

Downstream boundary represented as HT boundary in ISIS.

Flood zone represented as single ISIS reservoir unit into which Mill Beck can spill into from points between the Mill Pond outfall and the Long Culvert inlet.

Culvert represented as simple, uniform arch conduit units with even slope, with an orifice opening. Based on CCTV survey, not provided.

Penstock represented by sluice unit with logic control to close to 0.005 m when levels in the Mill Beck >= 16.7 mAD.

Mill Beck pumps represented as abstractions using pump curves from Ryedale District Council. Designed for 500 l/s, 2 pumps on duty/assist (50 year return on Derwent + 10 year return on Mill Beck) according to report, but represented as follows in model:

- Pump 1
  - <= 16.7 mAD, abstraction = 0.0 m^3/s
  - > 16.7 mAD <= 18.2 mAD, abstraction = -0.4 m^3/s
  - > 18.2 mAD <= 18.7 mAD, abstraction = -0.386 m^3/s
  - > 18.7 mAD, abstraction = -0.36 m^3/s
- Pump 2
  - <= 16.72 mAD, abstraction = 0.0 m^3/s
  - > 16.72 mAD <= 18.2 mAD, abstraction = -0.4 m^3/s
  - > 18.2 mAD <= 18.375 mAD, abstraction = -0.386 m^3/s
  - > 18.375 mAD, abstraction = -0.36 m^3/s

An Infoworks CS model of the Long Culvert is also provided to assess flooding from aperture within culvert in garage forecourt. This is now the LiDL supermarket and approximately corresponds with the CSO location.

B5.2 Hydrology

FEH statistical pooling and rainfall runoff methods for peak flow estimates, with adjustment for highly permeable catchment.

Details of method and results.

Mill Beck catchment 3.997 km^2.

Our investigations indicate a potentially larger catchment area than this.

Design storms using winter rainfall profile with 5.048 hr rainfall storm duration.

The main limitation of the hydrological analysis is that it failed to adjust / check for the implications for critical storm duration for the flood-locked scenario. This means it may have significantly underestimated peak water levels. Sensitivity analysis needs to be carried out to identify how this would have changed the conclusions of the report.

B5.3 Scenarios

Model file	Scenario	Events
MBFree.dat	Free discharge to Derwent	5, 10, 25, 50, 75, 100, 200 and 1000 year return periods
MBComb.dat	Combined flooding with fixed head on Derwent 19 mAD, penstock open, no pumps working	5, 10, 25, 50, 75, 100, 200 and 1000 year return periods
MB2pump.dat	Combined flooding with fixed head on Derwent 19 mAD, 2 pumps in PS working	5, 10, 25, 50, 75, 100, 200 and 1000 year return periods
MB1pump.dat	Combined flooding with fixed head on Derwent 19 mAD, 1 pump in PS working	5, 10, 25, 50, 75, 100, 200 and 1000 year return periods

Model verified to recorded water levels on the day of the survey and 3 high flow events during pumping operation.

Calibration using channel and floodplain roughness and structure coefficients.

Sensitivity tests for climate change, culvert blockage and roughness variations.

Model simulations for free discharge to Derwent and with high levels in Derwent, with 0, 1 or 2 pumps working.

B5.4 Results

Despite lack of detailed calibration and validation, the model verification is acceptable.

With both pumps operating, only one property is at risk of flooding for events of lesser magnitude than the 50yr return period flood. However, if only one pump is operating, 60 properties are at risk in a 25yr return period flood. Without the pumps, 54 properties are at risk in a 5yr flood.

The model identifies the garage that used to occupy the site of LiDL as being the first place to flood; the SoP of this property was 5years (or less) in the 1 pump scenario, 10years in the 2 pump scenario.

With free discharge to Derwent, 0 properties at risk of flooding at 100 year event.

With 50yr high levels in Derwent, 67 properties at risk of flooding at 100 year event.

Arup suggest that the results for one pump and no pumps are underestimates due to the storm durations used, particularly at low return periods. The construction of Lidl may have influenced flooding patterns in the centre of Norton by *displacing flood water. Some sewer assets in this location appear fairly recent in construction; this may also have altered flood behaviour in the area.*

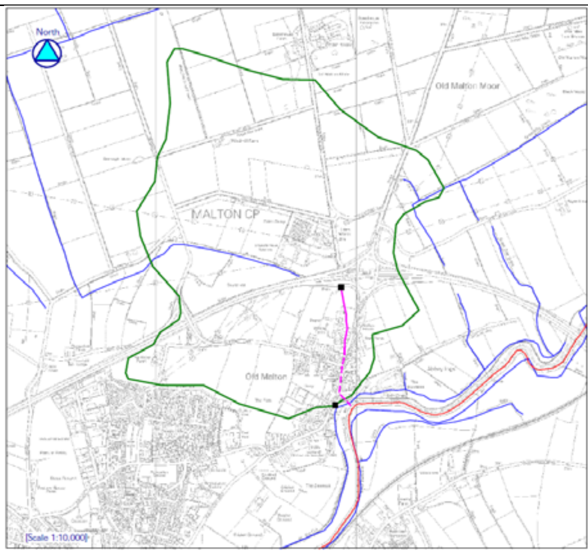
Pumping offers some property protection but significant road flooding would still occur at all return periods.

Sensitivity testing was carried out, and the Flow + 20% scenario may be considered indicative of climate change sensitivity. The sensitivities presented are based on the free discharge situation, and it is considered that the pumped situation would be much less sensitive (at least for blockages) because structures would already be surcharged.

Maximum Change in Water Level (mm)			
Flow +20%	Mannings ± 20%	Culvert 50% Blockage	Structure 50% Blockage
160 mm	120 mm	450 mm	200 mm

B6 Dales Area Floodplain Mapping Phase 1 Studies – Riggs Road Drain Old Malton

No overview included in the summary MDI_AppendixB_Model_Information_Sheets.pdf in Malton Data Improvements Model reports.

Study	Dales Area Floodplain Mapping Phase 1 Studies – Riggs Road Drain Old Malton	
Company	JBA	
Date	April 2005	
Scenarios		
Model Description	Hydrological assessment, hydraulic capacity assessment	

This exercise collated flood history information from stakeholders and the local residents, setting out a conceptual understanding of the flood mechanisms observed in Old Malton.

A hydrological assessment derived Design Peak Flow estimates for a range of return periods (plus climate change) at two locations on the Riggs Road Drain (one just downstream of the A64, and the other at the Cat Well / The Cut.

- The IH 124 method was used as the FEH CD-ROM does not delineate the Riggs Road Drain catchment and there are no local flow gauges.

A catchment walkover identified structures along the watercourse, their approximate dimensions, and estimate of hydraulic capacity based on the Mannings equation and the Design Peak Flows.

- The culverts and connectivity with the Cut and Cat Well were not fully surveyed.

The results indicate that the hydraulic capacity of the Riggs Road Drain is less than 20 year return period.

- The report recommends that the Flood Map "areas benefiting from flood defences" outline is incorrect and only reflects the River Derwent flooding, not the flooding associated with the Riggs Road Drain.

- The report identifies a number of issues for follow up survey and investigation, and recommends a range of actions for stakeholders including for Yorkshire Water to remove the Riggs Road Drain from public sewer status and for the Environment Agency to enmain it.

B7 Malton Data Improvements

See overview summary MDI_AppendixB_Model_Information_Sheets.pdf in Malton Data Improvements Model reports.

This model covers the River Derwent from Old Malton to south of Malton with and without the Derwent defences in Malton and Norton flood scheme, with separate models for the Mill Beck and Priorpot Beck. It also investigates the effect of the downstream Kirkham Sluices on water levels.

A key limitation was the instability of including the Mill Beck and Priorpot Becks in the 2D Tuflow model of the River Derwent, hence flooding is mapped using 1D results for these.

The channel has undergone little change since 2009 – growth of the island around the Castlegate Bridge may have introduced some changes in local water levels on the Derwent, but these are unlikely to be of a magnitude that could cause particular inaccuracies in terms of options or assessed flood risk in the context of this study. It is therefore considered appropriate to use the Malton Data improvements model as a source for water level data on the Derwent for this study.

B7.1 Derwent

B7.1.1 Model schematisation

Linked ISIS-Tuflow 1D-2D hydrodynamic model of 40 km from Derwent at Old Malton to Derwent downstream of Buttercrambe.

Developed from Section 105 C30/92 Survey River Derwent at Foulbridge, Malton and Scrayingham (Kennedy and Donkin, 1998) model through Malton and Norton, Priorpot Beck Flood Risk Mapping Phase 2 (JBA, 2001) model, and SFRM Phase 2 Mill Beck – S105 (Atkins, 2005) model.

Linked to the Dales Area Floodplain Mapping Phase 2 Studies 2004 – Lower Derwent (JBA, 2004) model to extend model extent to confluence.

Inflow boundary represented as QT boundary in ISIS, derived from FEH Statistical method, and a Lateral Inflow ReFH boundary distributed along the Derwent.

Downstream boundary represented as Normal Depth boundary in ISIS.

Malton FAS defences as represented in the earlier 1998 HEC-RAS model, updated with review of the FAS As-Built drawings. A new river topographic survey covers from downstream of the Malton FAS extent to the start of the Lower Derwent Model. A GPS point topographic elevation survey was conducted in Old Malton for the area extending beyond the LiDAR.

Flood zone represented as four 2D floodplain domains, with 10 m resolution at Malton and Norton, derived from LiDAR. Distributed roughness values for rural, woodland, roads and buildings.

The report states that the Cut in Malton and Old Malton is represented as a flow constriction in the Tuflow 2D domain allowing floodwater to drain back to the Derwent past the embankment. This probably refers to the Riggs Road Drain instead, however, and does not represent any of the flows from this catchment to the Derwent.

Kirkham Sluices represented as a Gated Weir unit in ISIS, set to be shut then open as levels in Malton rise. For the Kirkham-specific scenarios, this was specified as open, closed, or replaced by a weir only.

B7.1.2 Hydrology

FEH statistical method using AMAX data with a rating derived from correlation between Malton gauged levels (16 years of data) and Derwent at A64 daily flow and level data. Climatic adjustment for short record and the Archer method used for creating the hydrograph shape.

A ReFH boundary provided for Lateral Inflows through the Derwent.

Critical storm durations on the River Derwent are noted to be much longer than in the smaller tributaries of the Mill Beck and Priorpot Beck. The modelled hydrograph is 750 hrs duration.

B7.1.3 Scenarios

Model file	**Scenario**	**Events**
10_MDI_Design_WithD.dat	Design run with defences	2, 5, 10, 25, 50, 75, 100, 100+CC, 200

		and 1000 year return periods
11_MDI_Design_WithoutD.dat	Design run with defences	2, 5, 10, 25, 50, 75, 100, 100+CC, 200 and 1000 year return periods
01_MDI_WithD_Kirkham_Closed.dat	Design run with defences, Kirkham sluices closed	2, 25, 50 and 100 year return periods
01_MDI_WithD_Kirkham_Open.dat	Design run with defences, Kirkham sluices open	2, 25, 50 and 100 year return periods
01_MDI_WithD_Kirkham_Removed.dat	Design run with defences, Kirkham sluices removed	2, 25, 50 and 100 year return periods

The model was calibrated against water levels from Malton stage gauging station and Kirkham Sluices for the February 1999 and November 2000 events, using the Without Defences model.

B7.1.4 Results

Operation of Kirkham Sluices was shown to have minimal impact on water levels on the Derwent at Malton, increasing by 0.012 m when sluices are closed at the 100 year event.

The model is shown to be sensitive to design inflows and blockage on the Castlegate Bridge in Malton.

Using the results of the model, we have identified the following flood locking assessment:

- Malton – defences 75 yr SOP
  - Threshold?
- Norton – defences 75 yr SOP
  - Mill Beck PS start level 16.7 mAD (approx.. node MN2047)
  - Q75 results show 300hrs+ Derwent level over threshold.
- Old Malton – defences 200 yr SOP
  - RRD outfall soffit 17.16 mAD (approx. node MN3888)
  - Q200 results show 300hrs+ Derwent level over threshold.

The Mill Beck has a permanent PS that can remove water during this flood-locking up to a design standard of storm / peak flow on the Mill Beck itself.

In Malton and Old Malton, there is no such mechanism for the surface water, groundwater and Riggs Road Drain. The only release for water is via back-drainage of floodwater into the combined sewer system and SPS and via temporary pumping.

B7.2 Mill Beck

B7.2.1 Model schematisation

Uses the Mill Beck Phase 2 model with some updates and changes, including:

- minor changes to georeferencing (no hydraulic effect),
- node relabeling (no hydraulic effect),
- some trimming to the river bank cross-sections (possible hydraulic effect at high flows)
- some alterations to spill section levels (possible hydraulic effect at high flows),
- change of the long culvert from Sprung Arch to Assymetrical Conduit units (possible hydraulic effect at all flows)
- differences in the logic rules of the gate
- differences in the Mill Beck pumping rules

1D ISIS model of Mill Beck 1.1 km from weir upstream of Fish Hatchery to River Derwent.

Inflow boundary represented as ReFH unit in ISIS.

Downstream boundary represented as HT boundary in ISIS.

Flood zone represented as:

- 01 (With Defences) – no reservoir units, flooding represented in cross-sections only, no surcharging spill mechanism from Long Culvert.
- 02 (Without Defences, shortened) – no reservoir units, assumed Derwent floods up to Mill Pond outfall so model stops here, and flooding represented in cross-sections only
- 03 (Without Defences) – two reservoir units (one for Church Street and Welham Road, and another for Bark Knots fields) for spills from surcharged Long Culvert inlet, and flooding represented in cross-sections.

Culvert represented as simple, uniform conduit units with even slope, with an orifice opening. Manual slot for stability. Some discrepancy with previous Mill Beck Phase 2 representation.

Penstock represented by sluice unit with logic control to close completely when levels in the Mill Beck > 16.7 mAD according to report, but in models as:

- 01 (With Defences) – penstock permanently closed.
- 02 (Without Defences, shortened) – not featured.
- 03 (Without Defences) – penstock closes when level on Derwent side >25.1 mAD.

Mill Beck pumps represented as two abstraction units. Operating rules amended for improved stability to reduce hunting. According to the report, the pump is set to be off if the water level in the Long Culvert is less than 16.7mAOD. If the water level is above this trigger level but below 18.2mAOD then the pump abstracts 0.4 cumecs. When this reaches 18.2mAOD the capacity is reduced to 0.386 cumecs. Above 18.7mAOD the capacity reduces to 0.36 cumecs. This occurs when water levels upstream of the station (at MLB0031a) reach over 16.7mAOD. Represented as follows in model:

- 01 (With Defences) – 0.4 m^3/s abstraction when level >16.7 mAD (pump 1) or >16.72 mAD (pump 2).
- 02 (Without Defences, shortened) – not featured.
- 03 (Without Defences) – abstraction units present but set to zero.

B7.2.2 Hydrology

FEH Statistical method deriving QMED from catchment descriptors with donor adjustments. A permeable adjustment was applied for the growth curves. ReFH and catchment descriptors were used for hydrograph shape, scaled to peak flows.

Critical storm duration 5.25 hrs.

B7.2.3 Scenarios

Model file	**Scenario**	**Events**
01_MDI_MillBeck.dat	With Derwent defences – with 2 pumps, penstock closed, no flood zone reservoir units	2, 5, 10, 25, 50, 75, 100, 200 and 1000 year return periods
02_MDI_MillBeck_Shortened.dat	Without Derwent defences – only modelled as far downstream as Mill Pond (i.e. no PS or Long Culvert or flood zone reservoir units).	2, 5 and 10 year return periods
03_MDI_MillBeck_withoutd	Without Derwent defences – with 2 pumps, penstock closed, 2 flood zone reservoir units	25, 50, 75, 100, 100+CC and 200 year return periods

The scenarios appear to be mislabelled in the report, as reproduced above. The Shortened Mill Beck model would be expected to only be applicable for the largest flood events without defences, where the Derwent floods all the lower floodplains. The model files indicate that the Shortened Without Defences model is for the largest flood events, and the standard Without Defences model is for the events up to 10 year return period.

The With Defences Mill Beck model files also appear to be included without any flood zone reservoir units, preventing the representation of any water spilling from the Mill Beck as flooding the Church Street areas. Although this area is protected up to the design SOP of 75 years by the FAS for flooding from the River Derwent, the flood mechanism from the Mill Beck and residual surface water flooding is not represented.

B8 Malton, Norton and Old Malton Case Study Investigation

This is not a modelling study, but a desk-based investigation of the flood mechanisms in Malton, Norton and Old Malton. Data collection included resident surveys and information and data from stakeholders.

The assessment outlined the probable causes of flooding in each of the areas (reproduced below).

Location	Source of flooding						
	Main Rivers	Surface water (on the highway)	Surface water (other source)	Public sewerage systems	Ordinary water-courses	Ground water	Reservoirs
Castlegate and Sheepfoot Hill, Malton		[orange]			[grey]	[green]	[grey]
Railway Street, Malton		[green]			[grey]		[grey]
Welham Road, Church Street and St Nicholas Street, Norton	[yellow]	[green]		[green]	[grey]		[grey]
Old Malton Road, Old Malton		[orange]		[yellow]	[green]		[grey]

Confidence in source of flooding:	
[green]	High Confidence
[orange]	Reasonable confidence
[yellow]	Evidence collected suggests this could potentially be a source of flooding
[white]	No evidence on source of flooding available
[grey]	Source of flooding not relevant at this location

In Malton, the primary mechanism was natural elevation of groundwater levels, with some surface water overland flow flooding.

In Norton, the primary mechanism was surface water overland flow and capacity exceedance of the sewer systems, in particular noting the mechanism of penstock closure of the CSO to Mill Beck resulting in surcharging near St Nicholas Street.

In Old Malton, the only noted mechanism was ordinary watercourse flooding of the Riggs Road Drain.

Appendix C

Hydrology

Appendix C - Flood estimation calculation record

Introduction

This document is adapted from 197_08_SD01, a supporting document to the Environment Agency's flood estimation guidelines. It provides a record of the calculations and decisions made during flood estimation. It will often be complemented by more general hydrological information given in a project report. The information given here should enable the work to be reproduced in the future. This version of the record is for studies where flood estimates are needed at a multiple locations.

Note for analysts: This document contains guidance notes shown in hidden text. If they are not visible, they can be revealed by clicking the Show ¶ button on the toolbar.

Contents

ABBREVIATIONS

AM	Annual Maximum
AREA	Catchment area (km^2)
BFI	Base Flow Index
BFIHOST	Base Flow Index derived using the HOST soil classification
CFMP	Catchment Flood Management Plan
CPRE	Council for the Protection of Rural England
FARL	FEH index of flood attenuation due to reservoirs and lakes
FEH	Flood Estimation Handbook
FSR	Flood Studies Report
HOST	Hydrology of Soil Types
NRFA	National River Flow Archive
POT	Peaks Over a Threshold
QMED	Median Annual Flood (with return period 2 years)
ReFH	Revitalised Flood Hydrograph method
SAAR	Standard Average Annual Rainfall (mm)
SPR	Standard percentage runoff
SPRHOST	Standard percentage runoff derived using the HOST soil classification
Tp(0)	Time to peak of the instantaneous unit hydrograph
URBAN	Flood Studies Report index of fractional urban extent
URBEXT	FEH index of fractional urban extent
WINFAP-FEH	Windows Frequency Analysis Package – used for FEH statistical method

1 Method statement

1.1 Overview of requirements for flood estimates

Item	Comments
Purpose of study Approx. no. of flood estimates required Peak flows or hydrographs? Range of return periods and locations. Approx. time available	Further understanding of flood problem to small, flood-locked, urbanised catchments at Old Malton, Malton and Norton, to support **coarse** cost benefit. Detailed analysis is not justified at this stage of the project, however it is recognised that there are enough uncertainties in this catchment that higher than average effort may be necessary just to obtain reasonable answers. Cost benefit - requires high range of return periods, suggested 5,10,20, 30,50,75,100yr, 200yr. However, for events in excess of the standard of protection of local defences, the Derwent will be the source of flooding, and design flows / levels are already available for the Derwent through Malton. Joint probability analysis (Appendix E) has inferred a 1:5 ratio of return periods for rainfall in the study catchments during and immediately antecedent to flood locked conditions. The standard of protection on the Derwent defences is 200yr (Old Malton) or 50yr (Malton and Norton), and therefore the actual magnitudes of events to be interpreted need only go as high as 200 / 5 = 40yr (Old Malton) or 50 / 5 = 10yr (Malton & Norton) Mechanisms at all catchments are heavily influenced by flood locking, sometimes to extreme durations. Flood locking occurs due to high water levels on the Derwent – flood frequency relationships for the Derwent to be taken from previous studies (2003, 2009)

1.2 Overview of catchment

Item	Comments
Brief description of catchment, or reference to section in accompanying report	Norton: small catchment, highly permeable in upper reaches, influenced by groundwater (calculated separately), moderate urbanisation (combined sewer) Malton: a series of very small catchments, highly permeable, heavily influenced by groundwater, heavily urbanised. Old Malton: small, very flat, largely rural catchment, with some combined sewer systems. Possible influence due to A64 creating some bypassing of flow routes. Some of the catchment is highly permeable.

1.3 Source of flood peak data

Was the HiFlows UK dataset used? If so, which version? If not, why not? Record any changes made	Yes – Version 3.3.4 August 2014.

1.4 Gauging stations (flow or level)

None appropriate in the vicinity (Derwent only, and the Derwent is vastly bigger than the watercourses in the study scope)

1.5 Other data available and how it has been obtained

Flow gaugings (if planned to review	Not available – included in report recommendations for future studies

ratings)	
Historic flood data	Used as an understanding of flood mechanisms and frequencies. From anecdotal public & professional evidence. See Appendix A
Flow data for events	n/a
Rainfall data for events	TBR data (Scampston, Kjeld head) used for comparison with River Derwent in joint probability analysis of historic data. See Appendix E
Results from previous studies (e.g. CFMPs, Strategies)	Previous reports consulted – see Appendix E. Design flows for River Derwent adopted from EA Malton data improvements study (latest flood mapping reporting) Design flows are available from the Mill Beck report (2005). These identified a much smaller catchment size than that of this study. Rainfall run-off models compared to observed data, but the actual quality of the observed data for this study may have been significantly limited.
Other data or information (e.g. groundwater, tides)	Groundwater study conducted separately (Appendix D) Catchment drainage diagram obtained from IDB to delineate Old Malton drainage catchment (used in conjunction with LiDAR)

1.6 Initial choice of approach

1.6.1 Conceptual model

The River Derwent is capable of staying at an elevated level for a significant duration (2 days – 10 days), during which time smaller watercourses at Old Malton, Malton and Norton cannot discharge to the river, a phenomenon referred to in this study as “flood-locking”.

The flood problem is therefore identified as a mass balance problem, in which accumulated flood volumes are identified as the major source of flooding (flood peaks are, by contrast, less of a concern).

Over such long durations, small differences between inflows and outflows can accumulate to high volumes. Baseflows and groundwater flows make up a far higher proportion of the accumulated volume than rapid run-off.

Joint probability is a major influence in determining reasonable the actual joint probability of the coincidence of high rainfall over minor catchments in conjunction with high water levels on the Derwent.

1.6.2 Commentary on constraints to conventional hydrological analysis

Flood locking

Typically, the development of hydrological science has focussed on the prediction of statistical peak flows, for the critical storms of catchments. The effect of flood locking is to increase the critical storm duration to longer than the natural critical storm durations of catchments, and for Malton and Old Malton, which have next to no outflow during flood locking, this is a very significant effect. Therefore, the hydrological inputs needed for this study, which will not be related to the natural catchment critical storm duration, are less well supported by the underlying science.

Joint probability

We have made best estimates of the reasonable combinations of the interacting watercourses (see Appendix E), but there is only a short record of supporting data and the underlying science is still improving.

Permeable catchments

Groundwater is being addressed by a separate study (Appendix D). Adjustments can be made for high influence by ground water, but hydrology is typically less accurate under such circumstances. Ground water is an acknowledged influence on flooding, with springs from the corallian limestone aquifer contributing to flood volumes and infiltration using up an element of the combined sewer network capacity. Notably low percentage run-offs to Malton (9%) and Norton (15%). Old Malton quite normal at ~35%.

Small catchments

Hydrological analyses of small catchments typically have far fewer years of record to call upon (within the national pool of data) and as such are acknowledged to be less accurate, both in terms of available data and underlying . Moreover, at this scale of study, the underlying digital data of broadscale hydrology is too coarse for accurate delineation of catchment characteristics.

Heavily urbanised catchments – similar to small catchments, the amount of gauged data available for heavily urbanised catchments is relatively small, and the influence of urban drainage systems is highly variable and often at odds with the natural catchment. Mechanisms of flooding can mean that overland flow associated with more extreme events can flow in a different direction to flow in the drainage system. Overflows from CSOs can be associated with short duration events, while flood locking is more associated with long durations of accumulated discharge.

No gauged data on watercourses of interest.

Where a catchment is subject to uncertainty, gauged data can provide more understanding of a system's performance. There is however no data on the subject sites.

Short flood history.

The Derwent flood alleviation scheme was constructed in 2003, and out of bank flooding by the Derwent pre construction will have hidden many of the now observed mechanisms. Hence there are only 12 years of flood history to draw upon.

1.6.3 Appropriate Methods

Small catchments:

Recommended methods: RefH (where BFIHOST< 0.65) or statistical.

IH124 now largely considered superseded.

Heavily urbanised subcatchments

Recommended methods:

If URBEXT < 0.6: RefH or statistical.

If URBEXT >0.6, Modified Rational Method

Permeable catchments

Recommended methods:

Statistical methods generally preferred to rainfall-runoff (note however, estimates of Qmed can be a factor of 5 out).

RefH should not be used when BFIHOST>0.65 (which rules it out for Malton and Norton).

Long flood events (a consequence of flood locking)

While RefH is better than FEH at estimating peak flows, it is known to exaggerate flood volumes for event durations > critical duration.

Also considered:

Direct rainfall method – dismissed because the long durations of flood locking would have required the running of a lot of rainfall events to identify critical storm durations, and the storm durations would have been of significant length (>24hrs). Therefore the accumulated run times of this relatively detailed hydraulic routing approach would have made this method impractical within the project time frames.

1.6.4 Initial choice of method

The statistical method is the common element to the types of catchment above, but is not recommended for the most urbanised catchments,and needs to be coupled with a rainfall-runoff method to provide estimates of volume.

RefH is acceptable with small catchments and heavy urbanisation, but less reliable on permeable catchments. While RefH may prove useful for identifying peak flows (useful for calibrating other methods), its lack of robustness at longer duration events means that it can not be used as the basis for exploring critical event durations.

A range of methods is considered for each catchment, and selected on their merits on a case by case basis.

Software to be used (with version numbers)	ISIS v 3.7.0.22 WinFAP-FEH v3.0.003

Some subcatchments served by a combined sewer system that is not always aligned with the natural catchment. Preference still to use FEH, but with urban adjustment approach a la Kjeldsen, and permeability adjustments.

In some locations, roads act as catchwaters such that the natural catchment cannot be relied upon. In the upstream end of the Norton catchment, there is a dry valley that may have been intercepted by Beverley Road – directing extreme events into the Priorpot Beck catchment, however ground water flows are likely to carry on under the road into the Mill Beck.

Long durations of flooding are of particular concern – RefH has notable inaccuracies in such events.

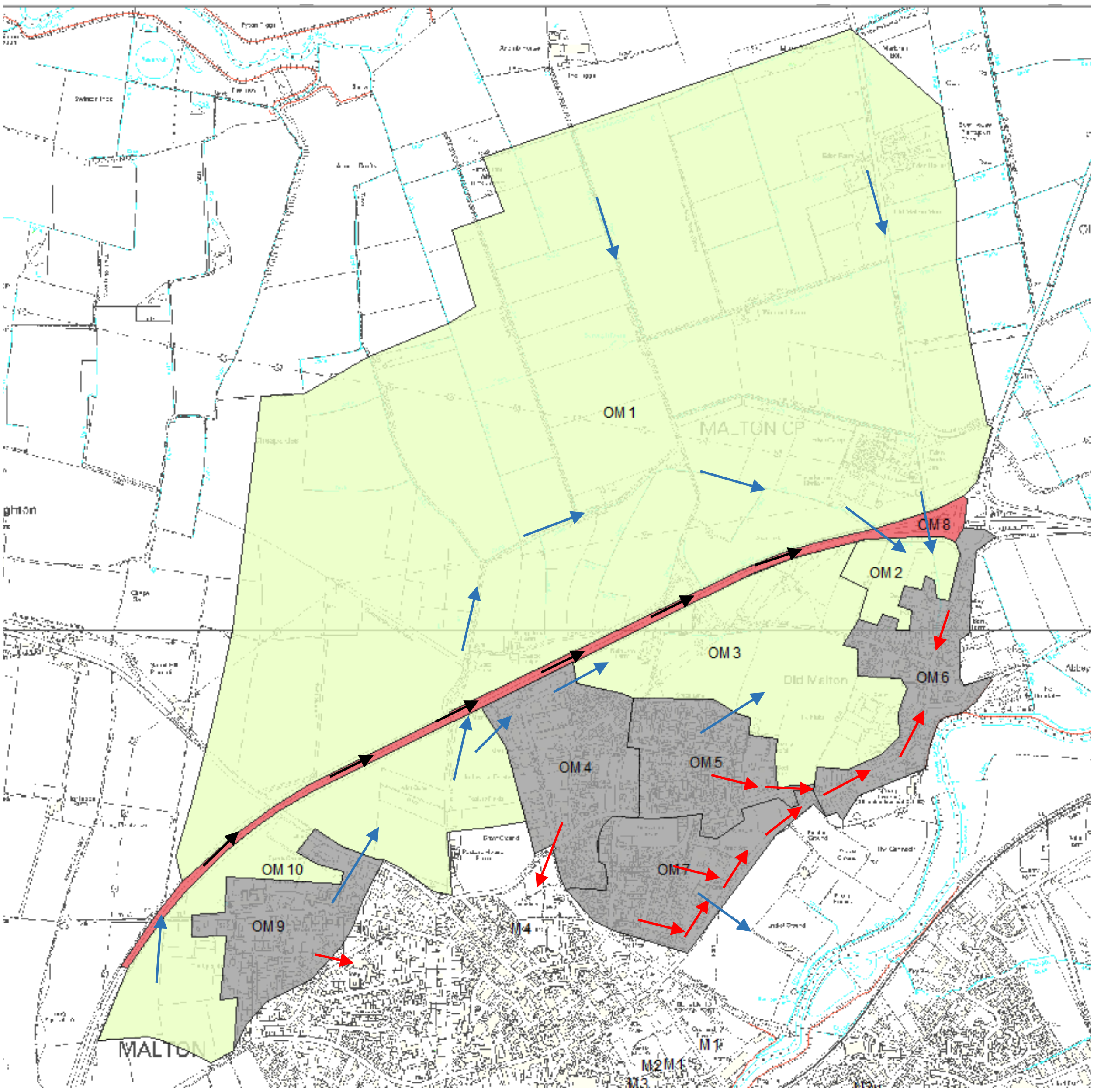


Figure 1: Catchment Layout at Old Malton
The Old Malton catchment is delineated by type of run-off and the route by which flow might arrive at Old Malton. Due to the degree of artificial influence involved, FEH digital catchments do not directly overlay the catchments.

OM1 – Rural field network – drains to Riggs Road Drain via two culverts under A64. SPRHOST~ 37%
OM2 – Rural field network, draining to Riggs Road Drain from downstream of A64. SPRHOST~ 37%
OM3 – Rural field network, drains to the "The Flats", which appears to be a natural sink. In very high events, could flow overland towards Town Street. SPRHOST~ 37%
OM4 – Urban area, separate sewer systems. Surface water drainage drains towards a chamber in OM3, from where it is diverted onto The Flats. Foul system drains into combined system in Malton (ie out of Old Malton catchment). SPRHOST~ 17%
OM5 – Urban area, combined sewers. Combined system drains towards Town Street, natural fall of land would drain towards The Flats. SPRHOST~ 37%
OM6 – Urban area of Old Malton, combined sewers. Some road drainage on north section of B1257 may drain directly to Riggs Road Drain. SPRHOST~ 37%
OM7 – Urban area of Old Malton, combined sewers. Combined system drains towards Town Street. Natual fall of land would drain exceedence flows towards The Cut via sports pitches (and out of Old Malton catchment), but it appears that embankments along Old Malton Road direct exceedence flow to Town Street as well. SPRHOST~ 37%

OM8 – The A64 – highways Agency sewer network. Comprises filter drainage with underlain pipes for downstream 900m, filter drainage only upstream of that. May act as a bypass flow route for flow from OM9 and OM10, below. SPRHOST not relevant
OM9 – Urban area of Malton, combined sewers. Combined system drains into Malton (and out of Old Malton catchment). Natural fall of land would drain exceedence flows into OM10, but roads may direct flow into Malton as well. SPRHOST~ 12%
OM10 – Fields within Malton environs.It appears that these would previously have drained north into OM1. Now it is plausible that they either drain into The Flats (via OM4) , OR they drain into the A64, bypassing the natural drainage route towards Old Malton. SPRHOST~ 12%

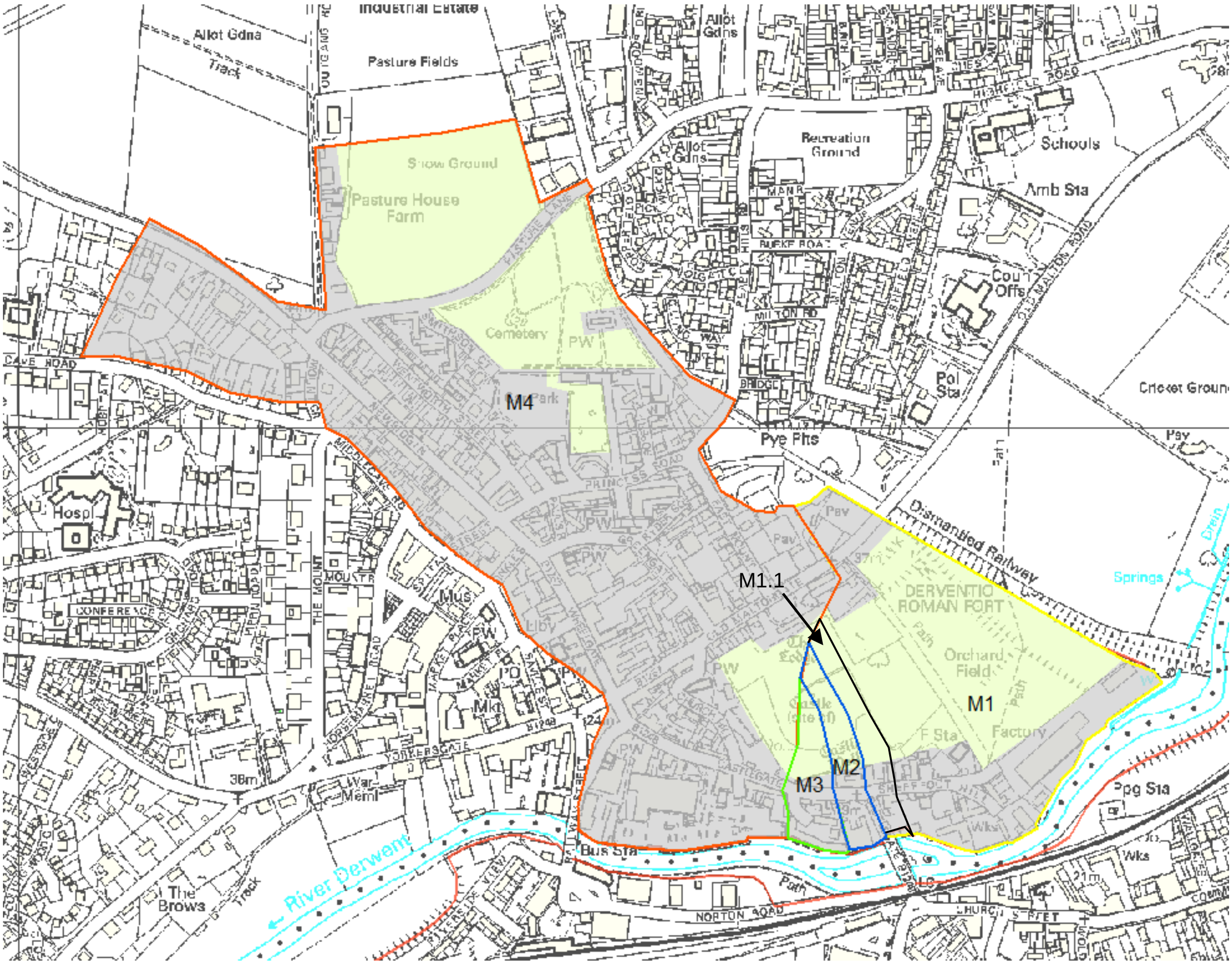


Figure 2: Malton Sub-catchments

The Malton subcatchments are all a mix of paved and unpaved catchment, characterised by the likely end destination of run-off. The detail of flow routes along Castlegate / Sheepfoot Hill can however mean that portions of the runoff from some catchments can end up in the end point of others (eg. high flows from M4 can carry on into M3, M2 or even M1). FEH is distorted, but indicates SPRHOST = 8.9 – 9.4%

M1 **-** Draining to area around bottom of Sheepfoot Hill and Tate Smith factory
M1.1 – Draining to boathouse upstream of Castlegate Bridge. Springs at north of properties on Castlegate can contribute to this area
M2 – Draining to Castlegate commercial premises. Springs at north of properties on Castlegate also contribute to this area
M3 – Draining to Chandler's Wharf estate. Springs at north of properties on Castlegate also contribute to this area
M4 – Draining to Morrison's car park. Combined sewers north of Yorkersgate flow to west rather than down the hill.

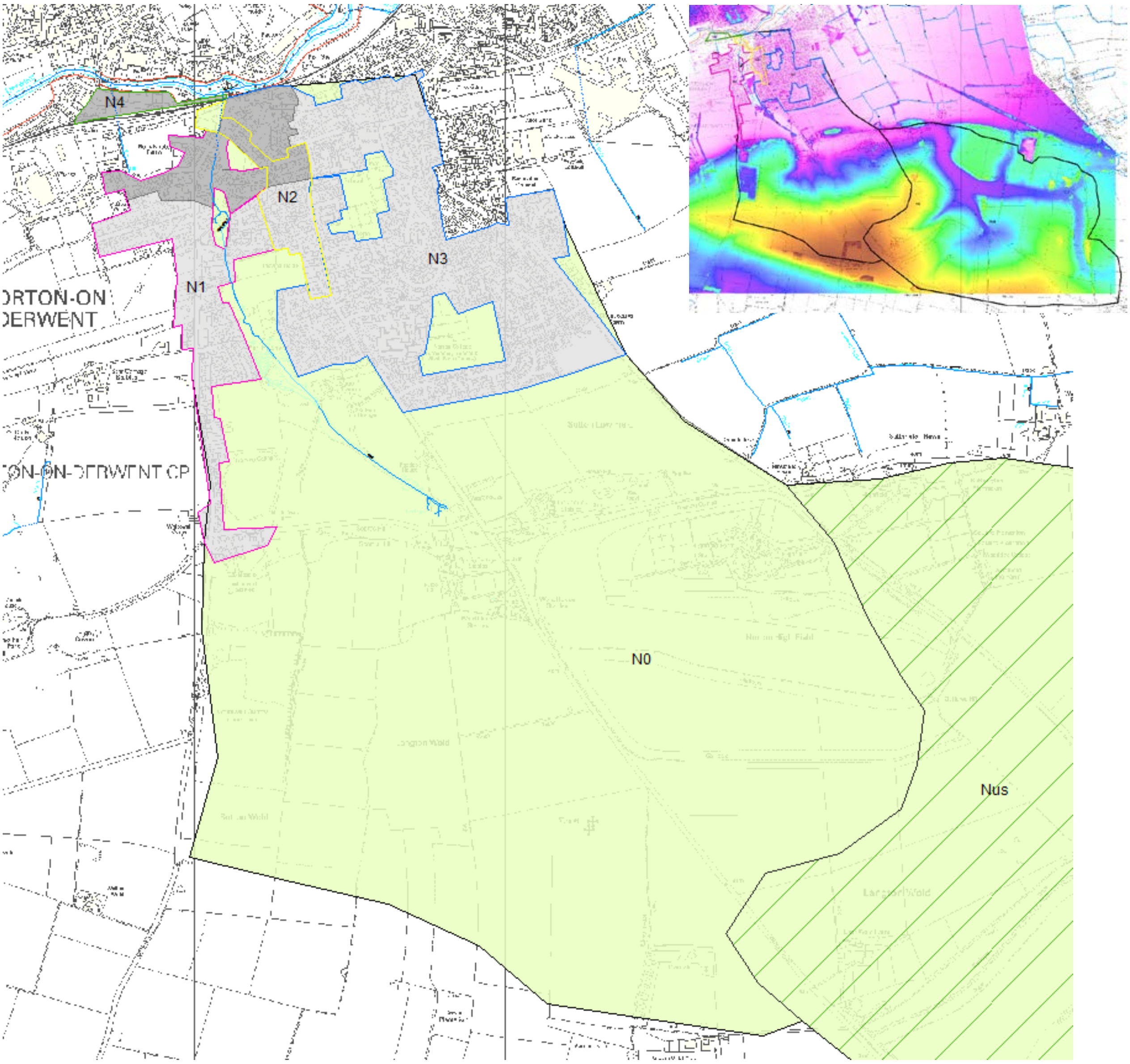


Figure 3: Norton Sub-catchments

The catchments for N1-N4 above are lighter colour upstream of CSO's that can freely discharge, allowing a pass-forward flow to the downstream sewer network. N1 and N2, discharge to the Mill Beck, N3 discharges towards the Derwent (and N4 has no CSO, hence is all coloured darker).

If the Welham Road CSO can discharge freely, the system functions as a whole in which the only outflows are the Church Road CSO, LidL PS and Mill Beck PS.
If the Welham Road CSO is closed, the Mill Beck direct catchment is based on N0 (plus Nus), plus exceedence flow from N1,2,3,4. Only once the Mill Beck floods can the drainage network and Mill Beck can be considered to be interacting. The drainage network catchment is based on the darker areas in Figure 3, plus a pass-forward flow from the upstream catchments.

N0 – Overall Norton catchment (including drainage network). The FEH digital catchment is distorted, but is a reasonable representation of overall catchment, and does allow interpretation of SPRHOST = 5% upstream of the Mill Beck's source (8.9% in "Nus"), and ~23.6% downstream. Overall SPRHOST = 14%
N0us - Subject to local topographic details, this catchment may flow into the headwaters of the Mill Beck (see inset), doubling the natural catchment of the Mill Beck. SPRHOST = 8.9%
N1 – Welham Road combined sewer catchment.
N2 – St. Nicholas Road combined sewer catchment.
N3 – Church Street combined sewer catchment.
N4 – Norton Road combined sewer catchment.

2 Locations where flood estimates required

The table below lists the locations of subject sites. The site codes listed below are used in all subsequent tables to save space.

2.1 Summary of subject sites

Site code	Watercourse	Site	Easting	Northing	AREA on FEH CD-ROM (km^2)	Revised AREA if altered (km^2)
RRD	Riggs Road Drain	North of A64				3.57
A64		A64				0.096
Flat		The Flats				0.41
MSS		Malton Separate sewered				0.22
MEC1		Malton East Combined				0.16
MEC2		Malton East Combined 2				0.20
OMC		Old Malton Combined				0.25
MMC		Malton Middlecave combined				0.18
MN		Malton North				0.43
Reasons for choosing above locations		Each represents a different mechanism or perceived mechanism, as follows:				

2.2 Important catchment descriptors at each subject site (incorporating any changes made)

Site code	AREA	PROPWET	BFIHOST	DPLBAR (km)	DPSBAR (m/km)	SAAR (mm)	SPRHOST	URBEXT
N0 (inc_all)	10.62	0.32	0.906	3.65	42.5	660	11.6	0.055
Nus	5.83	0.32	0.944	2.57	53.9	663	8.9	0
N1	0.203us 0.064ds	0.32	0.837	0.417us 0.222ds	30.3	653	26.2	0.506 us 0.65 ds
N2	0.045us 0.023ds	0.32	0.837	0.183us 0.127ds	30.3	653	26.2	0.5us 0.85 ds
N3	0.60us 0.038ds	0.32	0.837	0.755us 0.167ds	30.3	653	26.2	0.62us 0.71ds
N4	0.023	0.32	0.837	0.13	10	653	26.2	1
M1	0.11	0.32	0.917	0.30	16.9	656	8.9	0.38
M2	0.01	0.32	0.917	0.08	59.2	656	8.9	0.23
M3	0.01	0.32	0.917	0.08	74.9	656	8.9	0.29
M4	0.36	0.32	0.917	0.57	28.6	656	8.9	0.47
OM1	3.57	0.32	0.48	2.01	4.2	643	40	0
OM2	0.07	0.32	0.49	0.23	4.2	643	39	0
OM3	0.41	0.32	0.53	0.61	16.24	643	37	0
OM4	0.22	0.32	0.83	0.44	8.1	643	17	0.49

Site code	AREA	PROPWET	BFIHOST	DPLBAR (km)	DPSBAR (m/km)	SAAR (mm)	SPRHOST	URBEXT
OM5	0.16	0.32	0.53	0.37	16.24	643	37	0.33
OM6	0.18	0.32	0.53	0.39	16.24	643	37	0.48
OM7	0.19	0.32	0.77	0.41	25.55	643	21	0.34
OM8	0.10	0.32	0.53	0.28	18.25	643	37	1
OM9	0.18	0.32	0.90	0.39	18.25	647	12	0.57
OM10	0.43	0.32	0.90	0.63	18.25	647	12	0
OM0 (total)	5.52	0.32	0.56	2.55	8.6	643.4	35	0.093

2.3 Checking catchment descriptors

Record how catchment boundary was checked and describe any changes (refer to maps if needed)	Significant artificial modifications (elevated / cut roads, flat drained catchment) Catchment areas redrawn in GIS, using LiDAR, and local sewer plans / IDB plans, A64 Highways Agency plans to identify appropriate catchments (see Figures above) In the upstream end of the Norton catchment, there is a dry valley that may have been intercepted by Beverley Road – directing extreme events into the Priorpot Beck catchment, however ground water flows are likely to carry on under the road into the Mill Beck.
Record how other catchment descriptors (especially soils) were checked and describe any changes.	Fish ponds along the Mill Beck (N0-N5) are small in size and explicitly represented in the hydraulic model. There is therefore no reason to adjust FARL to match. All FARL values are set to 1. DPSBAR values have, where possible, been interpreted from extraction of FEH boundaries overlapping or adjacent to the relevant areas. Where not possible, and in particular on small catchments, DPSBAR has been inferred from measurement of an approximate S1085 slope for the catchment. DPLBAR values have been calculated from $AREA^{0.548}$. The impact of the estimates of DPLBAR and DPSBAR have been checked by comparison with an alternate measure of time to peak, wherein time to peak is assumed to be the time for flow to travel the Main Stream Length (MSL) at 1m/s, plus 5minutes time to enter the MSL. Time to peak values obtained by this method were found to correspond to values obtained using the assumed DPLBAR & DPSBAR values to within 0.05hr (3minutes). This was considered to be a strong confirmation of either approach, and to indicate that a lack of accurate digital catchment data was not a significant influence on catchment time to peak. Clear areas of differentiation between soil types identified by reference to soils and geology maps, and used in conjunction with FEH CD-Rom outputs to identify SPR / BFI values of underlying soil types. Area weighting method used to then apply these to individual catchment outlines.
Source of URBEXT	The URBext and SUBURBext layers were georeferenced in GIS to allow correct extraction of sub values, then used to calculate $URBEXT_{2000}$ from $URBEXT_{2000}$ = URBext + 0.5.SUBURBext. A check was carried out on this approach for an unaltered digital boundary.
Method for updating of URBEXT	CPRE formula from FEH Volume 4

3 Statistical method

3.1 Overview of estimation of QMED at each subject site

The subject sites are ungauged, and there are no suitable donor sites for data transfer.

The calculation of Qmed at each site is as shown in the appended calculation Qmed_239474.xls.

Use of donor sites:

Current guidance is that analogue sites should not be used for estimation of Qmed, however, it is recognised that the subject sites' size and groundwater influence make for a situation that will be poorly represented by use catchment descriptors alone. Because of this, and contrary to guidance, the use of data from local gauges is considered:

27038 Costa Beck and 26006 Elmswell Beck were used in the Mill Beck phase 2 report, but both are subject to backwater influences due to heavy weed growth and have not been included in the Hiflows_UK database. 26006 is over a chalk catchment rather than the corallian limestones,, but 27038 is a very similar catchment in terms of size and soils compared to the subject site.

27073 Brompton Beck at Snainton Ings (1981-2013) is, similar to Costa beck, on the Corallian Limestones, but free of the influence of drowning out, and with a comparable size catchment (12.9km2) to Mill Beck. While the Beck is a permeable catchment, a check against Qmed / 2 (and a visual check of the gauge record) shows no non-flood-years, so no adjustment is made to it.

The ratio of Qmed (obs)/Qmed (theory) at Brompton Beck is 1.64. With an adjustment to the weighting for its application to the Mill Beck site, this factor becomes 1.17, but due regard has to be taken for the behaviour of other gauges in the area:

Qmed (obs)/Qmed (theory) at 27038 = 2.28

Qmed (obs)/Qmed (theory) at 26006 = 4.03

While neither of these gauges should be used for Qmed estimation, they both indicate significantly higher Qmed(obs) values than Qmed(theory). It would seem reasonable therefore to use the unweighted adjustment factor for use of Brompton beck as an analogue

Norton N0 (whole catchment):

Qmed = 0.39 (no adjustment)   Weighted adjustment = 1.17, so adjusted Qmed = 0.46m3/s

Norton permeable catchment:

Qmed = 0.19 (no adjustment)   Weighted adjustment = 1.17, so adjusted Qmed = 0.22m3/s

Norton (downstream of permeable catchment)

Qmed = 0.18 (no adjustment)

A single site analysis in WinFAP-FEH of gauge 27073 gives the following growth curve. This exhibits an unusually flat response for a permeable catchment (where a flat response might be seen for low return periods, but a steep response is expected at high return periods).

Return period	Brompton Beck (single site)
2	1.03

5	1.31
10	1.46
25	1.65
50	1.78
100	1.91

Suitable donor sites were not found for Old Malton or Malton

Calculations of Qmed for each site by the FEH method can be found in **Qmed_239474_rev1. Generally speaking these values are only needed for the downstream end of each catchment, but their relative ratios have been used for**

1) Old Malton: Assessing the percentage of catchment flow that might diverted by use of the OM4 diversion option.

2) Malton: Assessing the relative magnitudes of flows to each flood cell in Malton, by comparison with M4. This allowed hydraulic methods to use a scaling factor to relate inflows to one set of hydrographs in the spreadsheet models, rather than extracting 20 odd hydrographs for 5 different flood cells. As the catchments are similar in size and nature, this was deemed reasonable.

3.2 Derivation of pooling groups

Pooling groups have been used to calculate growth curves for the three principal catchments: Malton, Old Malton, Norton, plus the undeveloped portion of the Norton catchment. This analysis is being used to scale rainfall runoff analyses for the three catchments; for the high level of the study it is not necessary or appropriate to develop growth curves for each individual sub-catchment (such an approach would introduce inconsistencies between sub-catchments anyway.)

Sensitivity analysis was performed on Old Malton to understand the influence of catchment flatness: OM1 is extremely flat, and it was thought that this would introduce an element of storage that is not directly involved in the selection of a pooling group. By deliberately selecting flatter pooling group members (lower values of DPSBAR), it was demonstrated that this resulted in flatter growth curves. It may therefore be the case that the overall Old Malton growth curve is steeper than reality.

Pooling group calculations are presented in appended calculations PoolingGroup_239474.docx and Permeable_adjustment_239474.xls

3.3 Flood estimates from the statistical method

Statistical analyses here are also used to consider the undeveloped portion of the Norton catchment, with a view to understanding later the degree to which the Norton flows can be calculated by addition of flows from different methods.

	Growth factors				Flows (m3/s)			
Return period	Norton [N0]	Norton (undeveloped) [N5 + Nus]	Malton [M4]	Old Malton [OM0]	Norton [N0]	Norton (undeveloped) [N5 + Nus]	Malton [M4]	Old Malton [OM0]
2	1.00	1.00	1.00	1.00	0.64	0.31	0.220	0.77
5	1.39	1.47	1.39	1.41	0.95	0.46	0.306	1.09
10	1.67	1.82	1.71	1.67	1.15	0.57	0.377	1.29

25	2.06	2.33	2.20	2.07	1.43	0.73	0.484	1.59
30	2.14	2.45	2.32	2.12	1.48	0.76	0.510	1.63
50	2.39	2.79	2.63	2.27	1.64	0.87	0.579	1.75
75	2.61	3.09	2.93	2.43	1.77	0.96	0.645	1.87

4 Revitalised flood hydrograph (REFH) method

As identified, RefH has significant shortcomings when applied to storm durations beyond the theoretical "natural critical catchment," as is necessary in this case. However, its ability for the prediction of peak flows should not be overlooked.

RefH has not been considered for Norton because it is generally not recommended for catchments with BFIHOST>0.65. Norton BFIHOST = 0.91.

While the Malton BFIHOST is similarly high, RefH has been considered here because the degree of urbanisation is so high (URBEXT = 0.47), and the percentage run-off is so low for the undeveloped catchment, the percentage contribution to flow from the undeveloped catchment is very small. This means that the amount of error that it can cause within RefH is much reduced. For valid comparison of methods, Malton flows are presented here with and without the Kjeldsen urban adjustment technique.

Results for OM1 have been extracted separately in this instance to allow understanding of the extent to which the large, flat rural catchment to the north of Old Malton may behave differently from the rest of the catchment. While this does exhibit a slightly flatter growth curve than the total catchment (as might be expected), it is not significantly different to a degree that would require separation of the catchments.

	Growth factors (inferred from peak flows)					Flows (m3/s)				
Return period	Norton	Malton	Malton (with Kjeldsen adjustment)	Old Malton	OM1	Norton	Malton	Malton (with Kjeldsen adjustment)	Old Malton	OM1
2		1	1	1	1		0.48	0.23	1.25	0.70
5		1.42	1.7	1.30	1.29		0.68	0.38	1.63	0.91
10		1.79	2.4	1.54	1.51		0.86	0.52	1.93	1.06
25		2.40	3.4	1.91	1.80		1.15	0.75	2.39	1.27
30		2.54	3.6	1.99	1.88		1.22	0.80	2.49	1.32
50		2.98	4.5	2.24	2.07		1.43	0.98	2.80	1.46
75		3.38	5.3	2.46	2.24		1.62	1.16	3.07	1.58

5 FEH rainfall-runoff method

5.1 Parameters for FEH rainfall-runoff model

Methods:
- FEA : Flood event analysis
- LAG : Catchment lag
- DT : Catchment descriptors with data transfer from donor catchment
- CD : Catchment descriptors alone
- BFI : SPR derived from baseflow index calculated from flow data

Site code	Rural (R) or urban (U)	Tp(0): method	Tp(0): value (hours)	SPR: method	SPR: value (%)	BF: method	BF: value (m^3/s)	If DT, numbers of donor sites used (see Section 5.2) and reasons
N0	R	CD	4.18	CD	11.6	CD	0.11	
M4	R	CD	0.26	CD		CD		
OM (total)	R	CD	5.15	CD		CD		

5.2 Donor sites for FEH rainfall-runoff parameters

In view of level of study (and difficulty of finding suitable donors in statistical method), rainfall-runoff donors have not been used in this instance.

5.3 Inputs to and outputs from FEH rainfall-runoff model

Site code	Storm duration (hours)	Storm area for ARF (if not catchment area)	Flood peaks (m^3/s) for the following return periods (in years)							
			2	5	10	25	30	50	75	100
N0	7.25		0.8	1.11	1.38	2.16	2.32	2.83	3.21	3.53
M4	1.25		0.45	0.63	0.79	1.06	1.12	1.32	1.49	1.63
OM (total)	8.75		1.10	1.76	2.18	2.88	3.02	3.48	3.81	4.08
			Inferred growth curves for the following return periods (in years)							
			2	5	10	25	30	50	75	100
N0			1	1.39	1.73	2.7	2.9	3.54	4.01	4.41
M4			1.00	1.41						
OM (total)										
Are the storm durations likely to be changed in the next stage of the study, e.g. by optimisation within a hydraulic model?					Yes, highly likely					

6 Modified rational method

The modified rational method has been used to investigate the Malton catchment, and the urbanised portion of the Norton catchment.

	Growth factors		Flows (m3/s)	
Return period	Norton (developed)	Malton [M4]	Norton (developed)	Malton [M4]
2	1	1	0.33	0.25
5	1.35	1.42	0.44	0.35
10	1.65	1.79	0.54	0.44
25	2.15	2.40	0.71	0.59
30	2.30	2.54	0.76	0.62

50	2.65	2.98	0.87	0.73
75	2.95	3.38	0.97	0.83

7 Discussion and summary of results

7.1 Comparison of results from different methods

7.1.1 Norton:

Three methods are considered for Norton:

a) The statistical method
b) The statistical method for the undeveloped catchment, PLUS the Modified Rational Method for the developed catchment
c) The FEH rainfall run-off method

	Growth Curves			Flows (m3/s)		
	Statistical	Statistical + MRM	FEH rainfall runoff	Statistical	Statistical + MRM	FEH rainfall runoff
2	1.00	1.00	1	0.64	0.64	0.8
5	1.48	1.41	1.39	0.95	0.9	1.11
10	1.80	1.73	1.73	1.15	1.11	1.38
25	2.23	2.24	2.7	1.43	1.43	2.16
30	2.31	2.37	2.9	1.48	1.52	2.32
50	2.56	2.72	3.54	1.64	1.74	2.83
75	2.76	3.02	4.01	1.77	1.93	3.21
100	2.89	3.26	4.41	1.85	2.09	3.53

The degree of correlation between methods a) and b) is encouraging. The growth curve from the FEH rainfall-runoff method appears to be unsupported by the pooling group results from the statistical analysis.

Of particular note is that the flood frequency curves from a) and b) are highly comparable to the design flows attained in the Mill Beck Phase 2 study (Atkins, 2005). While Atkins 2005 had assumed a smaller catchment than this, the rainfall runoff method had been validated against a number of observed events, so it is reasonable to expect results to be of a similar magnitude to this study.

<u>Conclusion - Norton:</u>

- Use whichever is the higher flow of methods a) and b).
- Scale FEH rainfall-runoff modules to match these flows at the peak of the critical design storm
- Use the scaled modules to consider events of different durations.

	Norton – best estimate peak flows (m3/s)
2	0.64
5	0.95
10	1.15
25	1.43
30	1.52
50	1.74
75	1.93
100	1.85

7.1.2 Malton:

Four methods were considered for Malton:

d) The statistical method; e) The FEH rainfall runoff method;

f) The RefH rainfall runoff method and g) The Modified Rational method

	Growth Curves					Flows (m3/s)				
	Statistical	FEH rainfall runoff	RefH rainfall runoff	RefH rainfall runoff (with Kjeldsen)	Modified Rational Method	Statistical	FEH rainfall runoff	RefH rainfall runoff	RefH rainfall runoff (with Kjeldsen)	Modified Rational Method
2	1.00	1.00	1.00	1.00	1.00	0.22	0.45	0.48	0.23	0.25
5	1.39	1.41	1.42	1.73	1.42	0.31	0.63	0.68	0.38	0.35
10	1.71	1.78	1.79	2.36	1.79	0.38	0.79	0.86	0.52	0.44
25	2.20	2.37	2.40	3.41	2.40	0.48	1.06	1.15	0.75	0.59
30	2.32	2.51	2.54	3.64	2.54	0.51	1.12	1.22	0.80	0.62
50	2.63	2.95	2.98	4.45	2.98	0.58	1.32	1.43	0.98	0.73
75	2.93	3.33	3.38	5.27	3.38	0.65	1.49	1.62	1.16	0.83
100	3.14	3.65	3.69	5.95	3.70	0.69	1.63	1.77	1.31	0.91

Conclusion - Malton:

The growth curves of FEH, the RefH rainfall runoff method (before the Kjeldsen adjustment) and MRM are all very similar, reflecting that the growth curve is strongly tied to the rainfall depth duration frequency relationship on such a heavily urbanised catchment. The question therefore is over which value of Qmed to use – the value implied by e) and f) (pre Kjeldsen), or that implied by d), g) and f) (post Kjeldsen adjustment).

Comparison of the higher value of Qmed with the available values of existing situation pump capacities suggests that flooding would occur very regularly, and this was considered to be too conservative – a value of 0.25m3/s was adopted, with sensitivity testing to be carried out on the impacts of this decision. Sensitivity testing in the hydraulic analysis suggested that once groundwater flow is taken into account, it was a much more dominant effect than storm runoff, such that the hydraulics are largely insensitive to the assumed Qmed (water levels +/- 0.03m).

The adopted method was to use the FEH rainfall runoff method, scaled to match a Qmed of 0.25m3/s.

The relative values of Qmed between the different flood cells were use to scale flows relative to the M4 hydrographs.

It was recognised that the combined system has a significant role in catchment M4 in diverting flow away from the catchment – to reflect this, any flows less than the 30yr flow for that portion of the catchment north of Yorkersgate (identified as 0.39m3/s) were assumed to be captured by the combined system and discharged away from the flood cells. This adjustment was done in the hydraulic model to retain control over the way that it was applied in different storm durations. In this way, the final flows used in the system are actually very similar to a RefH based approach including the Kjeldsen adjustment.

	Malton [M4]– best estimate peak flows before adjustments for combined sewer network(m3/s)
2	0.25
5	0.35
10	0.45
25	0.59
30	0.63
50	0.74
75	0.83
100	0.91

7.1.3 Old Malton:

Three methods were considered for Old Malton:

e) The statistical method
f) The FEH rainfall runoff method
g) The RefH rainfall runoff method

	Growth Curves			Flows (m3/s)		
	Statistical	FEH rainfall runoff	RefH rainfall runoff	Statistical	FEH rainfall runoff	RefH rainfall runoff
2	1.00	1.00	1.00	0.77	1.10	1.25
5	1.41	1.60	1.30	1.09	1.76	1.63
10	1.67	1.98	1.54	1.29	2.18	1.93
25	2.07	2.62	1.91	1.59	2.88	2.39
30	2.12	2.75	1.99	1.63	3.02	2.49
50	2.27	3.16	2.24	1.75	3.48	2.80
75	2.43	3.46	2.46	1.87	3.81	3.07
100	2.59	3.71	2.62	1.99	4.08	3.28

<u>Conclusion – Old Malton:</u>

The growth curves of the statistical and RefH methods are very similar, and it is noted that if anything, the statistical analysis sensitivity test suggests that this growth curve may be steeper than reality because of the influence of storage within the flat catchment of OM1. This seems reasonable grounds to dismiss the results of the FEH rainfall runoff method, which exhibits a much steeper growth curve.

There seems to be little reason to go against the more conservative values of Qmed presented by RefH, but RefH can not be used for assessing events greatly outside the indicated critical storm duration of the natural catchment.

Adopted method:

FEH rainfall-runoff units, scaled at their critical storm duration to match the peak flows from the RefH

	Old Malton – best estimate peak flows (m3/s)
2	1.25
5	1.63
10	1.93
25	2.39
30	2.49
50	2.80
75	3.07
100	3.28

7.2 Comparison with flood history

The flood history since construction of the 2003 flood alleviation scheme is not extensive (one event confirmed with certainty), but that event did indicate that in 2012, significant flooding occurred for a rainfall event that was not significant in magnitude – return period <1yr during the flood locked period.

However, permanent pumping station capacities are so small (21 l/s in total in the Malton catchments), and the periods of flood-locking are so long, that relatively any scale of event could cause flooding in the absence of emergency pumping. This means it is not really possible to use historic events as a check on flood hydrology, and this limitation goes for all areas considered.

7.2 Conclusions

The results selected above are the best estimates available with methods proportionate to the scale of this study, and the data available. It is recognised that there is significant residual uncertainty in the results, and **it is recommended** that this should be presented and considered in sensitivity analyses should the study progress to PAR.

It is recommended that flow monitoring should be undertaken on Malton sewers, the Riggs Road Drain in Old Malton, and the Mill Beck. Even establishing a more robust estimate of baseflow in the system will be of significant benefit in improving flow estimates.

Flood hydrographs have been developed for each area using the ISIS files listed below:

Files:

Norton2yr.IED
Norton5yr.IED
Norton10yr.IED
Norton25yr.IED
Norton30yr.IED
Norton50yr.IED
Norton75yr.IED
Norton100yr.IED
Malton.DAT
Old malton.DAT

Location: \\global\europe\Leeds\Jobs\230000\239474-00\0 Arup\0-12 Water\0-12-07 Calcs-Specs\Hydrology\Flow calculations\

8 Annex - supporting information

8.1 Pooling group composition

8.2 Additional supporting information

ARUP	Hydrological Estimation Points: Calculation of Qmed incorporating donor sites and gauged data	Job No.	239474	Job Name	Malton & Norton	By	LRJB	Checked		Date	#########

Table should identify all calculation points INCLUDING donor / analogue sites

Catchment Identifier	N0	N1u	N1d	N2u	N2d	N3u	N3d	N4	**M1**	**M2**	**M3**	**M4**	OM1	OM2	OM3	OM4	OM5
Gauged site?	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n
Gauging Station Name (if gauged)																	
Gauging Station No. (if gauged)																	

If not imported by the macro above, insert FEH catchment descriptors for all sites below using **paste special/values** - works for FEH CD-ROM v3.0 - otherwise paste each cell manually

Please note - easting and northing is for catchment centroid, not calculation point

	N0	N1u	N1d	N2u	N2d	N3u	N3d	N4	M1	M2	M3	M4	OM1	OM2	OM3	OM4	OM5
EASTING	480030	480030	480030	480030	480030	480030	480030	480030	428293	428293	428293	428293	478945	478945	478945	478945	478945
NORTHING	469750	469750	469750	469750	469750	469750	469750	469750	471973	471973	471973	471973	472926	472926	472926	472926	472926
AREA	10.62	0.203	0.1	0.1	0.1	0.6	0.1	0.1	0.11	0.1	0.1	0.36	3.57	0.1	0.411	0.221	0.164
BFIHOST	0.906	0.837	0.837	0.837	0.837	0.837	0.837	0.837	0.917	0.917	0.917	0.917	0.48	0.49	0.53	0.83	0.53
FARL	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
PROPWET	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32
SAAR	660	653	653	653	653	653	653	653	656	656	656	656	643	643	643	643	643
SPRHOST	11.6	26.2	26.2	26.2	26.2	26.2	26.2	26.2	8.9	8.9	8.9	8.9	40	39	37	17	37
URBEXT2000	0.055	0.506	0.65	0.5	0.85	0.62	0.71	1	0.38	0.23	0.29	0.47	0	0	0	0.49	0.33

Rural calculation

(using 'improved FEH procedures' 2008)

	N0	N1u	N1d	N2u	N2d	N3u	N3d	N4	M1	M2	M3	M4	OM1	OM2	OM3	OM4	OM5
QMED rural (m^3/s) =	**0.29**	**0.01**	**0.01**	**0.01**	**0.01**	**0.035**	**0.008**	**0.008**	**0.005**	**0.01**	**0.01**	**0.02**	**0.66**	**0.03**	**0.09**	**0.01**	**0.04**

Urban Conversion

(using 'Kjeldsen 2010)

	N0	N1u	N1d	N2u	N2d	N3u	N3d	N4	M1	M2	M3	M4	OM1	OM2	OM3	OM4	OM5
Year:	2015	2015	2015	2015	2015	2015	2015	2015	2015	2015	2015	2015	2015	2015	2015	2015	2015
adjustment factor	1.033	1.033	1.033	1.033	1.033	1.033	1.033	1.033	1.033	1.033	1.033	1.033	1.033	1.033	1.033	1.033	1.033
URBEXT adj	**0.057**	**0.523**	**0.671**	**0.516**	**0.878**	**0.640**	**0.733**	**1.033**	**0.392**	**0.238**	**0.300**	**0.485**	**0.000**	**0.000**	**0.000**	**0.506**	**0.341**
PRUAF	1.1344	1.4106	1.5275	1.4058	1.6898	1.5032	1.5762	1.8116	2.2664	1.7665	1.9665	2.5664	1.0000	1.0000	1.0000	1.7416	1.1429
UAF	1.3403	2.4564	3.0196	2.4345	3.9210	2.8964	3.2752	4.6924	6.6183	3.6985	4.7476	8.8658	1.0000	1.0000	1.0000	3.8571	1.4873
Qmed urban (m^3/s) =	**0.39**	**0.03**	**0.02**	**0.02**	**0.03**	**0.10**	**0.03**	**0.04**	**0.04**	**0.02**	**0.02**	**0.13**	**0.66**	**0.03**	**0.09**	**0.06**	**0.06**

Ungauged Sites

	N0	N1u	N1d	N2u	N2d	N3u	N3d	N4	M1	M2	M3	M4	OM1	OM2	OM3	OM4	OM5
			Answer from above scaled down from $0.1km^2$ to match catchment area				Answer from above scaled down from $0.1km^2$ to match catchment area			Answer from above scaled down from $0.1km^2$ to match catchment area							
Result																	
Qmed (m^3/s)	**0.3885**	**0.0345**	**0.0149**	**0.0084**	**0.0069**	**0.1023**	**0.0096**	**0.0083**	**0.0363**	**0.0019**	**0.0024**	**0.1333**	**0.6551**	**0.0212**	**0.0891**	**0.0577**	**0.0606**
Based on	Regression equation unadjusted	Regression equation unadjusted	Regression equation unadjusted	Regression equation unadjusted	Regression equation unadjusted	Regression equation unadjusted	Regression equation unadjusted	Regression equation unadjusted	Regression equation unadjusted	Regression equation unadjusted	Regression equation unadjusted	Regression equation unadjusted	Regression equation unadjusted	Regression equation unadjusted	Regression equation unadjusted	Regression equation unadjusted	Regression equation unadjusted

Confidence Limits - values

	N0	N1u	N1d	N2u	N2d	N3u	N3d	N4	M1	M2	M3	M4	OM1	OM2	OM3	OM4	OM5
68% Lower (m^3/s)	0.27	0.02	0.01	0.01	0.00	0.07	0.01	0.01	0.03	0.00	0.00	0.09	0.46	0.01	0.06	0.04	0.04
68% Upper (m^3/s)	0.56	0.05	0.02	0.01	0.01	0.15	0.01	0.01	0.05	0.00	0.00	0.19	0.94	0.03	0.13	0.08	0.09
95% Lower (m^3/s)	0.19	0.02	0.01	0.00	0.00	0.05	0.00	0.00	0.02	0.00	0.00	0.07	0.32	0.01	0.04	0.03	0.03
95% Upper (m^3/s)	0.80	0.07	0.03	0.02	0.01	0.21	0.02	0.02	0.07	0.00	0.00	0.27	1.34	0.04	0.18	0.12	0.12

Confidence Limits - percentage difference

	N0	N1u	N1d	N2u	N2d	N3u	N3d	N4	M1	M2	M3	M4	OM1	OM2	OM3	OM4	OM5
68% Lower (percentage)	-30.1	-30.1	-30.1	-30.1	-30.1	-30.1	-30.1	-30.1	-30.1	-30.1	-30.1	-30.1	-30.1	-30.1	-30.1	-30.1	-30.1
68% Upper (percentage)	43.1	43.1	43.1	43.1	43.1	43.1	43.1	43.1	43.1	43.1	43.1	43.1	43.1	43.1	43.1	43.1	43.1
95% Lower (percentage)	-51.2	-51.2	-51.2	-51.2	-51.2	-51.2	-51.2	-51.2	-51.2	-51.2	-51.2	-51.2	-51.2	-51.2	-51.2	-51.2	-51.2
95% Upper (percentage)	104.8	104.8	104.8	104.8	104.8	104.8	104.8	104.8	104.8	104.8	104.8	104.8	104.8	104.8	104.8	104.8	104.8

ARUP	Hydrological Estimation Points: Calculation of Qmed incorporating donor sites and gauged data	Job No.	239474	Job Name	Malton & Norton	By	LRJB	Checked		Date	########

Table should identify all calculation points I

Catchment Identifier	OM6	OM7	OM8	OM9	OM10		
Gauged site?	n	n	n	n	n	n	n
Gauging Station Name (if gauged)							
Gauging Station No. (if gauged)							

If not imported by the macro above, insert I

Please note - easting and northing is for ca

EASTING	478945	478945	478945	478945	478945		
NORTHING	472926	472926	472926	472926	472926		
AREA	0.181	0.194	0.1	0.176	0.429		
BFIHOST	0.53	0.77	0.53	0.9	0.9		
FARL	1	1	1	1	1		
PROPWET	0.32	0.32	0.32	0.32	0.32		
SAAR	643	643	643	647	647		
SPRHOST	37	21	37	12	12		
URBEXT2000	0.48	0.34	1	0.57	0		

Rural calculation

QMED rural (m^3/s) =	0.04	0.02	0.03	0.01	0.02		

Urban Conversion

Year:	2015	2015	2015	2015	2015	2015	2015
adjustment factor	1.033	1.033	1.033	1.033	1.033		
URBEXT adj	0.496	0.351	1.033	0.589	0.000		
PRUAF	1.2078	1.3851	1.4330	2.3374	1.0000		
UAF	1.7451	2.2593	2.8280	7.4278	1.0000		
Qmed urban (m^3/s) =	0.08	0.04	0.08	0.06	0.02		

Ungauged Sites

Result

Qmed (m^3/s)	0.0774	0.0407	0.0757	0.0642	0.0184		
Based on	Regression equation unadjusted	Regression equation unadjusted	Regression equation unadjusted	Regression equation unadjusted	Regression equation unadjusted	Regression equation unadjusted	Regression equation unadjusted

Confidence Limits - values

68% Lower (m^3/s)	0.05	0.03	0.05	0.04	0.01	#VALUE!	#VALUE!
68% Upper (m^3/s)	0.11	0.06	0.11	0.09	0.03	#VALUE!	#VALUE!
95% Lower (m^3/s)	0.04	0.02	0.04	0.03	0.01	#VALUE!	#VALUE!
95% Upper (m^3/s)	0.16	0.08	0.15	0.13	0.04	#VALUE!	#VALUE!

Confidence Limits - percentage differen

68% Lower (percentage)	-30.1	-30.1	-30.1	-30.1	-30.1	#VALUE!	#VALUE!
68% Upper (percentage)	43.1	43.1	43.1	43.1	43.1	#VALUE!	#VALUE!
95% Lower (percentage)	-51.2	-51.2	-51.2	-51.2	-51.2	#VALUE!	#VALUE!
95% Upper (percentage)	104.8	104.8	104.8	104.8	104.8	#VALUE!	#VALUE!

1 Pooling Group Derivation

1.1 Subject Site

M4 - largest catchment under assessment in Malton

Station created “999202”

Area	BFI	FARL	FPEXT	SAAR	URBEXT
0.36	0.917	1	0.09	656	0.47

1.2 Methodology

Improved FEH pooling group	Method	Used (Y/N)
	No review of pooling group	
	Minimal review of pooling group (based on HiFlows-UK suitability indication)	
	Detailed review of pooling group (beyond HiFlows-UK suitability indication)	Y

1.3 Pooling group derivation

The pooling group has been created using “only stations suitable for QMED and pooling” from HiFlows-UK.

Versions of FEH software and databases used in this study[mt1]:

FEH CD-ROM	V 3.0 (2009)[am2]
Winfap FEH	V 3.0.003 (2009)[am3]
HiFlows UK database	3.3.4

Initial Pooling group:

	Station	Distance	Years of data	QMED AM	L-CV	L-SKEW	Discordanc
1	76011 (Coal Burn @ Coalburn)	2.335	35	1.840	0.169	0.333	1.173
2	45816 (Haddeo @ Upton)	4.362	19	3.456	0.324	0.434	0.702
3	27051 (Crimple @ Burn Bridge)	4.472	40	4.539	0.222	0.149	0.333
4	28033 (Dove @ Hollinsclough)	4.628	33	4.666	0.266	0.415	0.478
5	27073 (Brompton Beck @ Snain	4.650	32	0.813	0.197	-0.022	0.505
6	27073 (Brompton Beck @ Snain	4.650	32	0.813	0.197	-0.022	0.505
7	91802 (Allt Leachdach @ Intake	4.908	34	6.350	0.153	0.257	1.141
8	54022 (Severn @ Plynlimon Flun	5.203	37	15.031	0.155	0.168	1.583
9	25003 (Trout Beck @ Moor Hou	5.276	39	15.164	0.176	0.291	0.652
10	49006 (Camel @ Camelford)	5.282	6	8.832	0.110	-0.293	2.722
11	25011 (Langdon Beck @ Langd	5.291	26	15.878	0.241	0.326	1.565
12	25019 (Leven @ Easby)	5.297	34	5.538	0.347	0.394	0.933
13	47022 (Tory Brook @ Newnham	5.330	19	7.331	0.257	0.071	0.532
14	26802 (Gypsey Race @ Kirby Gi	5.338	13	0.109	0.261	0.199	0.376
15	206006 (Annalong @ Recorder)	5.457	48	15.330	0.189	0.052	1.660
16	27010 (Hodge Beck @ Bransda	5.658	41	9.420	0.224	0.293	0.152
17	44008 (South Winterbourne @ V	5.749	33	0.420	0.395	0.332	1.989
18							
19	Total		521				
20	Weighted means				0.228	0.217	

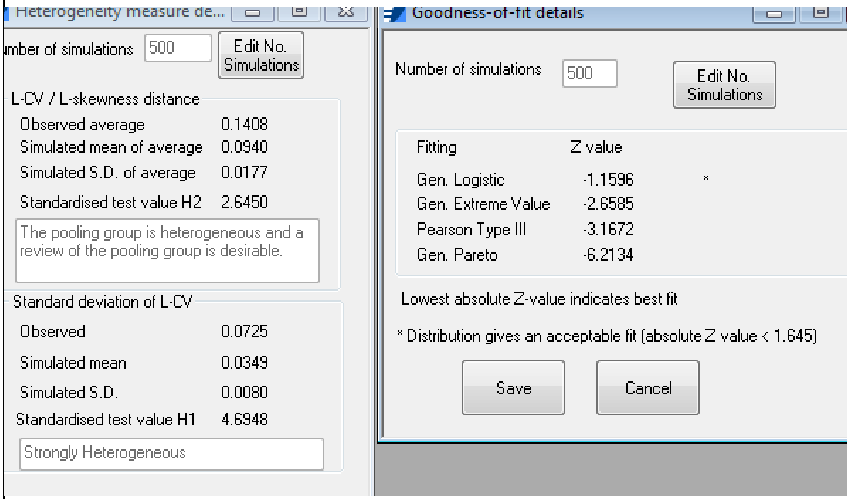
Key

Short Records

Discordant

No Pooling

No Pooling, No QMED



The number of small catchments present in the Hiflows-UK database is relatively small, and as a consequence, at this scale of catchment WinFAP-FEH has a slight tendency to select small catchments that may differ markedly from the subject site on other characteristics.

Sites Removed:

76011 – artificial influences, highly impermeable, steep catchment.

25003, 25011, 27010 – highly impermeable

47022, impermeable, with extensive artificial influences

54022, 91802 – rainfall far in excess of subject site, highly impermeable

206006 – highly impermeable, Irish catchment

Additional catchments were added to increase the number of years of record. The full 500 years were not obtained as the critical events are < 100years, and it was not felt that the stations being added were greatly increasing the appropriateness of the pooling group.

Job title	Malton & Norton Flood Study	Job number	Sheet number	Revision
		239474		
Calc title	Malton – Pooling group analysis	Member/Location	0-12-7	
		Drg. Ref.		
		Made by LRJB	Date 05/05/2015	Chd.

Final Pooling Group

Pooling-group details 999202 (29-05-2015 16:56)

AM Data | Catchment Descriptors

	Station	Distance	Years of data	QMED AM	L-CV	L-SKEW	Discordanc
1	45816 (Haddeo @ Upton)	4.362	19	3.456	0.324	0.434	0.655
2	27051 (Crimple @ Burn Bridge)	4.472	40	4.539	0.222	0.149	1.368
3	28033 (Dove @ Hollinsclough)	4.628	33	4.666	0.266	0.415	0.981
4	27073 (Brompton Beck @ Snain	4.650	32	0.813	0.197	-0.022	1.206
5	25019 (Leven @ Easby)	5.297	34	5.538	0.347	0.394	0.557
6	26802 (Gypsey Race @ Kirby Gr	5.338	13	0.109	0.261	0.199	0.402
7	44008 (South Winterbourne @ V	5.749	33	0.420	0.395	0.332	0.655
8	203046 (Rathmore Burn @ Rath	5.850	30	10.934	0.136	0.091	1.265
9	51002 (Horner Water @ West Lu	5.935	31	8.354	0.382	0.326	1.552
10	20002 (West Peffer Burn @ Luff	6.014	41	3.299	0.292	0.015	1.657
11	36010 (Bumpstead Brook @ Bro	6.088	45	6.759	0.418	0.228	1.256
12	48004 (Warleggan @ Trengoffe)	6.162	43	9.799	0.268	0.287	0.446
13							
14	Total		394				
15	Weighted means		745		0.291	0.234	

Key
Short Records
Discordant
No Pooling
No Pooling, No QMED

Heterogeneity measure de...

Number of simulations 500 Edit No. Simulations

L-CV / L-skewness distance

Observed average	0.1568
Simulated mean of average	0.0872
Simulated S.D. of average	0.0169
Standardised test value H2	4.1244

The pooling group is strongly heterogeneous and a review of the pooling group is essential.

Standard deviation of L-CV

Observed	0.0830
Simulated mean	0.0381
Simulated S.D.	0.0087
Standardised test value H1	5.1494

Strongly Heterogeneous

Goodness-of-fit details

Number of simulations 500 Edit No. Simulations

Fitting	Z value	
Gen. Logistic	0.5188	*
Gen. Extreme Value	-0.9361	*
Pearson Type III	-1.4573	
Gen. Pareto	-4.4088	

Lowest absolute Z-value indicates best fit

* Distribution gives an acceptable fit (absolute Z value < 1.645)

Save Cancel

Heterogeneity test – H2 value:	4.12
Heterogeneity status[mt4]:	FEH Vol3 Chapter 16.3.2 – "A representative heterogeneous pooling-group gives better flood frequency estimates than either single-site data or a pooling-group that has been made homogeneous by inappropriately removing sites."
Goodness-of-fit test[mt5] Acceptable distributions:	GL / GEV

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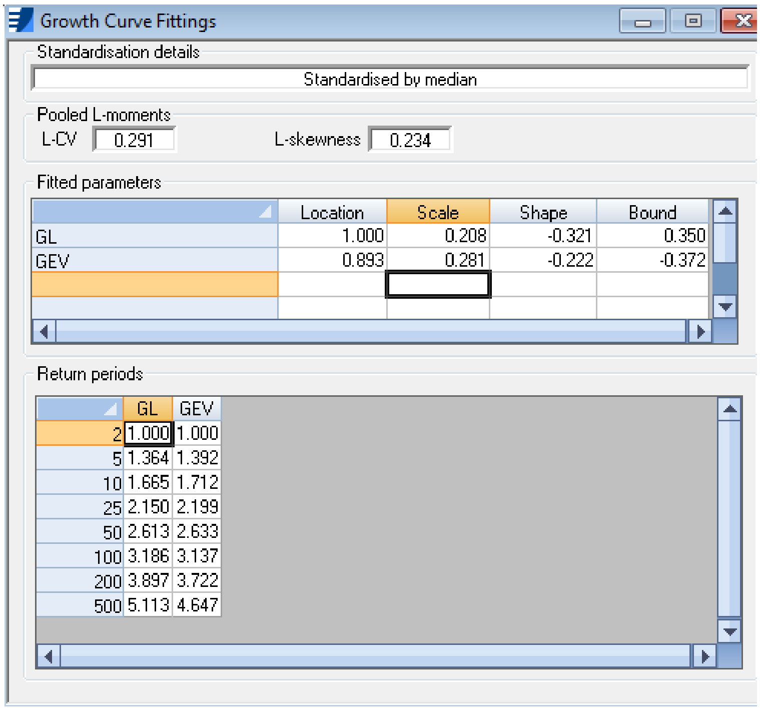
		Made by LRJB	Date 05/05/2015	Chd.

Derived Growth curves:



Growth Curve Fittings

Standardisation details

Standardised by median

Pooled L-moments

L-CV 0.291 L-skewness 0.234

Fitted parameters

	Location	Scale	Shape	Bound
GL	1.000	0.208	-0.321	0.350
GEV	0.893	0.281	-0.222	-0.372

Return periods

	GL	GEV
2	1.000	1.000
5	1.364	1.392
10	1.665	1.712
25	2.150	2.199
50	2.613	2.633
100	3.186	3.137
200	3.897	3.722
500	5.113	4.647

Permeable adjustment had minimal impact.

Job title	Malton & Norton Flood Study	Job number	Sheet number	Revision
		239474		
Calc title	Norton – Pooling group analysis	Member/Location	0-12-7	
		Drg. Ref.		
		Made by LRJB	Date 05/05/2015	Chd.

1 Pooling Group Derivation

1.1 Subject Site

N0 – Norton Mill Beck to Mill Beck pumping station.

Station created "999200"

Area	BFI	FARL	FPEXT	SAAR	URBEXT
10.62	0.906	1	0.203	660	0.057

1.2 Methodology

Improved FEH pooling group	Method	Used (Y/N)
	No review of pooling group	
	Minimal review of pooling group (based on HiFlows-UK suitability indication)	
	Detailed review of pooling group (beyond HiFlows-UK suitability indication)	Y

1.3 Pooling group derivation

The pooling group has been created using "only stations suitable for QMED and pooling" from HiFlows-UK.

Versions of FEH software and databases used in this study[mt1]:

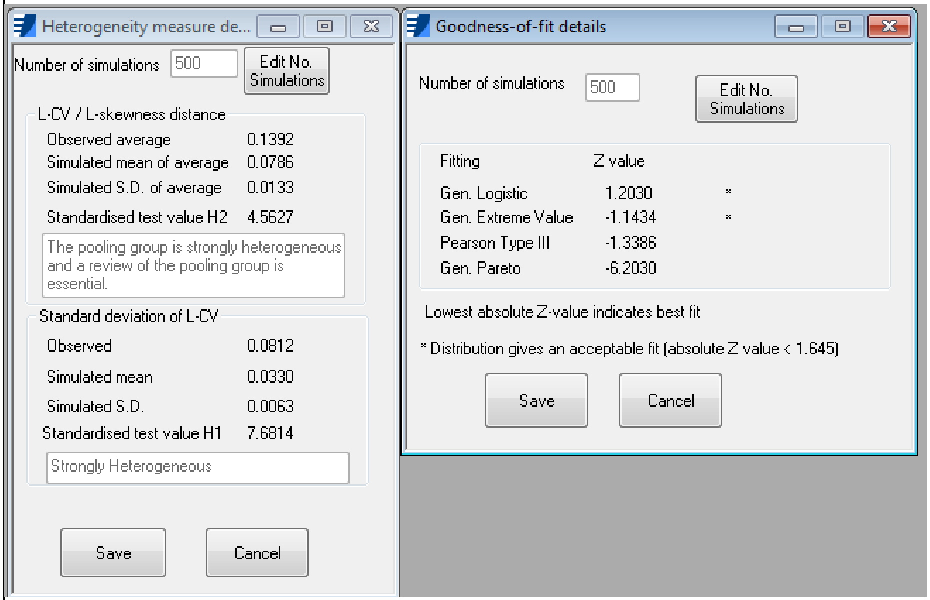
FEH CD-ROM	V 3.0 (2009)[am2]
Winfap FEH	V 3.0.003 (2009)[am3]
HiFlows UK database	3.3.4

Initial Pooling group:

Job title	Malton & Norton Flood Study	Job number	Sheet number	Revision
		239474		
Calc title	Norton – Pooling group analysis	Member/Location	0-12-7	
		Drg. Ref.		
		Made by LRJB	Date 05/05/2015	Chd.

	Station	Distance	Years of data	QMED AM	L-CV	L-SKEW	Discordancy
1	27073 (Brompton Beck @ Snain	0.566	32	0.813	0.197	-0.022	0.620
2	20002 (West Peffer Burn @ Luff	1.529	41	3.299	0.292	0.015	2.259
3	203046 (Rathmore Burn @ Rath	2.001	30	10.934	0.136	0.091	1.049
4	26802 (Gypsey Race @ Kirby Gi	2.029	13	0.109	0.261	0.199	0.526
5	25019 (Leven @ Easby)	2.159	34	5.538	0.347	0.394	1.008
6	27051 (Crimple @ Burn Bridge)	2.213	40	4.539	0.222	0.149	1.159
7	36010 (Bumpstead Brook @ Bro	2.231	45	6.759	0.418	0.228	1.644
8	72014 (Conder @ Galgate)	2.253	45	17.703	0.193	0.059	0.894
9	41020 (Bevern Stream @ Clappe	2.278	43	13.490	0.214	0.208	0.841
10	73015 (Keer @ High Keer Weir)	2.316	21	12.239	0.156	0.001	0.706
11	33054 (Babingley @ Castle Risir	2.355	36	1.129	0.214	0.069	0.223
12	44008 (South Winterbourne @ V	2.432	33	0.420	0.395	0.332	1.047
13	27010 (Hodge Beck @ Bransda	2.437	41	9.420	0.224	0.293	0.917
14	45816 (Haddeo @ Upton)	2.517	19	3.456	0.324	0.434	1.438
15	47022 (Tory Brook @ Newnham	2.525	19	7.331	0.257	0.071	0.406
16	33032 (Heacham @ Heacham)	2.528	44	0.461	0.315	0.099	1.264
17							
18	Total		536				
19	Weighted means				0.258	0.161	

	Station	Distance SDM	AREA	SAAR	FPEXT	FARL	URBEXT 200
1	27073 (Brompton Beck @ Snainton Ings)	0.566	8.060	721	0.237	1.000	0.008
2	20002 (West Peffer Burn @ Luffness)	1.529	26.310	616	0.128	0.996	0.002
3	203046 (Rathmore Burn @ Rathmore Bridge)	2.001	22.510	1043	0.073	1.000	0.000
4	26802 (Gypsey Race @ Kirby Grindalythe)	2.029	15.850	757	0.030	1.000	0.000
5	25019 (Leven @ Easby)	2.159	15.070	830	0.019	1.000	0.004
6	27051 (Crimple @ Burn Bridge)	2.213	8.150	855	0.013	1.000	0.006
7	36010 (Bumpstead Brook @ Broad Green)	2.231	27.580	588	0.045	0.999	0.007
8	72014 (Conder @ Galgate)	2.253	28.990	1183	0.082	0.975	0.006
9	41020 (Bevern Stream @ Clappers Bridge)	2.278	35.420	886	0.076	0.993	0.013
10	73015 (Keer @ High Keer Weir)	2.316	30.060	1158	0.075	0.976	0.003
11	33054 (Babingley @ Castle Rising)	2.355	48.510	686	0.118	0.944	0.005
12	44008 (South Winterbourne @ Winterbourne S	2.432	20.170	1012	0.015	1.000	0.004
13	27010 (Hodge Beck @ Bransdale Weir)	2.437	18.840	987	0.009	1.000	0.001
14	45816 (Haddeo @ Upton)	2.517	6.810	1210	0.011	1.000	0.005
15	47022 (Tory Brook @ Newnham Park)	2.525	13.450	1403	0.023	0.942	0.014
16	33032 (Heacham @ Heacham)	2.528	56.180	688	0.116	0.983	0.006
17							
18							



Review of the pooling group was carried out. Half of the catchments are of moderate to high SPR, but at this size of catchment, they have been selected by the software because of the small catchment size (of which the available pool is very small). As a sensitivity test, catchments with SPRHOST >40% were removed. Otherwise, there was little indication on hydrological grounds for revision of the pooling group

Final pooling group

Heterogeneity test – H2 value:	4.56
Heterogeneity status[mt4]:	FEH Vol3 Chapter 16.3.2 – "A representative heterogeneous pooling-group gives better flood frequency estimates than either single-site data or a pooling-group that has been made homogeneous by inappropriately removing sites."
Goodness-of-fit test[mt5]	GL / GEV
Acceptable distributions:	However, the permeability adjustment to the growth curve can only be implemented using GL – use GL

Sensitivity test pooling group:

203046, 27051, 36010, 41020, 27010, 47022 Removed (SPR > 30%)

Further 8 sites added, 22003,49003, 25011,47022, 28033 Removed (SPR > 30%)

49006 removed – only 6 years of record

Remaining no of years = 427. While this is short of the 500 mark, this analysis is largely focussed on return periods <75yr, so this is acceptable. It is not likely that a great number of hydrologically similar catchments lie further down the distance ranking.

Job title	Malton & Norton Flood Study	Job number	Sheet number	Revision
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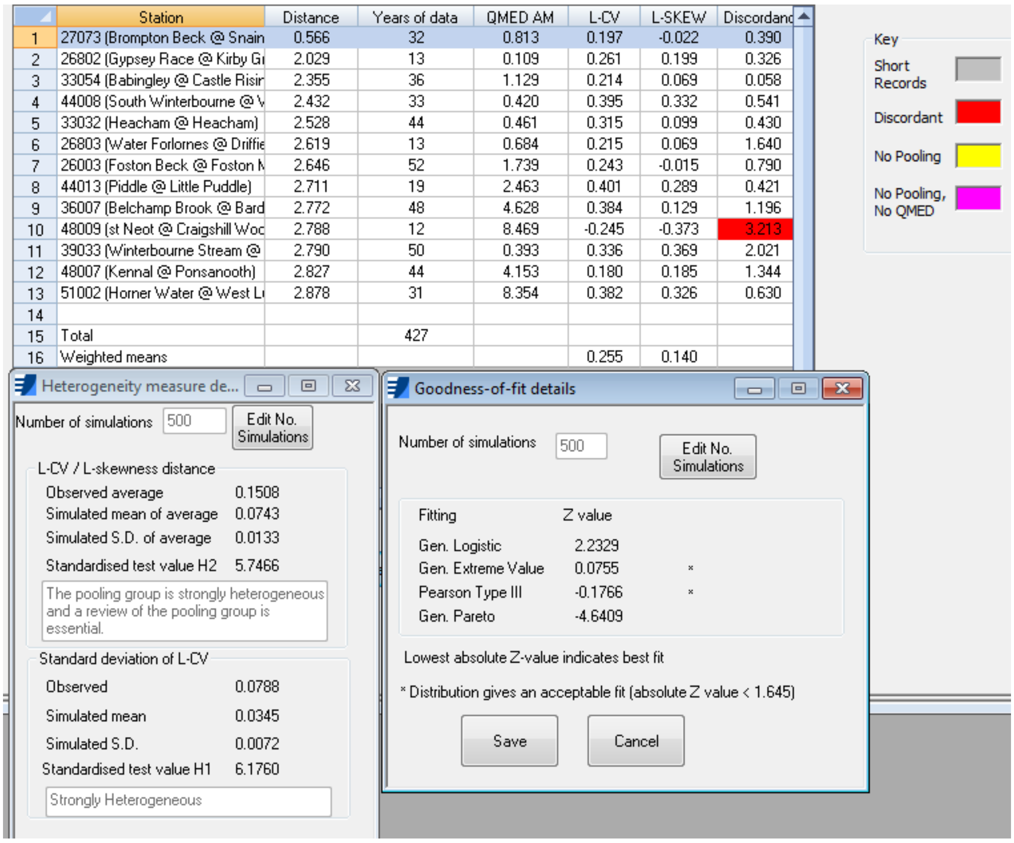
		Drg. Ref.		
		Made by LRJB	Date 05/05/2015	Chd.

Final Sensitivity testing pooling group



	Station	Distance	Years of data	QMED AM	L-CV	L-SKEW	Discordanc
1	27073 (Brompton Beck @ Snain	0.566	32	0.813	0.197	-0.022	0.390
2	26802 (Gypsey Race @ Kirby Gi	2.029	13	0.109	0.261	0.199	0.326
3	33054 (Babingley @ Castle Risir	2.355	36	1.129	0.214	0.069	0.058
4	44008 (South Winterbourne @ V	2.432	33	0.420	0.395	0.332	0.541
5	33032 (Heacham @ Heacham)	2.528	44	0.461	0.315	0.099	0.430
6	26803 (Water Forlornes @ Driffie	2.619	13	0.684	0.215	0.069	1.640
7	26003 (Foston Beck @ Foston N	2.646	52	1.739	0.243	-0.015	0.790
8	44013 (Piddle @ Little Puddle)	2.711	19	2.463	0.401	0.289	0.421
9	36007 (Belchamp Brook @ Bard	2.772	48	4.628	0.384	0.129	1.196
10	48009 (st Neot @ Craigshill Woc	2.788	12	8.469	-0.245	-0.373	3.213
11	39033 (Winterbourne Stream @	2.790	50	0.393	0.336	0.369	2.021
12	48007 (Kennal @ Ponsanooth)	2.827	44	4.153	0.180	0.185	1.344
13	51002 (Horner Water @ West Lu	2.878	31	8.354	0.382	0.326	0.630
14							
15	Total		427				
16	Weighted means				0.255	0.140	

Heterogeneity measure de...

Number of simulations 500 | Edit No. Simulations

L-CV / L-skewness distance

Observed average	0.1508
Simulated mean of average	0.0743
Simulated S.D. of average	0.0133
Standardised test value H2	5.7466

The pooling group is strongly heterogeneous and a review of the pooling group is essential.

Standard deviation of L-CV

Observed	0.0788
Simulated mean	0.0345
Simulated S.D.	0.0072
Standardised test value H1	6.1760

Strongly Heterogeneous

Goodness-of-fit details

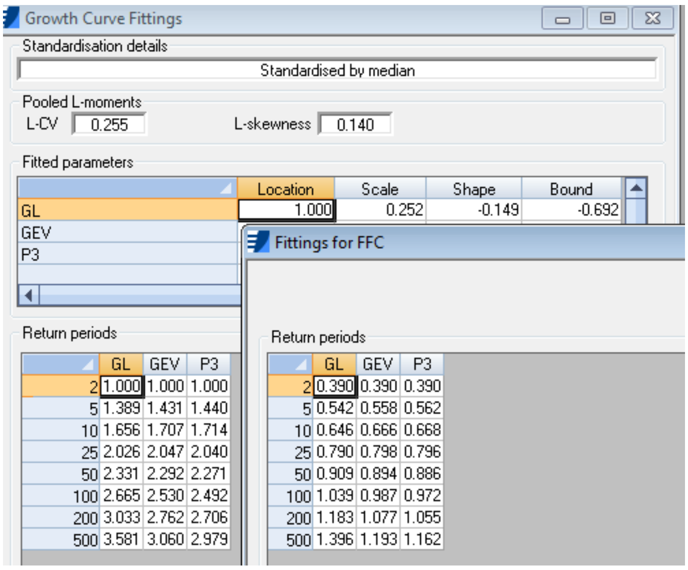
Number of simulations 500 | Edit No. Simulations

Fitting	Z value	
Gen. Logistic	2.2329	
Gen. Extreme Value	0.0755	*
Pearson Type III	-0.1766	*
Gen. Pareto	-4.6409	

Lowest absolute Z-value indicates best fit

* Distribution gives an acceptable fit (absolute Z value < 1.645)

Save | Cancel



Growth Curve Fittings

Standardisation details

Standardised by median

Pooled L-moments

L-CV 0.255 L-skewness 0.140

Fitted parameters

	Location	Scale	Shape	Bound
GL	1.000	0.252	-0.149	-0.692
GEV				
P3				

Return periods

	GL	GEV	P3
2	1.000	1.000	1.000
5	1.389	1.431	1.440
10	1.656	1.707	1.714
25	2.026	2.047	2.040
50	2.331	2.292	2.271
100	2.665	2.530	2.492
200	3.033	2.762	2.706
500	3.581	3.060	2.979

Fittings for FFC

Return periods

	GL	GEV	P3
2	0.390	0.390	0.390
5	0.542	0.558	0.562
10	0.646	0.666	0.668
25	0.790	0.798	0.796
50	0.909	0.894	0.886
100	1.039	0.987	0.972
200	1.183	1.077	1.055
500	1.396	1.193	1.162

1.4 Initial Growth curve derivation

Growth curve fittings. It can be seen that the pooling group selected for SPR < 30% is steeper in the lower return periods, but flattens off at the more extreme return periods. This seems consistent with the physical understanding of a catchment in which storage is being used up, and therefore the growth curve of the sensitivity test will be adopted rather than the conventional analysis.

	Pooling group			Sensitivity test		
Return period	GL	Permeability adjustmt	Growth curve	GEV	Permeability adjustmt (based on GL)	Growth curve
2	1.00	1.00	**1.00**	1.00	1.00	**1.00**
5	1.40	0.99	**1.39**	1.50	0.99	**1.48**
10	1.68	0.99	**1.67**	1.83	0.99	**1.80**
25	2.08	0.99	**2.06**	2.26	0.99	**2.23**
30	2.16	0.99	**2.14**	2.33	0.99	**2.31**
50	2.41	0.99	**2.39**	2.58	0.99	**2.56**
75	2.62	0.99	**2.61**	2.77	1.00	**2.76**
100	2.78	1.00	**2.77**	2.90	1.00	**2.89**
200	3.20	1.00	**3.19**	3.21	1.00	**3.22**

2 Norton Permeable catchment

2.1 Subject Site – Norton permeable catchment

Station created "999204"

Area	BFI	FARL	FPEXT	SAAR	URBEXT
8.30	0.954	1	0.047	673	0.000

2.2 Methodology

Improved FEH pooling group	Method	Used (Y/N)
	No review of pooling group	

	Minimal review of pooling group (based on HiFlows-UK suitability indication)	
	Detailed review of pooling group (beyond HiFlows-UK suitability indication)	Y

2.3 Pooling group derivation

The pooling group has been created using “only stations suitable for QMED and pooling” from HiFlows-UK.

Versions of FEH software and databases used in this study[mt6]:

FEH CD-ROM	V 3.0 (2009)[am7]
Winfap FEH	V 3.0.003 (2009)[am8]
HiFlows UK database	3.3.4

Given the difficulty in finding enough catchments with SPR< 30, 700 years of record were selected for the initial pooling group formation:

	Station	Distance	Years of data	QMED AM	L-CV	L-SKEW	Discordanc
1	27051 (Crimple @ Burn Bridge)	0.593	40	4.539	0.222	0.149	0.251
2	26802 (Gypsey Race @ Kirby Gı	0.950	13	0.109	0.261	0.199	0.381
3	25019 (Leven @ Easby)	0.975	34	5.538	0.347	0.394	0.680
4	45816 (Haddeo @ Upton)	1.221	19	3.456	0.324	0.434	0.701
5	28033 (Dove @ Hollinsclough)	1.398	33	4.666	0.266	0.415	0.857
6	27010 (Hodge Beck @ Bransda	1.423	41	9.420	0.224	0.293	0.423
7	44008 (South Winterbourne @ V	1.509	33	0.420	0.395	0.332	1.038
8	49006 (Camel @ Camelford)	1.598	6	8.832	0.110	-0.293	3.286
9	47022 (Tory Brook @ Newnham	1.622	19	7.331	0.257	0.071	0.304
10	25011 (Langdon Beck @ Langd	1.648	26	15.878	0.241	0.326	1.472
11	203046 (Rathmore Burn @ Rath	1.651	30	10.934	0.136	0.091	0.852
12	22003 (Usway Burn @ Shillmoor	1.668	26	19.220	0.303	0.303	0.421
13	36010 (Bumpstead Brook @ Bro	1.698	45	6.759	0.418	0.228	1.705
14	20002 (West Peffer Burn @ Luff	1.857	41	3.299	0.292	0.015	1.756
15	26803 (Water Forlornes @ Driffie	1.941	13	0.684	0.215	0.069	1.721
16	206006 (Annalong @ Recorder)	1.946	48	15.330	0.189	0.052	1.675
17	27032 (Hebden Beck @ Hebdeı	2.016	46	4.082	0.211	0.258	0.570
18	51002 (Horner Water @ West Lı	2.032	31	8.354	0.382	0.326	0.991
19	44013 (Piddle @ Little Puddle)	2.036	19	2.463	0.401	0.289	1.302
20	25003 (Trout Beck @ Moor Hou	2.039	39	15.164	0.176	0.291	1.070
21	72014 (Conder @ Galgate)	2.097	45	17.703	0.193	0.059	0.359
22	73015 (Keer @ High Keer Weir)	2.104	21	12.239	0.156	0.001	0.654
23	41020 (Bevern Stream @ Clappe	2.120	43	13.490	0.214	0.208	0.532
24							
25	Total		711				
26	Weighted means				0.261	0.211	

Review of the pooling group was carried out. Catchments with SPRHOST >30% were removed. Otherwise, there was little indication on hydrological grounds for revision of the pooling group

20002, 22003, 25003, 25011, 25019, 27010, 27032, 27051, 28033, 36010, 41020, 45816, 47022, 49006, 72014, 73015, 203046, 206006, 49006

Added:

48009, 27073, 28058,48007,51003,39033,47021,24007,47009, 44003, 43806

Removed: 48009, 28058, 51003, 47021, 24007

Final pooling group

	Station	Distance	Years of data	QMED AM	L-CV	L-SKEW	Discordanc
1	27051 (Crimple @ Burn Bridge)	0.593	40	4.539	0.222	0.149	0.201
2	26802 (Gypsey Race @ Kirby Gi	0.950	13	0.109	0.261	0.199	0.644
3	44008 (South Winterbourne @ V	1.509	33	0.420	0.395	0.332	0.644
4	26803 (Water Forlornes @ Driffie	1.941	13	0.684	0.215	0.069	1.156
5	51002 (Horner Water @ West Lu	2.032	31	8.354	0.382	0.326	0.947
6	44013 (Piddle @ Little Puddle)	2.036	19	2.463	0.401	0.289	0.982
7	27073 (Brompton Beck @ Snain	2.132	32	0.813	0.197	-0.022	2.547
8	48007 (Kennal @ Ponsanooth)	2.241	44	4.153	0.180	0.185	1.004
9	39033 (Winterbourne Stream @	2.381	50	0.393	0.336	0.369	1.939
10	47009 (Tiddy @ Tideford)	2.446	43	5.916	0.171	0.144	0.779
11	44003 (Asker @ Bridport)	2.553	30	14.636	0.253	0.221	0.219
12	43806 (Wylye @ Brixton Deverill	2.608	21	1.914	0.383	0.222	0.938
13							
14	Total		369				
15	Weighted means				0.281	0.210	

Heterogeneity measure de...

Number of simulations: 500 — Edit No. Simulations

L-CV / L-skewness distance

Observed average	0.1297
Simulated mean of average	0.0805
Simulated S.D. of average	0.0158
Standardised test value H2	3.1189

The pooling group is heterogeneous and a review of the pooling group is desirable.

Standard deviation of L-CV

Observed	0.0870
Simulated mean	0.0344
Simulated S.D.	0.0073
Standardised test value H1	7.1654

Strongly Heterogeneous

Goodness-of-fit details

Number of simulations: 500 — Edit No. Simulations

Fitting	Z value	
Gen. Logistic	1.6038	*
Gen. Extreme Value	0.0393	*
Pearson Type III	-0.4202	*
Gen. Pareto	-3.6137	

Lowest absolute Z-value indicates best fit

* Distribution gives an acceptable fit (absolute Z value < 1.645)

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2.4 Growth curve derivation

	Pooling group		
Return period	GL	Permeability adjustmt	Growth curve
2	1.00	1.00	**1.00**
5	1.48	0.99	**1.47**
10	1.84	0.99	**1.82**
25	2.23	0.99	**2.33**
30	2.48	0.99	**2.45**
50	2.82	0.99	**2.79**
75	3.12	0.99	**3.09**
100	3.35	1.00	**3.32**
200	3.95	1.00	**3.93**

3 Norton downstream of permeable

3.1 Subject Site – Norton permeable catchment

Station created “999205”

Area	BFI	FARL	FPEXT	SAAR	URBEXT
2.32	0.837	1	0.757	653	0.261

3.2 Methodology

Improved FEH pooling group	Method	Used (Y/N)
	No review of pooling group	
	Minimal review of pooling group (based on HiFlows-UK suitability indication)	
	Detailed review of pooling group (beyond HiFlows-UK suitability indication)	Y

3.3 Pooling group derivation

The pooling group has been created using “only stations suitable for QMED and pooling” from HiFlows-UK.

ARUP

Calculation Sheet

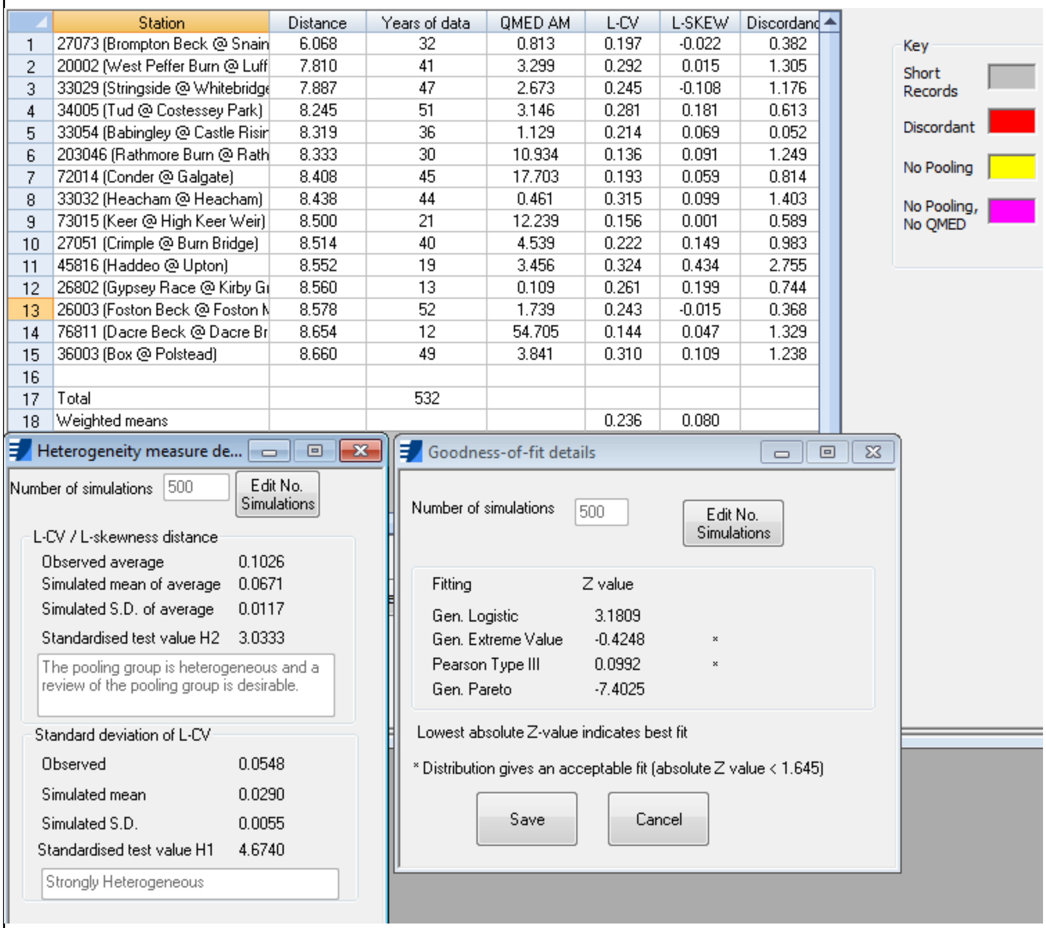
Job title	Malton & Norton Flood Study	Job number	Sheet number	Revision
		239474		
Calc title	Norton – Pooling group analysis	Member/Location	0-12-7	
		Drg. Ref.		
		Made by LRJB	Date 05/05/2015	Chd.

Versions of FEH software and databases used in this study[mt9]:

FEH CD-ROM	V 3.0 (2009)[am10]
Winfap FEH	V 3.0.003 (2009)[am11]
HiFlows UK database	3.3.4

Excessively impermeable sites were removed (SPR> 40%), but it was not felt justified to limit the pooling group to SPR< 30% as in the previous pooling groups

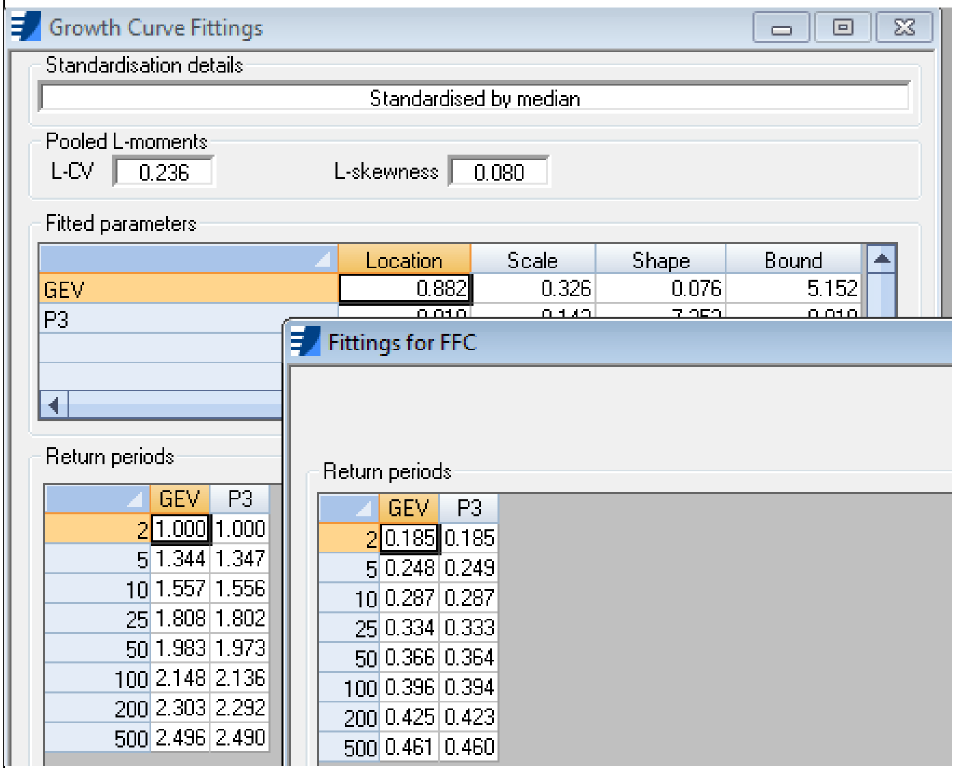
Final Pooling Group



	Station	Distance	Years of data	QMED AM	L-CV	L-SKEW	Discordanc
1	27073 (Brompton Beck @ Snain	6.068	32	0.813	0.197	-0.022	0.382
2	20002 (West Peffer Burn @ Luff	7.810	41	3.299	0.292	0.015	1.305
3	33029 (Stringside @ Whitebridge	7.887	47	2.673	0.245	-0.108	1.176
4	34005 (Tud @ Costessey Park)	8.245	51	3.146	0.281	0.181	0.613
5	33054 (Babingley @ Castle Risir	8.319	36	1.129	0.214	0.069	0.052
6	203046 (Rathmore Burn @ Rath	8.333	30	10.934	0.136	0.091	1.249
7	72014 (Conder @ Galgate)	8.408	45	17.703	0.193	0.059	0.814
8	33032 (Heacham @ Heacham)	8.438	44	0.461	0.315	0.099	1.403
9	73015 (Keer @ High Keer Weir)	8.500	21	12.239	0.156	0.001	0.589
10	27051 (Crimple @ Burn Bridge)	8.514	40	4.539	0.222	0.149	0.983
11	45816 (Haddeo @ Upton)	8.552	19	3.456	0.324	0.434	2.755
12	26802 (Gypsey Race @ Kirby Gi	8.560	13	0.109	0.261	0.199	0.744
13	26003 (Foston Beck @ Foston N	8.578	52	1.739	0.243	-0.015	0.368
14	76811 (Dacre Beck @ Dacre Br	8.654	12	54.705	0.144	0.047	1.329
15	36003 (Box @ Polstead)	8.660	49	3.841	0.310	0.109	1.238
16							
17	Total		532				
18	Weighted means				0.236	0.080	

Job title	Malton & Norton Flood Study	Job number	Sheet number	Revision
		239474		
Calc title	Norton – Pooling group analysis	Member/Location	0-12-7	
		Drg. Ref.		
		Made by LRJB	Date 05/05/2015	Chd.

Growth curve outputs (unadjusted for permeability)



Growth Curve Fittings

Standardisation details

Standardised by median

Pooled L-moments

L-CV 0.236 L-skewness 0.080

Fitted parameters

	Location	Scale	Shape	Bound
GEV	0.882	0.326	0.076	5.152
P3	[illegible]	[illegible]	[illegible]	[illegible]

Return periods

	GEV	P3
2	1.000	1.000
5	1.344	1.347
10	1.557	1.556
25	1.808	1.802
50	1.983	1.973
100	2.148	2.136
200	2.303	2.292
500	2.496	2.490

Fittings for FFC

Return periods

	GEV	P3
2	0.185	0.185
5	0.248	0.249
10	0.287	0.287
25	0.334	0.333
50	0.366	0.364
100	0.396	0.394
200	0.425	0.423
500	0.461	0.460

3.4 Growth curve derivation

	Pooling group		
Return period	GL	Permeability adjustmt	Growth curve
2	1.00	1.00	**1.00**
5	1.34	0.99	**1.33**
10	1.56	0.99	**1.54**
25	1.81	0.99	**1.79**
30	1.86	0.99	**1.84**
50	1.98	0.99	**1.96**
75	2.08	0.99	**2.06**
100	2.15	1.00	**2.15**
200	2.30	1.00	**2.30**

Job title	Malton & Norton Flood study	Job number	Sheet number	Revision
		239474		
Calc title	Old Malton – Pooling group analysis	Member/Location	0-12-7	
		Drg. Ref.		
		Made by LRJB	Date 05/05/2015	Chd.

1 Pooling Group Derivation

1.1 Subject Site

Old Malton (Riggs Road Drain outfall)

OM1,2,5,6,7,8, 9,10

Grid Reference: 479950, 472725

AREA	URBEXT	SPRHOST	BFIHOST	FPEXT	SAAR	DPLBAR	DPSBAR
4.884	0.083	35.5	0.55	0.345	643.5	2.38	7.9

1.2 Methodology

Improved FEH pooling group	Method	Used (Y/N)
	No review of pooling group	
	Minimal review of pooling group (based on HiFlows-UK suitability indication)	
	Detailed review of pooling group (beyond HiFlows-UK suitability indication)	Y

1.3 Pooling group derivation

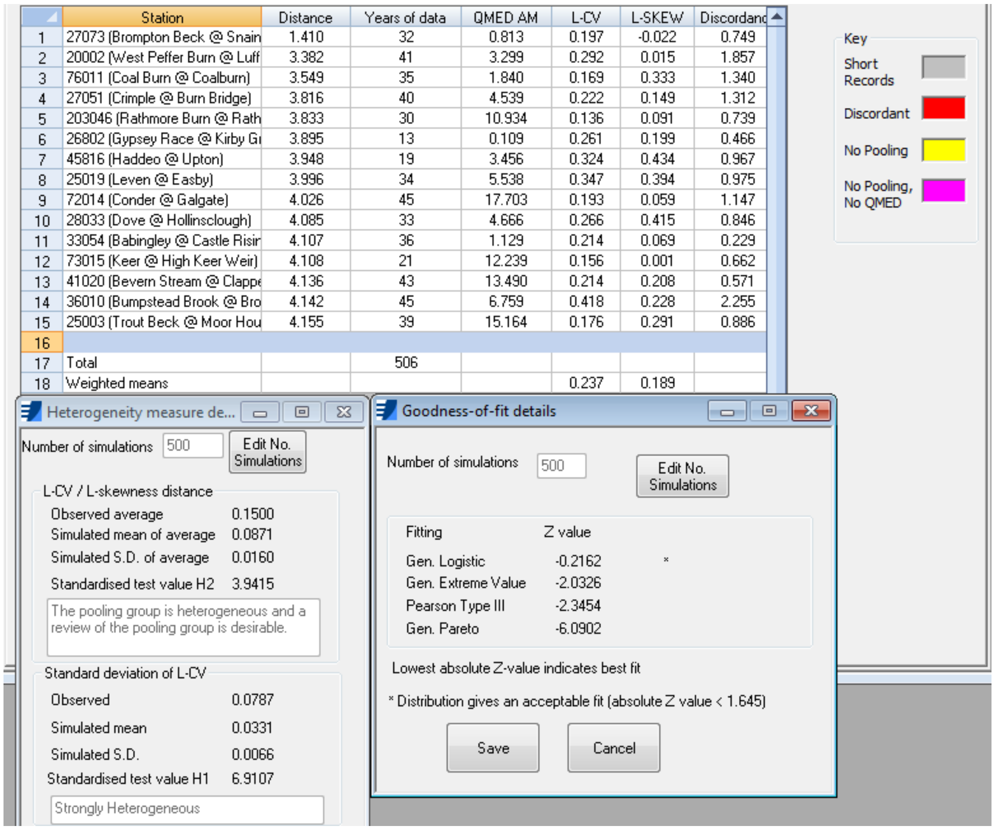
The pooling group has been created using “only stations suitable for QMED and pooling” from HiFlows-UK.

Versions of FEH software and databases used in this study:

FEH CD-ROM	V 3.0 (2009)
Winfap FEH	V 3.0.003 (2009)
HiFlows UK database	V3.3.4

Job title	Malton & Norton Flood study	Job number	Sheet number	Revision
		239474		
Calc title	Old Malton – Pooling group analysis	Member/Location	0-12-7	
		Drg. Ref.		
		Made by LRJB	Date 05/05/2015	Chd.

Initial pooling group



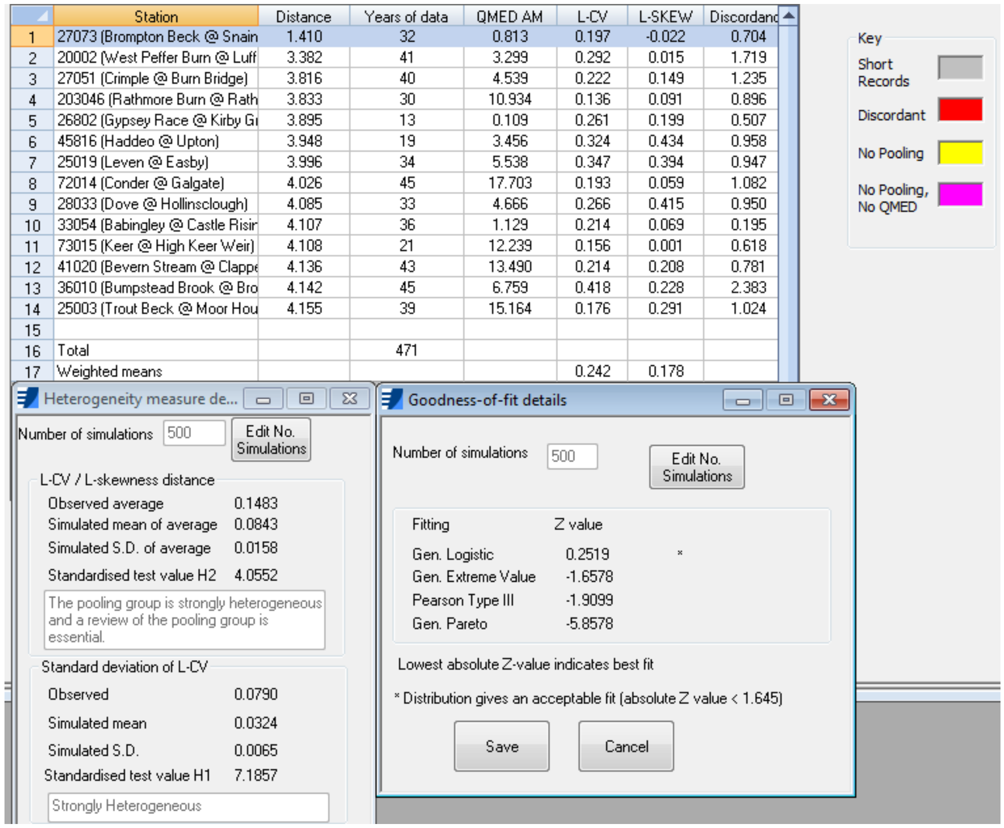
	Station	Distance	Years of data	QMED AM	L-CV	L-SKEW	Discordanc
1	27073 (Brompton Beck @ Snain	1.410	32	0.813	0.197	-0.022	0.749
2	20002 (West Peffer Burn @ Luff	3.382	41	3.299	0.292	0.015	1.857
3	76011 (Coal Burn @ Coalburn)	3.549	35	1.840	0.169	0.333	1.340
4	27051 (Crimple @ Burn Bridge)	3.816	40	4.539	0.222	0.149	1.312
5	203046 (Rathmore Burn @ Rath	3.833	30	10.934	0.136	0.091	0.739
6	26802 (Gypsey Race @ Kirby Gr	3.895	13	0.109	0.261	0.199	0.466
7	45816 (Haddeo @ Upton)	3.948	19	3.456	0.324	0.434	0.967
8	25019 (Leven @ Easby)	3.996	34	5.538	0.347	0.394	0.975
9	72014 (Conder @ Galgate)	4.026	45	17.703	0.193	0.059	1.147
10	28033 (Dove @ Hollinsclough)	4.085	33	4.666	0.266	0.415	0.846
11	33054 (Babingley @ Castle Risir	4.107	36	1.129	0.214	0.069	0.229
12	73015 (Keer @ High Keer Weir)	4.108	21	12.239	0.156	0.001	0.662
13	41020 (Bevern Stream @ Clappe	4.136	43	13.490	0.214	0.208	0.571
14	36010 (Bumpstead Brook @ Bro	4.142	45	6.759	0.418	0.228	2.255
15	25003 (Trout Beck @ Moor Hou	4.155	39	15.164	0.176	0.291	0.886
16							
17	Total		506				
18	Weighted means				0.237	0.189	

Review of pooling group

Station number	Comment
76011	Removed Experimental catchment, monitoring afforestation

Job title	Malton & Norton Flood study	Job number	Sheet number	Revision
		239474		
Calc title	Old Malton – Pooling group analysis	Member/Location	0-12-7	
		Drg. Ref.		
		Made by LRJB	Date 05/05/2015	Chd.

Final pooling group



	Station	Distance	Years of data	QMED AM	L-CV	L-SKEW	Discordanc
1	27073 (Brompton Beck @ Snain	1.410	32	0.813	0.197	-0.022	0.704
2	20002 (West Peffer Burn @ Luff	3.382	41	3.299	0.292	0.015	1.719
3	27051 (Crimple @ Burn Bridge)	3.816	40	4.539	0.222	0.149	1.235
4	203046 (Rathmore Burn @ Rath	3.833	30	10.934	0.136	0.091	0.896
5	26802 (Gypsey Race @ Kirby Gi	3.895	13	0.109	0.261	0.199	0.507
6	45816 (Haddeo @ Upton)	3.948	19	3.456	0.324	0.434	0.958
7	25019 (Leven @ Easby)	3.996	34	5.538	0.347	0.394	0.947
8	72014 (Conder @ Galgate)	4.026	45	17.703	0.193	0.059	1.082
9	28033 (Dove @ Hollinsclough)	4.085	33	4.666	0.266	0.415	0.950
10	33054 (Babingley @ Castle Risir	4.107	36	1.129	0.214	0.069	0.195
11	73015 (Keer @ High Keer Weir)	4.108	21	12.239	0.156	0.001	0.618
12	41020 (Bevern Stream @ Clappe	4.136	43	13.490	0.214	0.208	0.781
13	36010 (Bumpstead Brook @ Bro	4.142	45	6.759	0.418	0.228	2.383
14	25003 (Trout Beck @ Moor Hou	4.155	39	15.164	0.176	0.291	1.024
15							
16	Total		471				
17	Weighted means				0.242	0.178	

Sensitivity Test

It is notable that the Old Malton catchment is much flatter (DPSBAR = 8m/km) than any of the members of the pooling group. It also has a much higher FPEXT value. This suggests that the pooling group outputs are likely to result in a higher growth curve than expected at Old Malton.

As a sensitivity test, it has been attempted to select flatter catchments in the pooling group.

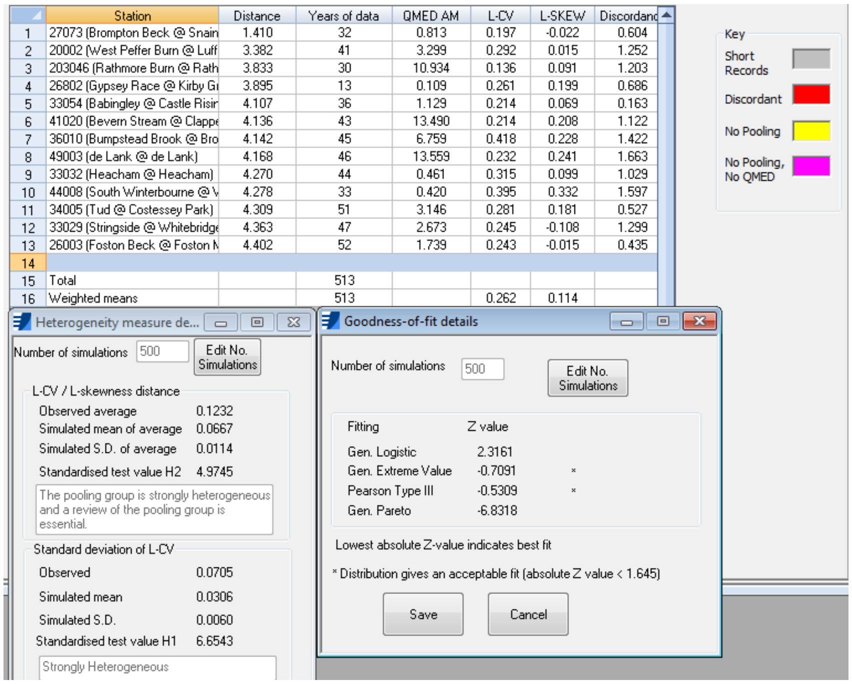
Initial Pooling Group

Anticipating the need to reject a lot of sites, 1000 years were selected for the initial PG size

	Station	Distance	Years of data	QMED AM	L-CV	L-SKEW	Discordanc
1	27073 (Brompton Beck @ Snain	1.410	32	0.813	0.197	-0.022	0.727
2	20002 (West Peffer Burn @ Luff	3.382	41	3.299	0.292	0.015	1.085
3	76011 (Coal Burn @ Coalburn)	3.549	35	1.840	0.169	0.333	1.766
4	27051 (Crimple @ Burn Bridge)	3.816	40	4.539	0.222	0.149	0.451
5	203046 (Rathmore Burn @ Rath	3.833	30	10.934	0.136	0.091	0.902
6	26802 (Gypsey Race @ Kirby Gi	3.895	13	0.109	0.261	0.199	0.355
7	45816 (Haddeo @ Upton)	3.948	19	3.456	0.324	0.434	1.207
8	25019 (Leven @ Easby)	3.996	34	5.538	0.347	0.394	1.322
9	72014 (Conder @ Galgate)	4.026	45	17.703	0.193	0.059	0.672
10	28033 (Dove @ Hollinsclough)	4.085	33	4.666	0.266	0.415	0.983
11	33054 (Babingley @ Castle Risir	4.107	36	1.129	0.214	0.069	0.206
12	73015 (Keer @ High Keer Weir)	4.108	21	12.239	0.156	0.001	0.757
13	41020 (Bevern Stream @ Clappe	4.136	43	13.490	0.214	0.208	0.551
14	36010 (Bumpstead Brook @ Bro	4.142	45	6.759	0.418	0.228	2.100
15	25003 (Trout Beck @ Moor Hou	4.155	39	15.164	0.176	0.291	0.832
16	49003 (de Lank @ de Lank)	4.168	46	13.559	0.232	0.241	0.384
17	25011 (Langdon Beck @ Langd	4.254	26	15.878	0.241	0.326	1.444
18	33032 (Heacham @ Heacham)	4.270	44	0.461	0.315	0.099	1.132
19	44008 (South Winterbourne @ V	4.278	33	0.420	0.395	0.332	1.627
20	27010 (Hodge Beck @ Bransda	4.279	41	9.420	0.224	0.293	0.371
21	206006 (Annalong @ Recorder)	4.305	48	15.330	0.189	0.052	1.495
22	34005 (Tud @ Costessey Park)	4.309	51	3.146	0.281	0.181	0.268
23	76811 (Dacre Beck @ Dacre Br	4.354	12	54.705	0.144	0.047	1.090
24	33029 (Stringside @ Whitebridge	4.363	47	2.673	0.245	-0.108	1.496
25	26003 (Foston Beck @ Foston N	4.402	52	1.739	0.243	-0.015	0.712
26	72007 (Brock @ U/s a6)	4.412	34	31.410	0.184	0.257	2.516
27	22003 (Usway Burn @ Shillmoor	4.432	26	19.220	0.303	0.303	0.692
28	36003 (Box @ Polstead)	4.434	49	3.841	0.310	0.109	0.858

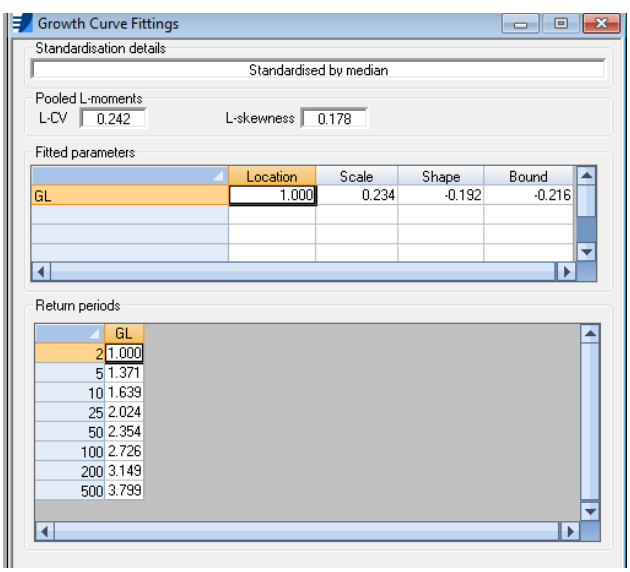
Pooling group after removal of sites with DPSBAR>60:

Job title	Malton & Norton Flood study	Job number	Sheet number	Revision
		239474		
Calc title	Old Malton – Pooling group analysis	Member/Location	0-12-7	
		Drg. Ref.		
		Made by LRJB	Date 05/05/2015	Chd.



	Station	Distance	Years of data	QMED AM	L-CV	L-SKEW	Discordanc
1	27073 (Brompton Beck @ Snain	1.410	32	0.813	0.197	-0.022	0.604
2	20002 (West Peffer Burn @ Luff	3.382	41	3.299	0.292	0.015	1.252
3	203046 (Rathmore Burn @ Rath	3.833	30	10.934	0.136	0.091	1.203
4	26802 (Gypsey Race @ Kirby Gı	3.895	13	0.109	0.261	0.199	0.686
5	33054 (Babingley @ Castle Risir	4.107	36	1.129	0.214	0.069	0.163
6	41020 (Bevern Stream @ Clappe	4.136	43	13.490	0.214	0.208	1.122
7	36010 (Bumpstead Brook @ Bro	4.142	45	6.759	0.418	0.228	1.422
8	49003 (de Lank @ de Lank)	4.168	46	13.559	0.232	0.241	1.663
9	33032 (Heacham @ Heacham)	4.270	44	0.461	0.315	0.099	1.029
10	44008 (South Winterbourne @ V	4.278	33	0.420	0.395	0.332	1.597
11	34005 (Tud @ Costessey Park)	4.309	51	3.146	0.281	0.181	0.527
12	33029 (Stringside @ Whitebridge	4.363	47	2.673	0.245	-0.108	1.299
13	26003 (Foston Beck @ Foston N	4.402	52	1.739	0.243	-0.015	0.435
14							
15	Total		513				
16	Weighted means		513		0.262	0.114	

1.4 Growth curve derivation

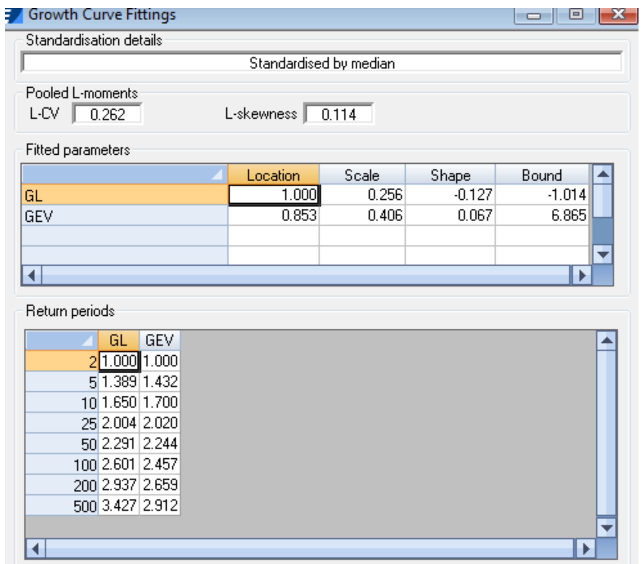


	Location	Scale	Shape	Bound
GL	1.000	0.234	-0.192	-0.216

	GL
2	1.000
5	1.371
10	1.639
25	2.024
50	2.354
100	2.726
200	3.149
500	3.799

Job title	Malton & Norton Flood study	Job number 239474	Sheet number	Revision
Calc title	Old Malton – Pooling group analysis	Member/Location	0-12-7	
		Drg. Ref.		
		Made by LRJB	Date 05/05/2015	Chd.

Sensitivity Growth curve – it can be seen that the growth curve is slightly flatter (but not dramatically different from the main growth curve). This seems in keeping with the understanding of the physical situation, so the sensitivity growth curve is adopted.


Growth Curve Fittings

Standardisation details

Standardised by median

Pooled L-moments

L-CV 0.262 L-skewness 0.114

Fitted parameters

	Location	Scale	Shape	Bound
GL	1.000	0.256	-0.127	-1.014
GEV	0.853	0.406	0.067	6.865

Return periods

	GL	GEV
2	1.000	1.000
5	1.389	1.432
10	1.650	1.700
25	2.004	2.020
50	2.291	2.244
100	2.601	2.457
200	2.937	2.659
500	3.427	2.912

Permeable adjustments

There are a number of permeable catchments in the pooling group; the growth curve is adjusted to take account of these, as documented in "Permeable_adjustment_OldMalton.xls". Results below

	Pooling Group Growth Curve	Permeability adjustmt	Adjusted Growth curve
2	1.00	1.00	1.00
5	1.43	0.986	1.41
10	1.70	0.985	1.67
25	2.02	0.986	1.99
30	2.15	0.987	2.12
50	2.29	0.990	2.27
75	2.45	0.992	2.43
100	2.60	0.995	2.59

ARUP	Job No.	Sheet No.	Rev.
	000000-00		
	Member/Location		
Job Title: Permeable catchment calculation template	Drg. Ref.		
Calculation: Permeable catchment adjustments to growth curve - Inputs	Made by: LRJB	Date: 20/05/2011	Chd.

Subject site name: 999202 Malton M1

PLEASE NOTE, BECAUSE OF STEP 4, USERS SHOULD ALWAYS START FROM THE ORIGINAL TEMPLATE

>>>Step 1: reference the filepath to wherever WinFAP-FEH data is stored on your computer:

File path: H:\WINFAP-FEH_v3.3.4\Suitable for Pooling\

>>>Step 2: select whether subject site is gauged or not in the drop-down selector below
If the subject site is gauged, but should not be included in the pooling group, select "Ungauged"

Subject Site: Ungauged

>>>Step 3: insert pooling group station numbers into table below, then click on **import** button >>>
(allow macro about a minute to complete its task)
WARNING - STROBE EFFECTS

Import

>>> Step 4: you will need to insert below any flow data pre-dating 1900 (consult [AM] to see where this may be the case)

>>> Step 5: Check total number of years of record, Pooled L-CV and Pooled L-Skew to confirm that data matches WinFAP pooling group

>>> Step 6: if subject site is ungauged, you willl need to fill in the SDM values yourself, either by copying across from WinFAP pooling group table, or by inputting catchment data for Area, SAAR,FPEXT, FARL and SPRHOST.

>>>Step 7: now go to [Outputs]

Data from FEH

TOTAL NUMBER OF YEARS OF RECORD:	363

Pooled L-CV	0.282
Pooled L-Skew	0.228

	Subject Site	WinFAP-FEH Pooling group																							
0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
Station Number	999022	45816	27051	28033	27073	25019	26802	203046	51002	20002	36010	48004													
Distance SDM	0	4.36161	4.47216	4.62752	4.64953	5.29739	5.33814	5.85047	5.93515	6.0139	6.08829	6.16182													
AREA	0.36	6.81	8.15	7.93	8.06	15.07	15.85	22.51	20.38	26.31	27.58	25.26													
SAAR	656	1210	855	1346	721	830	757	1043	1485	616	588	1445													
FPEXT	0.09	0.011	0.013	0.008	0.237	0.019	0.031	0.073	0.003	0.128	0.045	0.035													
FARL	1	1	1	1	1	1	1	1	0.978	0.996	0.999	0.978													
URBEXT 2000	0.47	0.005	0.006	0	0.008	0.004	0	0	1E-04	0.002	0.008	0.003													
BFIHOST	0.917	0.59	0.309	0.403	0.887	0.525	0.959	0.43	0.539	0.471	0.387	0.499													
SPRHOST	8.9	31.27	40.77	42.49	17.77	38.58	5.67	36.88	29.75	32.18	44.57	35.7													
LCV		0.324	0.222	0.266	0.197	0.347	0.261	0.135	0.385	0.292	0.418	0.268													
Lskew		0.434	0.149	0.415	-0.022	0.394	0.199	0.102	0.340	0.015	0.228	0.287													
Years		##	##	##	##	##	##	##	##	##	##	##													
Qmed		3.456	4.539	4.666	0.813	5.539	0.109	10.871	7.757	3.299	6.759	9.799													
Permeable catchment?	PERMEABLE				PERMEABLE		PERMEABLE																		

ARUP

Job No.	Sheet No.	Rev.
000000-00		
Member/Location		
Drg. Ref.		
Made by LRJB	Date 20/05/2011	Chd.

Job Title Permeable catchment calculation template

Calculation Permeable catchment adjustments to growth curve - Inputs

Hydrological year	Imported flow record (m3/s)																							
1941																									
1942																									
1943																									
1944																									
1945																									
1946																									
1947																									
1948																									
1949																									
1950																									
1951																									
1952																									
1953																									
1954																									
1955																									
1956																									
1957																									
1958																									
1959																									
1960																									
1961																									
1962																									
1963																									
1964																									
1965										7.17															
1966				4.70						4.69															
1967										3.69	21.00														
1968										3.08	8.83														
1969				3.50						1.80	4.77	14.55													
1970				2.82						2.61	6.76	6.11													
1971				6.32		6.22				1.83	4.35	8.66													
1972			3.85	10.26		3.09			4.57	0.17	2.09	8.73													
1973			4.81	3.02		2.18			12.20	0.13	2.29	15.68													
1974			2.23	4.52		4.23			10.60	2.05	13.81	12.97													
1975			5.12	6.61		25.18			17.38	1.17	0.62	13.97													
1976			4.24	3.50		4.09			6.60	4.51	6.68	4.72													
1977			3.59	4.05		6.34			4.35	2.79	13.34	9.98													
1978			6.05	3.99		7.17			5.79	3.30	3.82	5.32													
1979			4.51	5.54		6.58				3.73	6.08	23.68													
1980			3.87	4.61	1.04	7.28				2.75	5.11	7.76													
1981			3.61	4.14	1.17	3.63		8.92		5.86	6.91	17.40													
1982			4.02		0.65	7.54		7.51		3.77	9.70	10.01													
1983			7.38	4.25	1.10	7.64		9.99		3.81	16.20	4.72													
1984			4.90	3.18	0.63	3.99		14.36		4.86	4.36	5.69													
1985			4.71	7.05	0.92	9.36		11.50	10.99	4.68	2.13	12.28													
1986			5.24		0.69	15.50		10.66	21.89	2.08	12.15	9.80													
1987			4.88		0.81	3.49		15.13	5.79	3.53	18.90	9.59													
1988			2.59		0.20	1.14		10.32	4.80	0.35	1.80	8.71													
1989			3.29		0.30	3.55		11.57		0.47	13.79	6.24													
1990			2.29		0.74	3.99		10.77		4.09	0.45	4.96													
1991			4.93		0.41	3.98		11.96	3.07	5.67	3.30	3.88													
1992			6.38		0.53	15.97		12.30	13.73	4.36	10.56	13.84													
1993		2.38	7.02		0.98	6.09		11.00	26.33	3.85	16.72	7.11													
1994		4.02	2.97		0.73	4.99		8.20	17.17	1.92	6.83	7.58													
1995		1.64	1.68		0.55	4.30		8.41	5.40	2.79	3.52	7.99													
1996		5.79	2.85	2.62	0.57			8.31	12.97	3.30	0.59	3.93													
1997		3.23	5.53	6.91	0.95		0.20	11.16	15.03	2.68	9.90	9.36													
1998		11.66	3.59	18.71	1.32		0.11	11.22	19.90	4.26	7.97	8.31													
1999		3.93	4.87	4.89	0.74			15.65	7.16	3.49	8.83	22.02													
2000		7.87	7.61	8.38	0.84		0.26	11.00	40.80	3.59	13.98	16.49													
2001		3.62	6.06	7.40	0.68			11.02	18.94	2.06	27.76	9.08													
2002		3.02	3.51	7.59	1.06		0.15	9.05	4.39	5.83	14.34	9.98													
2003		2.73	7.12	3.93	1.27	7.45	0.13	10.87	4.61	2.59	5.64	10.79													
2004		2.04	3.33	4.88	0.72	18.88	0.08	11.55	3.09	1.76	3.07	9.64													
2005		3.79	2.26	3.45	0.65	4.92	0.10	9.29	6.21	1.64	0.82	10.47													
2006		2.83	9.38	3.49	1.16	9.52	0.07	6.31	5.92		25.05	10.14													
2007		10.20	7.41	5.41	1.27	4.87	0.14	17.74	8.35		5.51	11.04													
2008		3.46	2.98	4.94	0.87	8.70	0.07	9.02	12.71		15.20	16.13													
2009		2.44	4.56	3.35	1.10	10.33	0.14	7.60	5.43		6.60	11.38													
2010		2.15	3.40	4.67	1.12	3.85	0.04	6.50	4.64		4.51	35.32													
2011		4.56	8.35	11.69	0.82	4.87	0.11	12.72	21.53		9.84	10.28													
2012																									
2013																									
2014																									
2015																									

ARUP	Job	Sheet No.	Rev
	000000-00		
	Member/Location		
Job Title: Permeable catchment calculation template	Drg.		
Calculation: Permeable catchment adjustments to growth curve - Outputs	Made: LRJB	Date: 20/05/2011	Chd

Subject site name:	999202 Malton M1

>>> Step 1 - press [Calculate permeable adjustment] button to right>>>

Calculate permeable adjustment

>>> Step 2 - select approach to urban adjustment of growth curve
(select Option 3 as default)

Urban adjustment method	3)	Kjeldsen (2009)

Pooling Group: Before permeable adjustment

Pooled L-CV	0.282
Pooled L Skew	0.228
NUMBER OF YEARS OF RECORD:	363

	Subject Site	Pooling Group																								
Rank	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
Station Number		45816	27051	28033	27073	25019	26802	203046	51002	20002	36010	48004														
Distance SDM	0	4.36	4.47	4.63	4.65	5.30	5.34	5.85	5.94	6.01	6.09	6.16														
LCV		0.324	0.222	0.266	0.197	0.347	0.261	0.135	0.385	0.292	0.418	0.268														
Lskew		0.434	0.149	0.415	-0.022	0.394	0.199	0.102	0.340	0.015	0.228	0.287														
Years of Record		19	40	33	32	34	13	31	32	41	45	43														
Qmed		3.46	4.54	4.67	0.81	5.54	0.11	10.87	7.76	3.30	6.76	9.80														

ARUP	Job	Sheet No.	Rev
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	Member/Location		
Job Title: Permeable catchment calculation template	Drg.		
Calculation: Permeable catchment adjustments to growth curve - Outputs	Made: LRJB	Date: 20/05/2011	Chd

Generalised Logistic Growth curve adjustment for urbanisation at Subject Site - with no adjustment for permeable record

Notes:
- urban adjustment only applicable for 2 years < Tr < 1,000years.
- permeable adjustment is only documented for the Generalised Logistic Distribution

Year of interest:	2015

SPRHOST	8.90	(%)	(copied from inputs)
$URBEXT_{2000}$	0.47	(fraction)	(copied from inputs)
$URBEXT_{adj}$	0.49	(fraction)	(calculated from $URBEXT_{2000}$ and year of assessment, this page)
UAF	8.87	(factor)	(calculated from URBEXT and PRUAF, this page)
PRUAF	2.57	(factor)	(calculated from SPRHOST and URBEXT, this page)

$L\text{-}CV_{URBAN}$	0.2120	$= L\text{-}CV*0.5547^{URBEXT}$
$L\text{-}SKEW_{URBAN}$	0.3162	$= [(L\text{-}SKEW + 1) * 1.1545^{URBEXT}] -1$
k_{URBAN}	-0.3162	$= -L\text{-}SKEW$
β_{URBAN}	0.1998	$= \dfrac{LCV.k.\sin(\pi.k)}{k.\pi.(k+LCV) - LCV.\sin(\pi.k)}$

Q / Qmed (rural) $= 1 + b/k.(1-(T-1)-k)$

Q / Qmed (urban)

$= Tr.UAF^{-[(LN(Tr)-LN(2)) / (LN(1000)-LN(2))]}$ (method 1)

$= 1 + [(Tr-1)*(z_{1000}/UAF-1) / (z_{1000}-1)]$ (method 2)

$= 1 + \beta_{URBAN}/k_{URBAN}.(1-(T-1)^{-k_{URBAN}})$ (method 3)

z_{1000} =	5.9

Flood Frequency Curves (before permeability adjustment)

Return period (years)	Annual Exceedence probability (%)	Q / Qmed ('z') Before urban adjustment	Q / Qmed ('z') After urban adjustment
2	50.000	1.000	1.00
5	20.000	1.470	1.35
10	10.000	1.822	1.63
25	4.000	2.345	2.09
50	2.000	2.806	2.53
100	1.000	3.339	3.07
200	0.500	3.960	3.74
	#DIV/0!	#NUM!	#NUM!
	#DIV/0!	#NUM!	#NUM!
	#DIV/0!	#NUM!	#NUM!
	#DIV/0!	#NUM!	#NUM!
	#DIV/0!	#NUM!	#NUM!
	#DIV/0!	#NUM!	#NUM!

ARUP	Job	Sheet No.	Rev
	000000-00		
	Member/Location		
Job Title: Permeable catchment calculation template	Drg.		
Calculation: Permeable catchment adjustments to growth curve - Outputs	Made: LRJB	Date: 20/05/2011	Chd

L-Moments based on Flood Years

For sites denoted as permeable (SPRHOST>20%), the non-flood years (where Q<Qmed/2) have been removed from the flow record.
The L- Moments have been recalculated on the basis of the flood years only.

	Subject Site	Pooling Group																								
Rank	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
Station Number		45816	27051	28033	27073	25019	26802	203046	51002	20002	36010	48004														
Flood Years					30		12																			
LCV'					0.17		0.23																			
Lskew'					0.05		0.26																			
Qmed'					0.8		0.1																			

Pooling Group: After permeable adjustment

The L-Moments have then been rescaled for the missing years using the approach from FEH chapter 19, equations 19.1 - 19.9.

Pooled L-CV	0.279
Pooled L Skew	0.236

Pooled k*	-0.236
Pooled β*	0.284

Number of Flood years:	360

	Subject Site	Pooling Group																								
Rank	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
Station Number		45816	27051	28033	27073	25019	26802	203046	51002	20002	36010	48004														
k*		-0.4	-0.1	-0.4	-0	-0.4	-0.2	-0.1	-0.3	-0	-0.2	-0.3														
β*		0.3	0.2	0.2	0.2	0.3	0.2	0.1	0.4	0.3	0.5	0.3														
LCV*		0.32	0.22	0.27	0.18	0.35	0.24	0.14	0.39	0.29	0.42	0.27														
Lskew*		0.43	0.15	0.41	0.04	0.39	0.25	0.10	0.34	0.01	0.23	0.29														

ARUP	Job: 000000-00	Sheet No.	Rev
	Member/Location		
Job Title: Permeable catchment calculation template	Drg.		
Calculation: Permeable catchment adjustments to growth curve - Outputs	Made: LRJB	Date: 20/05/2011	Chd

Generalised Logistic Growth curve adjustment for urbanisation at Subject Site

Notes: urban adjustment only applicable for 2 years < Tr < 1,000years.
permeable adjustment is only documented for the Generalised Logistic Distribution

$L\text{-}CV_{URBAN}$	0.2094	=	$L\text{-}CV*0.5547^{URBEXT}$
$L\text{-}SKEW_{URBAN}$	0.3255	=	$[(L\text{-}SKEW + 1) * 1.1545^{URBEXT}] -1$
k_{URBAN}	-0.3255	=	-L-SKEW
β_{URBAN}	0.1956	=	$\frac{LCV.k.\sin(\pi.k)}{k.\pi.(k+LCV) - LCV.\sin(\pi.k)}$

Q / Qmed = $1 + \beta/k.(1-(T-1)^{-k})$

Q / Qmed (URBAN) = $Tr.UAF^{-[(LN(Tr)-LN(2)) / (LN(1000)-LN(2))]}$ (method 1)

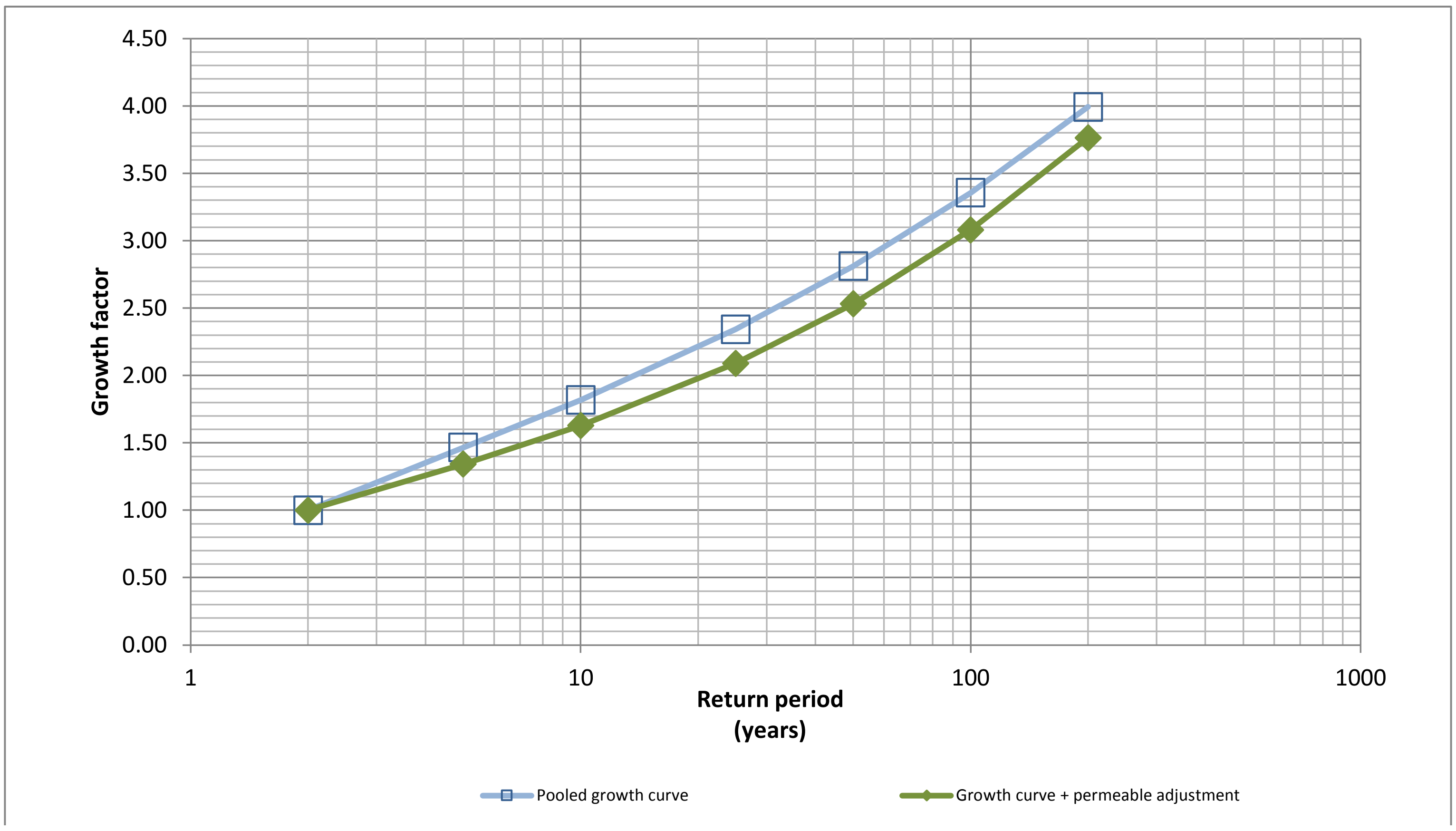
= $1 + [(Tr-1)*(z_{1000}/UAF-1) / (z_{1000}-1)]$ (method 2)

= $1 + \beta_{URBAN}/k_{URBAN}.(1-(T-1)^{-k_{URBAN}})$ (method 3)

$z_{1000} =$	5.9

Flood Frequency Curves:

Return period (years)	Annual Exceedence probability (%)	Permeability adjusted growth curve Q / Qmed ('z'): Before urban adjustment	After urban adjustment	Permeability adjustment ratios $z_{(adjusted)} / z_{(unadjusted)}$: Before urban adjustment	After urban adjustment
2	50.000	1.00	1.00	1.00	1.00
5	20.000	1.47	1.34	1.00	1.00
10	10.000	1.82	1.63	1.00	1.00
25	4.000	2.34	2.09	1.00	1.00
50	2.000	2.81	2.53	1.00	1.00
100	1.000	3.36	3.08	1.00	1.00
200	0.500	3.99	3.76	1.01	1.01
0	#DIV/0!	#NUM!	#NUM!	#NUM!	#NUM!
0	#DIV/0!	#NUM!	#NUM!	#NUM!	#NUM!
0	#DIV/0!	#NUM!	#NUM!	#NUM!	#NUM!
0	#DIV/0!	#NUM!	#NUM!	#NUM!	#NUM!
0	#DIV/0!	#NUM!	#NUM!	#NUM!	#NUM!
0	#DIV/0!	#NUM!	#NUM!	#NUM!	#NUM!



ARUP	Job 000000-00	Sheet No.	Rev
	Member/Location		
Job Title: Permeable catchment calculation template	Drg.		
Calculation: Permeable catchment adjustments to growth curve - Outputs	Made LRJB	Date 20/05/2011	Chd

ARUP	Job No.	Sheet No.	Rev.
	000000-00		
	Member/Location		
Job Title: Permeable catchment calculation template	Drg. Ref.		
Calculation: Permeable catchment adjustments to growth curve - Inputs	Made by: LRJB	Date: 20/05/2011	Chd.

Subject site name: Norton catchment - upstream

PLEASE NOTE, BECAUSE OF STEP 4, USERS SHOULD ALWAYS START FROM THE ORIGINAL TEMPLATE

>>>Step 1: reference the filepath to wherever WinFAP-FEH data is stored on your computer:

File path: H:\WINFAP-FEH_v3.3.4\Suitable for Pooling\

>>>Step 2: select whether subject site is gauged or not in the drop-down selector below
If the subject site is gauged, but should not be included in the pooling group, select "Ungauged"

Subject Site: Ungauged

>>>Step 3: insert pooling group station numbers into table below, then click on **import** button >>>
(allow macro about a minute to complete its task)
WARNING - STROBE EFFECTS

Import

>>> Step 4: you will need to insert below any flow data pre-dating 1900 (consult [AM] to see where this may be the case)

>>> Step 5: Check total number of years of record, Pooled L-CV and Pooled L-Skew to confirm that data matches WinFAP pooling group

>>> Step 6: if subject site is ungauged, you willl need to fill in the SDM values yourself, either by copying across from WinFAP pooling group table, or by inputting catchment data for Area, SAAR,FPEXT, FARL and SPRHOST.

>>>Step 7: now go to [Outputs]

Data from FEH

TOTAL NUMBER OF YEARS OF RECORD:	329

Pooled L-CV	0.290
Pooled L-Skew	0.217

	Subject Site	WinFAP-FEH Pooling group																							
0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
Station Number		26802	44008	26803	51002	44013	27073	48007	39033	47009	44003	43806													
Distance SDM		0.9497	1.50881	1.94056	2.03156	2.03642	2.13208	2.24141	2.38147	2.44627	2.55292	2.60765													
AREA	8.3	15.85	20.17	32.43	20.38	31.27	8.06	26.83	45.34	37.37	48.51	50.04													
SAAR	673	757	1012	721	1485	1004	721	1294	717	1276	924	968													
FPEXT	0.047	0.031	0.015	0.016	0.003	0.015	0.237	0.026	0.033	0.024	0.025	0.037													
FARL	1	1	1	1	0.978	1	1	0.866	1	1	0.994	1													
URBEXT 2000	0	0	0.004	0.007	1E-04	0.004	0.008	0.01	0.001	0.011	0.015	0.003													
BFIHOST	0.954	0.959	0.811	0.949	0.539	0.889	0.887	0.736	0.766	0.591	0.696	0.931													
SPRHOST	6.39	5.67	19.55	6.51	29.75	12.27	17.77	8.59	22.35	30.81	26.49	8.34													
LCV		0.26	0.39	0.21	0.38	0.40	0.20	0.18	0.34	0.17	0.25	0.38													
Lskew		0.20	0.33	0.07	0.33	0.29	-0.02	0.18	0.37	0.14	0.22	0.22													
Years		13	33	13	31	19	32	44	50	43	30	21													
Qmed		0.1	0.4	0.7	8.4	2.5	0.8	4.2	0.4	5.9	14.6	1.9													
Permeable catchment?	PERMEABLE	PERMEABLE	PERMEABLE	PERMEABLE		PERMEABLE	PERMEABLE	PERMEABLE				PERMEABLE													

Hydrological year	Imported flow record (m3/s)																								
1941																									
1942																									
1943																									
1944																									
1945																									
1946																									
1947																									
1948																									
1949																									
1950																									
1951																									
1952																									
1953																									
1954																									
1955																									
1956																									

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Job Title: Permeable catchment calculation template

Calculation: Permeable catchment adjustments to growth curve - Inputs

Made by: LRJB | Date: 20/05/2011 | Chd.

1957											
1958											
1959											
1960											
1961											
1962								0.28			
1963								0.29			
1964								0.09			
1965								0.39			
1966								0.57		14.90	
1967								0.42		15.53	
1968							4.31	0.51		10.02	
1969							4.53	0.26	5.77	12.21	
1970							3.29	0.46	5.14	11.09	
1971							2.89	0.31	5.92	10.02	
1972							3.18	0.27	6.47	14.59	
1973				12.20			6.41	0.32	7.99	10.28	
1974		0.47		10.60			4.57	0.55	5.74	12.50	
1975		0.06		17.38			3.09	0.36	3.91	3.46	
1976		0.42		6.60			3.91	0.43	4.81	9.50	
1977		0.64		4.35			4.18	0.73	4.77	16.83	
1978		0.85		5.79			4.08	0.52	5.13	26.72	
1979		0.51					6.58	0.31	10.21	19.20	
1980		0.63				1.04	3.98	0.40	6.86		
1981		0.48				1.17	4.74	0.60	5.77		
1982		0.34				0.65	3.94	0.46	4.61		
1983		0.26				1.10	4.13	0.25	5.96		
1984		0.26				0.63	3.32	0.22	4.92		
1985		0.28		10.99		0.92	4.54	0.30	5.63		
1986				21.89		0.69	3.60	0.31	6.48		
1987				5.79		0.81	6.89	0.41	7.72		
1988				4.80		0.20	3.33	0.30	5.92		
1989						0.30	5.43	0.51	7.79		
1990						0.74	3.26	0.29	4.76		
1991		0.33		3.07		0.41	1.66	0.16	2.21		3.74
1992		0.33		13.73		0.53	5.21	0.44	9.14		2.82
1993		1.02		26.33	5.27	0.98	6.26	0.56	6.81		2.08
1994		0.94		17.17	5.27	0.73	4.65	0.72	8.98		2.90
1995		0.25		5.40	1.35	0.55	3.67	0.33	7.16		0.76
1996		0.13		12.97	1.16	0.57	3.03	0.21	5.41	7.51	0.50
1997	0.20	0.88		15.03	4.77	0.95	5.00	0.38	7.11	25.32	1.56
1998	0.11	0.41	0.64	19.90	4.77	1.32	5.94	0.60	10.47	13.72	4.06
1999		0.29	0.50	7.16	2.24	0.74	6.84	0.71	10.08	25.62	3.24
2000	0.26	0.95	1.01	40.80	9.78	0.84	7.96	1.13	10.58	27.10	4.16
2001		0.18		18.94	1.61	0.68	4.29	0.57	6.87	10.01	1.27
2002	0.15	1.99	0.89	4.39	6.12	1.06	8.39	0.74	8.91	25.95	2.82
2003	0.13	0.30	0.68	4.61	1.33	1.27	4.06	0.39	4.93	16.82	0.83
2004	0.08	0.12	0.33	3.09	0.78	0.72	2.27	0.13	3.44	8.84	0.65
2005	0.10	0.18	0.89	6.21	0.98	0.65	3.10	0.13	4.92	12.98	0.78
2006	0.07	0.54	1.21	5.92	3.63	1.16	5.40	2.93	8.58	17.86	1.85
2007	0.14	0.45	1.13	8.35	3.04	1.27	3.57	0.61	5.60	21.71	2.42
2008	0.07	0.60	0.53	12.71	2.46	0.87	4.85	0.52	7.07	14.68	6.67
2009	0.14	0.60	1.16	5.43	3.15	1.10	3.21	0.49	4.48	14.74	1.49
2010	0.04	0.17	0.58	4.64	0.95	1.12	3.39	0.17	4.61	11.23	0.48
2011	0.11	1.45	0.61	21.53	1.69	0.82	5.14	0.15	6.02	37.37	1.91
2012											
2013											
2014											
2015											

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Subject site name:	Norton catchment - upstream

>>> Step 1 - press [Calculate permeable adjustment] button to right>>>

Calculate permeable adjustment

>>> Step 2 - select approach to urban adjustment of growth curve
(select Option 3 as default)

Urban adjustment method	3)	Kjeldsen (2009)

Pooling Group: Before permeable adjustment

Pooled L-CV	0.290
Pooled L Skew	0.217
NUMBER OF YEARS OF RECORD:	329

	Subject Site	Pooling Group																							
Rank	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
Station Number		26802	44008	26803	51002	44013	27073	48007	39033	47009	44003	43806														
Distance SDM	0	0.95	1.51	1.94	2.03	2.04	2.13	2.24	2.38	2.45	2.55	2.61														
LCV		0.261	0.395	0.215	0.382	0.401	0.197	0.180	0.336	0.171	0.253	0.383														
Lskew		0.199	0.332	0.069	0.326	0.289	-0.022	0.185	0.369	0.144	0.221	0.222														
Years of Record		13	33	13	31	19	32	44	50	43	30	21														
Qmed		0.11	0.42	0.68	8.35	2.46	0.81	4.15	0.39	5.92	14.64	1.91														

Generalised Logistic Growth curve adjustment for urbanisation at Subject Site - with no adjustment for permeable record

Notes: - urban adjustment only applicable for 2 years < Tr < 1,000years.
- permeable adjustment is only documented for the Generalised Logistic Distribution

Year of interest:	2011

SPRHOST	6.39	(%)	(copied from inputs)
$URBEXT_{2000}$	0.00	(fraction)	(copied from inputs)
$URBEXT_{adj}$	0.00	(fraction)	(calculated from $URBEXT_{2000}$ and year of assessment, this page)
UAF	1.00	(factor)	(calculated from URBEXT and PRUAF, this page)
PRUAF	1.00	(factor)	(calculated from SPRHOST and URBEXT, this page)

$L\text{-}CV_{URBAN}$	0.2895	$= L\text{-}CV \cdot 0.5547^{URBEXT}$
$L\text{-}SKEW_{URBAN}$	0.2169	$= [(L\text{-}SKEW + 1) \cdot 1.1545^{URBEXT}] - 1$
k_{URBAN}	-0.2169	$= -L\text{-}SKEW$
β_{URBAN}	0.2977	$= \dfrac{LCV.k.\sin(\pi.k)}{k.\pi.(k+LCV) - LCV.\sin(\pi.k)}$

Q / Qmed (rural) $= 1 + b/k.(1-(T-1)^{-k})$

Q / Qmed (urban) $= Tr.UAF^{-[(LN(Tr)-LN(2)) / (LN(1000)-LN(2))]}$ (method 1)

$= 1 + [(Tr-1)^{*}(z_{1000}/UAF-1) / (z_{1000}-1)]$ (method 2)

z_{1000} =	5.8

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$= \quad 1 + \beta_{URBAN}/k_{URBAN}.(1-(T-1)^{-k_{URBAN}})$ (method 3)

Flood Frequency Curves (before permeability adjustment)

Return period (years)	Annual Exceedence probability (%)
1.5	66.667
2	50.000
2.33	42.918
5	20.000
10	10.000
25	4.000
30	3.333
50	2.000
75	1.333
100	1.000
200	0.500
500	0.200
1000	0.100

Q / Qmed ('z')	
Before urban adjustment	After urban adjustment
0.808	0.81
1.000	1.00
1.088	1.09
1.481	1.48
1.838	1.84
2.362	2.36
2.476	2.48
2.820	2.82
3.118	3.12
3.346	3.35
3.953	3.95
4.908	4.91
5.766	5.77

L-Moments based on Flood Years

For sites denoted as permeable (SPRHOST>20%), the non-flood years (where Q<Qmed/2) have been removed from the flow record. The L- Moments have been recalculated on the basis of the flood years only.

	Subject Site	Pooling Group																								
Rank	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
Station Number		26802	44008	26803	51002	44013	27073	48007	39033	47009	44003	43806														
Flood Years		12	27	12		15	30	43				15														
LCV'		0.23	0.33	0.19		0.34	0.17	0.17				0.27														
Lskew'		0.26	0.38	0.11		0.24	0.05	0.22				0.26														
Qmed'		0.12	0.48	0.79		3.15	0.83	4.18				2.82														

Pooling Group: After permeable adjustment

The L-Moments have then been rescaled for the missing years using the approach from FEH chapter 19, equations 19.1 - 19.9.

Pooled L-CV	0.280
Pooled L Skew	0.226

Pooled k*	-0.226
Pooled β*	0.287

Number of Flood years:	308

	Subject Site	Pooling Group																								
Rank	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
Station Number		26802	44008	26803	51002	44013	27073	48007	39033	47009	44003	43806														
k*		-0.2	-0.4	-0.1	-0.3	-0.2	-0	-0.2	-0.4	-0.1	-0.2	-0.2														
β*		0.2	0.4	0.2	0.4	0.5	0.2	0.2	0.3	0.2	0.3	0.4														
LCV*		0.24	0.37	0.20	0.38	0.42	0.18	0.17	0.34	0.17	0.25	0.35														

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Lskew*												
		0.25	0.36	0.10	0.32	0.21	0.04	0.22	0.37	0.14	0.22	0.21

Generalised Logistic Growth curve adjustment for urbanisation at Subject Site

Notes: urban adjustment only applicable for 2 years < Tr < 1,000years.

permeable adjustment is only documented for the Generalised Logistic Distribution

$L\text{-}CV_{URBAN}$	0.2804	$= L\text{-}CV*0.5547^{URBEXT}$
$L\text{-}SKEW_{URBAN}$	0.2264	$= [(L\text{-}SKEW + 1) * 1.1545^{URBEXT}] -1$
k_{URBAN}	-0.2264	$= -L\text{-}SKEW$
β_{URBAN}	0.2865	$= \frac{LCV.k.\sin(\pi.k)}{k.\pi.(k+LCV) - LCV.\sin(\pi.k)}$

Q / Qmed $= 1 + \beta/k.(1-(T-1)^{-k})$

Q / Qmed (URBAN) $= Tr.UAF^{-[(LN(Tr)-LN(2)) / (LN(1000)-LN(2))]}$ (method 1)

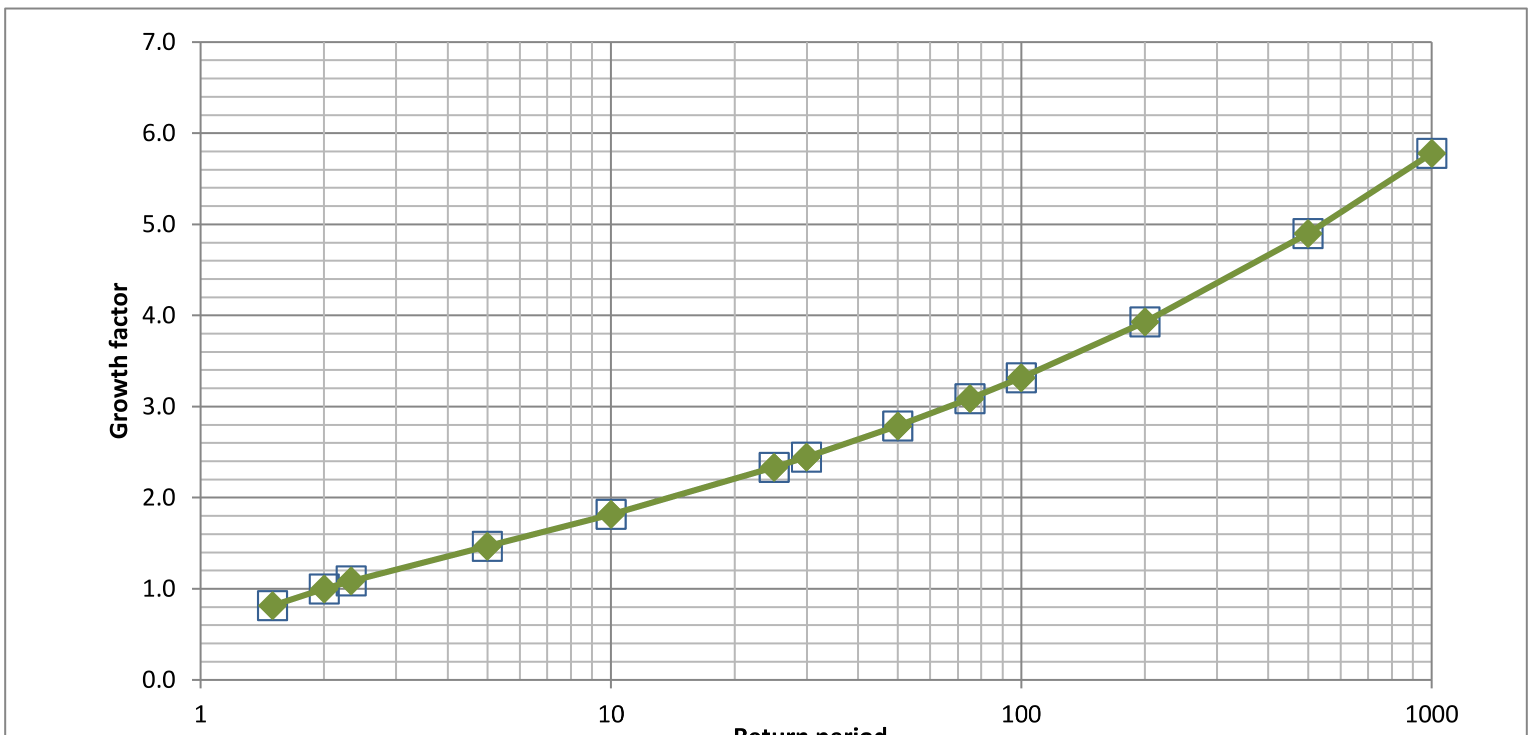
$= 1 + [(Tr-1)*(z_{1000}/UAF-1) / (z_{1000}-1)]$ (method 2)

$= 1 + \beta_{URBAN}/k_{URBAN}.(1-(T-1)^{-k_{URBAN}})$ (method 3)

z_{1000} = 5.8

Flood Frequency Curves:

Return period (years)	Annual Exceedence probability (%)	Permeability adjusted growth curve Q / Qmed ('z'): Before urban adjustment	Permeability adjusted growth curve Q / Qmed ('z'): After urban adjustment	Permeability adjustment ratios $z_{(adjusted)} / z_{(unadjusted)}$: Before urban adjustment	Permeability adjustment ratios $z_{(adjusted)} / z_{(unadjusted)}$: After urban adjustment
1.5	66.667	0.8	0.82	1.0	1.01
2	50.000	1.0	1.00	1.0	1.00
2.33	42.918	1.1	1.08	1.0	1.00
5	20.000	1.5	1.47	1.0	0.99
10	10.000	1.8	1.82	1.0	0.99
25	4.000	2.3	2.33	1.0	0.99
30	3.333	2.4	2.45	1.0	0.99
50	2.000	2.8	2.79	1.0	0.99
75	1.333	3.1	3.09	1.0	0.99
100	1.000	3.3	3.32	1.0	0.99
200	0.500	3.9	3.93	1.0	0.99
500	0.200	4.9	4.90	1.0	1.00
1000	0.100	5.8	5.78	1.0	1.00



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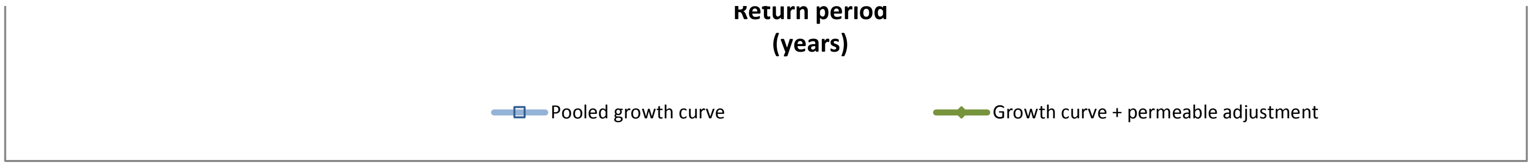
Calculation: Permeable catchment adjustments to growth curve - Outputs	Made: LRJB	Date: 20/05/2011	Chd



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Job Title: Permeable catchment calculation template	Drg. Ref.		
Calculation: Permeable catchment adjustments to growth curve - Inputs	Made by LRJB	Date 20/05/2011	Chd.

Subject site name: Norton - sites of SPR<30%

PLEASE NOTE, BECAUSE OF STEP 4, USERS SHOULD ALWAYS START FROM THE ORIGINAL TEMPLATE

>>>Step 1: reference the filepath to wherever WinFAP-FEH data is stored on your computer:

File path: H:\WINFAP-FEH_v3.3.4\Suitable for Pooling\

>>>Step 2: select whether subject site is gauged or not in the drop-down selector below
If the subject site is gauged, but should not be included in the pooling group, select "Ungauged"

Subject Site: Ungauged

>>>Step 3: insert pooling group station numbers into table below, then click on **import** button >>>
(allow macro about a minute to complete its task)
WARNING - STROBE EFFECTS

Import

>>> Step 4: you will need to insert below any flow data pre-dating 1900 (consult [AM] to see where this may be the case)

>>> Step 5: Check total number of years of record, Pooled L-CV and Pooled L-Skew to confirm that data matches WinFAP pooling group

>>> Step 6: if subject site is ungauged, you willl need to fill in the SDM values yourself, either by copying across from WinFAP pooling group table, or by inputting catchment data for Area, SAAR,FPEXT, FARL and SPRHOST.

>>>Step 7: now go to [Outputs]

Data from FEH

TOTAL NUMBER OF YEARS OF RECORD:	415

Pooled L-CV	0.288
Pooled L-Skew	0.167

	Subject Site	WinFAP-FEH Pooling group																							
0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
Station Number		27073	26802	33054	44008	33032	26803	26003	44013	36007	39033	48007	51002												
Distance SDM		0.57468	2.01773	2.35029	2.42091	2.5232	2.60877	2.64069	2.70117	2.76591	2.78199	2.81875	2.8681												
AREA	10.62	8.06	15.85	48.51	20.17	56.18	32.43	59.4	31.27	58.16	45.34	26.83	20.38												
SAAR	660	721	757	686	1012	688	721	698	1004	560	717	1294	1485												
FPEXT	0.2023	0.237	0.031	0.118	0.015	0.116	0.016	0.106	0.015	0.079	0.033	0.026	0.003												
FARL	1	1	1	0.944	1	0.983	1	0.987	1	0.996	1	0.866	0.978												
URBEXT 2000	0.057	0.008	0	0.005	0.004	0.006	0.007	0.004	0.004	0.004	0.001	0.01	1E-04												
BFIHOST	0.906	0.887	0.959	0.906	0.811	0.968	0.949	0.88	0.889	0.523	0.766	0.736	0.539												
SPRHOST	11.6	17.77	5.67	9.73	19.55	6.01	6.51	10.32	12.27	36.21	22.35	8.59	29.75												
LCV		0.20	0.26	0.21	0.39	0.32	0.21	0.24	0.40	0.38	0.34	0.18	0.38												
Lskew		-0.02	0.20	0.07	0.33	0.10	0.07	-0.01	0.29	0.13	0.37	0.18	0.33												
Years		32	13	36	33	44	13	52	19	48	50	44	31												
Qmed		0.8	0.1	1.1	0.4	0.5	0.7	1.7	2.5	4.6	0.4	4.2	8.4												
Permeable catchment?	PERMEABLE	PERMEABLE	PERMEABLE	PERMEABLE	PERMEABLE	PERMEABLE	PERMEABLE	PERMEABLE	PERMEABLE			PERMEABLE													

Hydrological year	Imported flow record (m3/s)																								
1941																									
1942																									
1943																									
1944																									
1945																									
1946																									
1947																									
1948																									
1949																									
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1956																									
1957																									

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Job Title: Permeable catchment calculation template

Calculation: Permeable catchment adjustments to growth curve - Inputs

Made by: LRJB Date: 20/05/2011 Chd.

1958													
1959								2.38					
1960								2.86					
1961								2.09					
1962								2.09			0.28		
1963								1.42			0.29		
1964								0.54		0.44	0.09		
1965								2.77		3.56	0.39		
1966						0.41		1.76		2.06	0.57		
1967						0.74		1.02		5.34	0.42		
1968						0.74		2.91		8.63	0.51	4.31	
1969						0.83		2.38		3.56	0.26	4.53	
1970						0.38		1.19		4.17	0.46	3.29	
1971						0.28		1.25		5.45	0.31	2.89	
1972						0.16		0.37		0.14	0.27	3.18	
1973						0.18		0.84		1.36	0.32	6.41	12.20
1974					0.47	0.57				8.77	0.55	4.57	10.60
1975					0.06	0.16		1.27		0.42	0.36	3.09	17.38
1976				2.14	0.42	0.96		2.95		3.99	0.43	3.91	6.60
1977				1.16	0.64	0.45		1.92		3.65	0.73	4.18	4.35
1978				2.14	0.85	1.11		2.54		11.02	0.52	4.08	5.79
1979				1.13	0.51	1.20		2.71		4.63	0.31	6.58	
1980		1.04		2.07	0.63	0.82		2.70		5.41	0.40	3.98	
1981		1.17		0.99	0.48	0.31		1.23		9.44	0.60	4.74	
1982		0.65		1.54	0.34	0.71		1.61		9.11	0.46	3.94	
1983		1.10		0.99	0.26	0.42		2.19		8.22	0.25	4.13	
1984		0.63		0.97	0.26	0.50		1.69		4.42	0.22	3.32	
1985		0.92		0.95	0.28	0.42		1.95		2.12	0.30	4.54	10.99
1986		0.69		0.97		0.43		1.55		7.66	0.31	3.60	21.89
1987		0.81		1.45		0.87		1.79		12.27	0.41	6.89	5.79
1988		0.20		0.62		0.22		0.42		7.49	0.30	3.33	4.80
1989		0.30		0.57		0.14		0.45		9.72	0.51	5.43	
1990		0.74		0.40		0.13		1.27		0.41	0.29	3.26	
1991		0.41		0.36	0.33	0.08		0.27		0.89	0.16	1.66	3.07
1992		0.53		0.84	0.33			1.14		4.63	0.44	5.21	13.73
1993		0.98		1.87	1.02			2.68	5.27	7.27	0.56	6.26	26.33
1994		0.73		1.24	0.94	0.74		1.66	5.27	4.78	0.72	4.65	17.17
1995		0.55		1.23	0.25	0.18		1.22	1.35	1.88	0.33	3.67	5.40
1996		0.57		1.13	0.13	0.19		0.91	1.16	0.20	0.21	3.03	12.97
1997		0.95	0.20	1.39	0.88	0.59		1.72	4.77	3.30	0.38	5.00	15.03
1998		1.32	0.11	1.36	0.41	0.80	0.64	2.22	4.77	3.41	0.60	5.94	19.90
1999		0.74		1.10	0.29	0.47	0.50	1.71	2.24	5.70	0.71	6.84	7.16
2000		0.84	0.26	1.67	0.95	0.77	1.01	2.94	9.78	12.02	1.13	7.96	40.80
2001		0.68		1.13	0.18	0.53		1.87	1.61	15.33	0.57	4.29	18.94
2002		1.06	0.15	1.53	1.99	0.74	0.89	2.78	6.12	11.50	0.74	8.39	4.39
2003		1.27	0.13	1.49	0.30	0.54	0.68	1.81	1.33	3.56	0.39	4.06	4.61
2004		0.72	0.08	1.06	0.12	0.41	0.33	1.36	0.78	4.63	0.13	2.27	3.09
2005		0.65	0.10	0.58	0.18	0.22	0.89	1.55	0.98	0.79	0.13	3.10	6.21
2006		1.16	0.07	1.90	0.54	0.73	1.21	2.20	3.63	3.73	2.93	5.40	5.92
2007		1.27	0.14	1.12	0.45	0.45	1.13	3.21	3.04	7.02	0.61	3.57	8.35
2008		0.87	0.07	1.01	0.60	0.96	0.53	2.02	2.46	10.70	0.52	4.85	12.71
2009		1.10	0.14	1.41	0.60	0.57	1.16	2.56	3.15	5.76	0.49	3.21	5.43
2010		1.12	0.04	0.87	0.17	0.31	0.58	1.58	0.95	3.82	0.17	3.39	4.64
2011		0.82	0.11	1.60	1.45	0.34	0.61	1.33	1.69	7.37	0.15	5.14	21.53
2012													
2013													
2014													
2015													

ARUP	Job	Sheet No.	Rev
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	Member/Location		
Job Title: Permeable catchment calculation template	Drg.		
Calculation: Permeable catchment adjustments to growth curve - Outputs	Made: LRJB	Date: 20/05/2011	Chd

Subject site name:	Norton - sites of SPR<30%

>>> Step 1 - press [Calculate permeable adjustment] button to right>>>

Calculate permeable adjustment

>>> Step 2 - select approach to urban adjustment of growth curve
(select Option 3 as default)

Urban adjustment method	3)	Kjeldsen (2009)

Pooling Group: Before permeable adjustment

Pooled L-CV	0.288
Pooled L Skew	0.167
NUMBER OF YEARS OF RECORD:	415

	Subject Site	Pooling Group																								
Rank	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
Station Number		27073	26802	33054	44008	33032	26803	26003	44013	36007	39033	48007	51002													
Distance SDM	0	0.57	2.02	2.35	2.42	2.52	2.61	2.64	2.70	2.77	2.78	2.82	2.87													
LCV		0.197	0.261	0.214	0.395	0.315	0.215	0.243	0.401	0.384	0.336	0.180	0.382													
Lskew		-0.022	0.199	0.069	0.332	0.099	0.069	-0.015	0.289	0.129	0.369	0.185	0.326													
Years of Record		32	13	36	33	44	13	52	19	48	50	44	31													
Qmed		0.81	0.11	1.13	0.42	0.46	0.68	1.74	2.46	4.63	0.39	4.15	8.35													

Generalised Logistic Growth curve adjustment for urbanisation at Subject Site - with no adjustment for permeable record

Notes: - urban adjustment only applicable for 2 years < Tr < 1,000years.
- permeable adjustment is only documented for the Generalised Logistic Distribution

Year of interest:	2015

SPRHOST	11.60	(%)	(copied from inputs)
$URBEXT_{2000}$	0.06	(fraction)	(copied from inputs)
$URBEXT_{adj}$	0.06	(fraction)	(calculated from $URBEXT_{2000}$ and year of assessment, this page)
UAF	1.35	(factor)	(calculated from URBEXT and PRUAF, this page)
PRUAF	1.14	(factor)	(calculated from SPRHOST and URBEXT, this page)

$L\text{-}CV_{URBAN}$	0.2782	$= L\text{-}CV \cdot 0.5547^{URBEXT}$
$L\text{-}SKEW_{URBAN}$	0.1770	$= [(L\text{-}SKEW + 1) \cdot 1.1545^{URBEXT}] - 1$
k_{URBAN}	-0.1770	$= -L\text{-}SKEW$
β_{URBAN}	0.2870	$= \dfrac{LCV.k.\sin(\pi.k)}{k.\pi.(k+LCV) - LCV.\sin(\pi.k)}$

Q / Qmed (rural) $= 1 + b/k.(1-(T-1)^{-k})$

Q / Qmed (urban)

$= Tr.UAF^{-[(LN(Tr)-LN(2)) / (LN(1000)-LN(2))]}$ (method 1)

$= 1 + [(Tr-1)*(z_{1000}/UAF-1) / (z_{1000}-1)]$ (method 2)

$= 1 + \beta_{URBAN}/k_{URBAN}.(1-(T-1)^{-k_{URBAN}})$ (method 3)

z_{1000} =	5.0

Flood Frequency Curves (before permeability adjustment)

ARUP		Job	Sheet No.	Rev
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		Member/Location		
Job Title	Permeable catchment calculation template	Drg.		
Calculation	Permeable catchment adjustments to growth curve - Outputs	Made LRJB	Date 20/05/2011	Chd

Return period	Annual Exceedence probability	Q / Qmed ('z')	
		Before urban adjustment	After urban adjustment
(years)	(%)		
1.5	66.667	0.805	0.81
2	50.000	1.000	1.00
2.33	42.918	1.087	1.08
5	20.000	1.465	1.45
10	10.000	1.792	1.77
25	4.000	2.251	2.22
30	3.333	2.348	2.32
50	2.000	2.635	2.61
75	1.333	2.879	2.85
100	1.000	3.062	3.04
200	0.500	3.538	3.52
500	0.200	4.256	4.25
1000	0.100	4.876	4.88

L-Moments based on Flood Years

For sites denoted as permeable (SPRHOST>20%), the non-flood years (where Q<Qmed/2) have been removed from the flow record.
The L- Moments have been recalculated on the basis of the flood years only.

	Subject Site	Pooling Group																								
Rank	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
Station Number		27073	26802	33054	44008	33032	26803	26003	44013	36007	39033	48007	51002													
Flood Years		30	12	34	27	34	12	46	15			43														
LCV'		0.17	0.23	0.19	0.33	0.22	0.19	0.18	0.34			0.17														
Lskew'		0.05	0.26	0.13	0.38	0.14	0.11	0.08	0.24			0.22														
Qmed'		0.8	0.1	1.1	0.5	0.6	0.8	1.8	3.1			4.2														

Pooling Group: After permeable adjustment
The L-Moments have then been rescaled for the missing years using the approach from FEH chapter 19, equations 19.1 - 19.9.

Pooled L-CV	0.274	**Pooled k***	-0.187	Number of Flood years:	382
Pooled L Skew	0.187	**Pooled β***	0.282		

	Subject Site	Pooling Group																								
Rank	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
Station Number		27073	26802	33054	44008	33032	26803	26003	44013	36007	39033	48007	51002													
k*		-0	-0.2	-0.1	-0.4	-0.1	-0.1	-0.1	-0.2	-0.1	-0.4	-0.2	-0.3													
β*		0.2	0.2	0.2	0.4	0.3	0.2	0.2	0.5	0.4	0.3	0.2	0.4													
LCV*		0.18	0.24	0.20	0.37	0.28	0.20	0.21	0.42	0.38	0.34	0.17	0.38													
Lskew*		0.04	0.25	0.12	0.36	0.09	0.10	0.06	0.21	0.13	0.37	0.22	0.33													

Generalised Logistic Growth curve adjustment for urbanisation at Subject Site

Notes: urban adjustment only applicable for 2 years < Tr < 1,000years.

permeable adjustment is only documented for the Generalised Logistic Distribution

$L\text{-}CV_{URBAN}$	0.2650	$= L\text{-}CV*0.5547^{URBEXT}$

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	Member/Location		
Job Title: Permeable catchment calculation template	Drg.		
Calculation: Permeable catchment adjustments to growth curve - Outputs	Made: LRJB	Date: 20/05/2011	Chd

L-SKEW$_{URBAN}$	0.1971	= [(L-SKEW + 1) * 1.1545^{URBEXT}] -1
k$_{URBAN}$	-0.1971	= -L-SKEW
β$_{URBAN}$	0.2713	= $\frac{LCV.k.\sin(\pi.k)}{k.\pi.(k+LCV) - LCV.\sin(\pi.k)}$

Q / Qmed = $1 + \beta/k.(1-(T-1)^{-k})$

Q / Qmed (URBAN) = $Tr.UAF^{-[(LN(Tr)-LN(2)) / (LN(1000)-LN(2))]}$ (method 1)

= $1 + [(Tr-1)*(z_{1000}/UAF-1) / (z_{1000}-1)]$ (method 2)

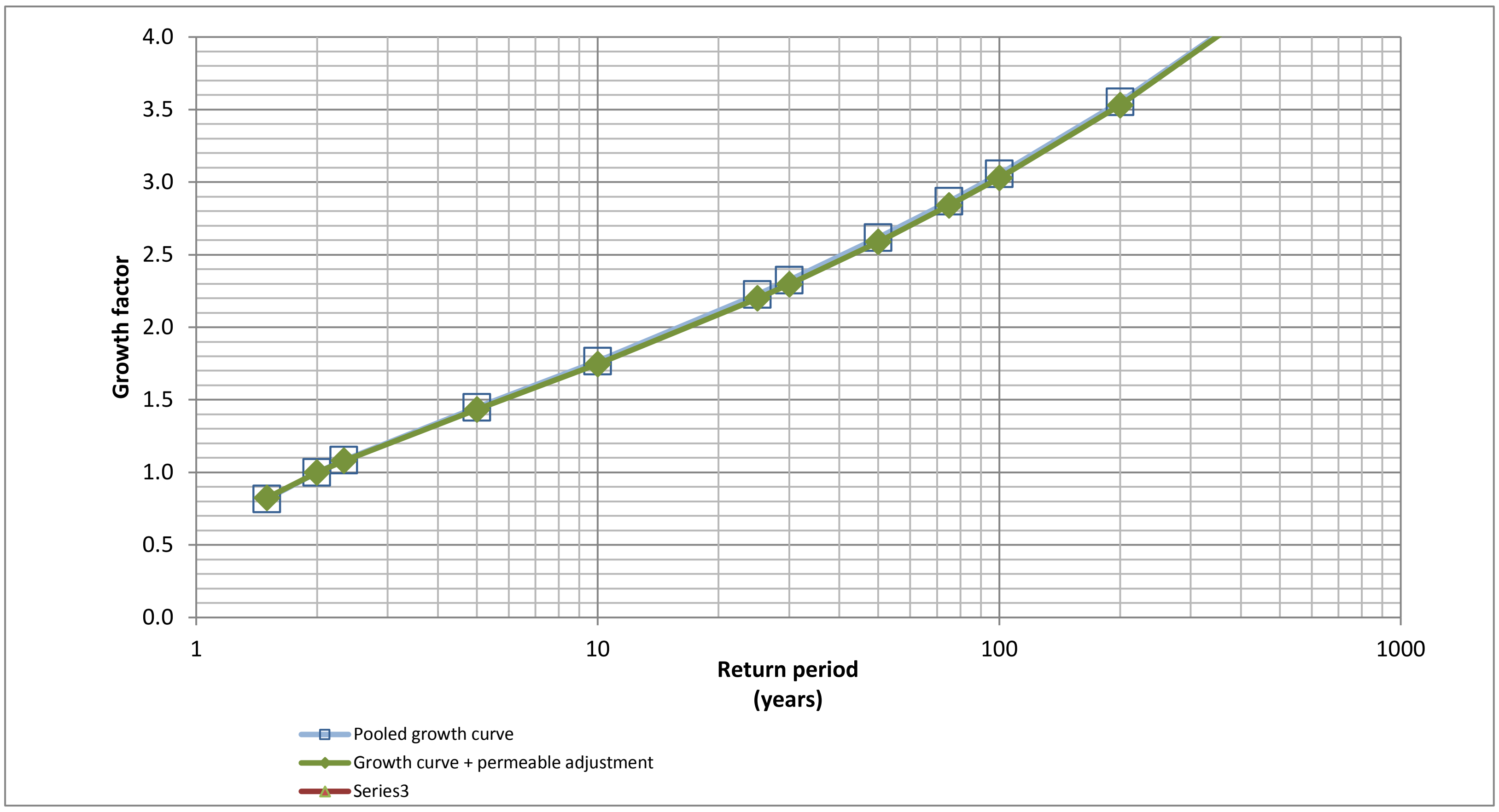
= $1 + \beta_{URBAN}/k_{URBAN}.(1-(T-1)^{-k_{URBAN}})$ (method 3)

z_{1000} =	5.0

Flood Frequency Curves:

Return period (years)	Annual Exceedence probability (%)	Permeability adjusted growth curve Q / Qmed ('z'): Before urban adjustment	After urban adjustment	Permeability adjustment ratios $z_{(adjusted)} / z_{(unadjusted)}$: Before urban adjustment	After urban adjustment
1.5	66.667	0.8	0.8242	1.01	1.014
2	50.000	1.0	1.0000	1.00	1.000
2.33	42.918	1.1	1.0796	1.00	0.996
5	20.000	1.4	1.4325	0.99	0.987
10	10.000	1.8	1.7460	0.99	0.986
25	4.000	2.2	2.1987	0.99	0.988
30	3.333	2.3	2.2966	0.99	0.989
50	2.000	2.6	2.5878	0.99	0.992
75	1.333	2.9	2.8387	1.00	0.995
100	1.000	3.1	3.0286	1.00	0.998
200	0.500	3.6	3.5310	1.00	1.004
500	0.200	4.3	4.3073	1.01	1.014
1000	0.100	5.0	4.9941	1.02	1.022

0



ARUP	Job No. 000000-00	Sheet No.	Rev.
	Member/Location		
Job Title: Permeable catchment calculation template	Drg. Ref.		
Calculation: Permeable catchment adjustments to growth curve - Inputs	Made by LRJB	Date 20/05/2011	Chd.

Subject site name: Costa Beck

PLEASE NOTE, BECAUSE OF STEP 4, USERS SHOULD ALWAYS START FROM THE ORIGINAL TEMPLATE

>>>Step 1: reference the filepath to wherever WinFAP-FEH data is stored on your computer:

File path: H:\WINFAP-FEH_v3.3.4\Not suitable for QMED or Pooling\

>>>Step 2: select whether subject site is gauged or not in the drop-down selector below
If the subject site is gauged, but should not be included in the pooling group, select "Ungauged"

Subject Site: Gauged

>>>Step 3: insert pooling group station numbers into table below, then click on **import** button >>>
(allow macro about a minute to complete its task)
WARNING - STROBE EFFECTS

Import

>>> Step 4: you will need to insert below any flow data pre-dating 1900 (consult [AM] to see where this may be the case)

>>> Step 5: Check total number of years of record, Pooled L-CV and Pooled L-Skew to confirm that data matches WinFAP pooling group

>>> Step 6: if subject site is ungauged, you willl need to fill in the SDM values yourself, either by copying across from WinFAP pooling group table, or by inputting catchment data for Area, SAAR,FPEXT, FARL and SPRHOST.

>>>Step 7: now go to [Outputs]

Data from FEH

TOTAL NUMBER OF YEARS OF RECORD:	0

Pooled L-CV	0.370
Pooled L-Skew	0.476

	Subject Site	WinFAP-FEH Pooling group																							
0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
Station Number	27038																								
Distance SDM	0																								
AREA	7.98																								
SAAR	722																								
FPEXT	0.1253																								
FARL	0.99																								
URBEXT 2000	0.022																								
BFIHOST	0.774																								
SPRHOST	10.72																								
LCV																									
Lskew																									
Years																									
Qmed																									
Permeable catchment?	PERMEABLE																								

Hydrological year	Imported flow record (m3/s)																								
1941																									
1942																									
1943																									
1944																									
1945																									
1946																									
1947																									
1948																									
1949																									
1950																									
1951																									
1952																									
1953																									
1954																									
1955																									
1956																									
1957																									

ARUP		Job No.	Sheet No.	Rev.
		000000-00		
		Member/Location		
Job Title	Permeable catchment calculation template	Drg. Ref.		
Calculation	Permeable catchment adjustments to growth curve - Inputs	Made by LRJB	Date 20/05/2011	Chd.

1958	
1959	
1960	
1961	
1962	
1963	
1964	
1965	
1966	
1967	
1968	
1969	
1970	0.93
1971	1.54
1972	1.17
1973	1.33
1974	1.31
1975	1.23
1976	1.29
1977	3.23
1978	1.74
1979	4.52
1980	1.43
1981	1.06
1982	1.06
1983	1.16
1984	0.94
1985	1.36
1986	0.96
1987	1.15
1988	0.75
1989	1.00
1990	2.50
1991	1.02
1992	4.84
1993	1.23
1994	0.97
1995	0.86
1996	0.93
1997	2.40
1998	2.32
1999	3.33
2000	5.95
2001	1.31
2002	1.40
2003	1.82
2004	1.42
2005	2.85
2006	5.03
2007	8.86
2008	2.71
2009	3.41
2010	1.54
2011	2.88
2012	
2013	
2014	
2015	

ARUP	Job: 000000-00	Sheet No.	Rev
	Member/Location		
Job Title: Permeable catchment calculation template	Drg.		
Calculation: Permeable catchment adjustments to growth curve - Outputs	Made: LRJB	Date: 20/05/2011	Chd

Subject site name:	Costa Beck

>>> Step 1 - press [Calculate permeable adjustment] button to right>>>

Calculate permeable adjustment

>>> Step 2 - select approach to urban adjustment of growth curve
(select Option 3 as default)

Urban adjustment method	3)	Kjeldsen (2009)

Pooling Group: Before permeable adjustment

Pooled L-CV	0.370
Pooled L Skew	0.476
NUMBER OF YEARS OF RECORD:	0

	Subject Site	Pooling Group																							
Rank	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Station Number																									
Distance SDM	0	1.00																							
LCV																									
Lskew																									
Years of Record																									
Qmed																									

Generalised Logistic Growth curve adjustment for urbanisation at Subject Site - with no adjustment for permeable record

Notes: - urban adjustment only applicable for 2 years < Tr < 1,000years.
- permeable adjustment is only documented for the Generalised Logistic Distribution

Year of interest:	2015

SPRHOST	10.72	(%)	(copied from inputs)
$URBEXT_{2000}$	0.02	(fraction)	(copied from inputs)
$URBEXT_{adj}$	0.02	(fraction)	(calculated from $URBEXT_{2000}$ and year of assessment, this page)
UAF	1.14	(factor)	(calculated from URBEXT and PRUAF, this page)
PRUAF	1.06	(factor)	(calculated from SPRHOST and URBEXT, this page)

$L\text{-}CV_{URBAN}$	0.3653	$= L\text{-}CV \cdot 0.5547^{URBEXT}$
$L\text{-}SKEW_{URBAN}$	0.4805	$= [(L\text{-}SKEW + 1) \cdot 1.1545^{URBEXT}] - 1$
k_{URBAN}	-0.4805	$= -L\text{-}SKEW$
β_{URBAN}	0.3253	$= \dfrac{LCV.k.\sin(\pi.k)}{k.\pi.(k+LCV) - LCV.\sin(\pi.k)}$

Q / Qmed (rural) $= 1 + b/k.(1-(T-1)^{-k})$

Q / Qmed (urban)

$= Tr.UAF^{-[(LN(Tr)-LN(2)) / (LN(1000)-LN(2))]}$ (method 1)

$= 1 + [(Tr-1)*(z_{1000}/UAF-1) / (z_{1000}-1)]$ (method 2)

$= 1 + \beta_{URBAN}/k_{URBAN}.(1-(T-1)^{-k_{URBAN}})$ (method 3)

z_{1000} =	17.0

ARUP	Job	Sheet No.	Rev
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	Member/Location		
Job Title: Permeable catchment calculation template	Drg.		
Calculation: Permeable catchment adjustments to growth curve - Outputs	Made: LRJB	Date: 20/05/2011	Chd

Flood Frequency Curves (before permeability adjustment)

Return period (years)	Annual Exceedence probability (%)
2	50.000
5	20.000
10	10.000
25	4.000
50	2.000
100	1.000
200	0.500
	#DIV/0!
	#DIV/0!
	#DIV/0!
	#DIV/0!
	#DIV/0!
	#DIV/0!

Q / Qmed ('z') Before urban adjustment	After urban adjustment
1.000	1.00
1.654	1.64
2.292	2.27
3.477	3.44
4.762	4.72
6.536	6.48
8.993	8.94
#NUM!	#NUM!
#NUM!	#NUM!
#NUM!	#NUM!
#NUM!	#NUM!
#NUM!	#NUM!
#NUM!	#NUM!

L-Moments based on Flood Years

For sites denoted as permeable (SPRHOST>20%), the non-flood years (where Q<Qmed/2) have been removed from the flow record.
The L- Moments have been recalculated on the basis of the flood years only.

	Subject Site	Pooling Group																						
Rank	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Station Number																									
Flood Years																									
LCV'	0.34																								
Lskew'	0.42																								
Qmed'																									

Pooling Group: After permeable adjustment
The L-Moments have then been rescaled for the missing years using the approach from FEH chapter 19, equations 19.1 - 19.9.

Pooled L-CV	0.416
Pooled L Skew	0.405

Pooled k*	-0.405
Pooled β*	0.420

Number of Flood years:	28

	Subject Site	Pooling Group																						
Rank	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Station Number																									
k*	-0.4																								
β*	0.4																								
LCV*	0.42																								
Lskew*	0.41																								

ARUP	Job	Sheet No.	Rev
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	Member/Location		
Job Title: Permeable catchment calculation template	Drg.		
Calculation: Permeable catchment adjustments to growth curve - Outputs	Made: LRJB	Date: 20/05/2011	Chd

Generalised Logistic Growth curve adjustment for urbanisation at Subject Site

Notes: urban adjustment only applicable for 2 years < Tr < 1,000years.

permeable adjustment is only documented for the Generalised Logistic Distribution

$L\text{-}CV_{URBAN}$	0.4106	$= L\text{-}CV*0.5547^{URBEXT}$
$L\text{-}SKEW_{URBAN}$	0.4097	$= [\,(L\text{-}SKEW + 1) * 1.1545^{URBEXT}\,] -1$
k_{URBAN}	-0.4097	$= -L\text{-}SKEW$
β_{URBAN}	0.4110	$= \dfrac{LCV.k.\sin(\pi.k)}{k.\pi.(k+LCV) - LCV.\sin(\pi.k)}$

Q / Qmed $= 1 + \beta/k.(1-(T-1)^{-k})$

Q / Qmed (URBAN) $= Tr.UAF^{-[\,(LN(Tr)-LN(2)) / (LN(1000)-LN(2))\,]}$ (method 1)

$= 1 + [\,(Tr-1)*(z_{1000}/UAF-1) / (z_{1000}-1)\,]$ (method 2)

$= 1 + \beta_{URBAN}/k_{URBAN}.(1-(T-1)^{-k_{URBAN}})$ (method 3)

$z_{1000} =$ 17.0

Flood Frequency Curves:

Return period (years)	Annual Exceedence probability (%)	Permeability adjusted growth curve Q / Qmed ('z'): Before urban adjustment	Permeability adjusted growth curve Q / Qmed ('z'): After urban adjustment	Permeability adjustment ratios $z_{(adjusted)} / z_{(unadjusted)}$: Before urban adjustment	Permeability adjustment ratios $z_{(adjusted)} / z_{(unadjusted)}$: After urban adjustment
2	50.000	1.00	1.00	1.00	1.00
5	20.000	1.78	1.77	1.08	1.08
10	10.000	2.49	2.46	1.09	1.09
25	4.000	3.72	3.69	1.07	1.07
50	2.000	4.98	4.94	1.05	1.05
100	1.000	6.63	6.59	1.01	1.02
200	0.500	8.81	8.77	0.98	0.98
0	#DIV/0!	#NUM!	#NUM!	#NUM!	#NUM!
0	#DIV/0!	#NUM!	#NUM!	#NUM!	#NUM!
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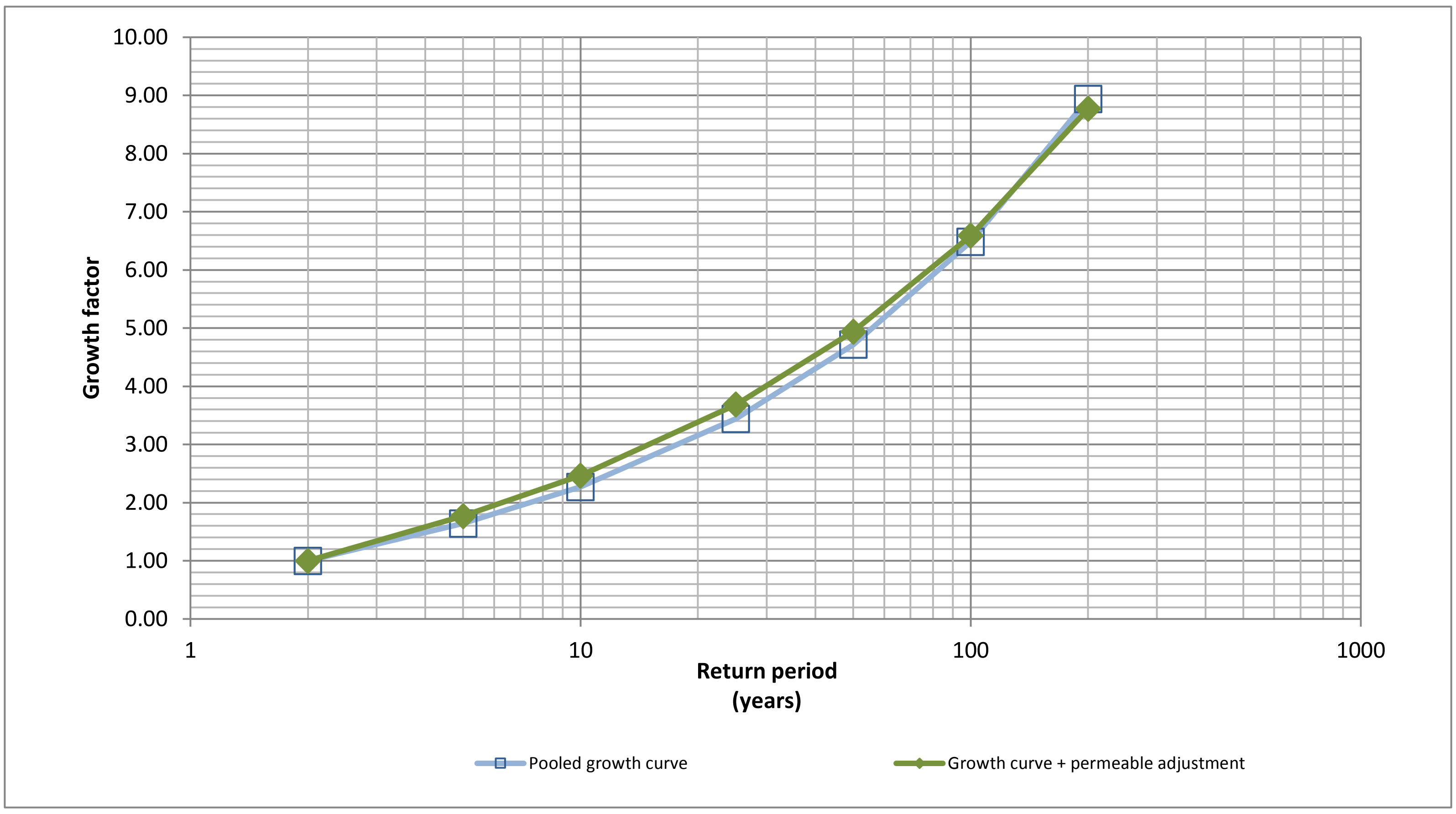

ARUP

Job No.	Sheet No.	Rev.
000000-00		

Member/Location

Drg. Ref.

Job Title Permeable catchment calculation template

Calculation Permeable catchment adjustments to growth curve - Inputs

Made by LRJB Date 20/05/2011 Chd.

Subject site name:	999200 Mill Beck at Norton

PLEASE NOTE, BECAUSE OF STEP 4, USERS SHOULD ALWAYS START FROM THE ORIGINAL TEMPLATE

>>>Step 1: reference the filepath to wherever WinFAP-FEH data is stored on your computer:

File path:	H:\WINFAP-FEH_v3.3.4\Suitable for Pooling\

>>>Step 2: select whether subject site is gauged or not in the drop-down selector below
If the subject site is gauged, but should not be included in the pooling group, select "Ungauged"

Subject Site:	Ungauged

>>>Step 3: insert pooling group station numbers into table below, then click on **import** button >>>
(allow macro about a minute to complete its task)
WARNING - STROBE EFFECTS

Import

>>> Step 4: you will need to insert below any flow data pre-dating 1900 (consult [AM] to see where this may be the case)

>>> Step 5: Check total number of years of record, Pooled L-CV and Pooled L-Skew to confirm that data matches WinFAP pooling group

>>> Step 6: if subject site is ungauged, you willl need to fill in the SDM values yourself, either by copying across from WinFAP pooling group table, or by inputting catchment data for Area, SAAR,FPEXT, FARL and SPRHOST.

>>>Step 7: now go to [Outputs]

Data from FEH

TOTAL NUMBER OF YEARS OF RECORD:	395

Pooled L-CV	0.253
Pooled L-Skew	0.125

	Subject Site	WinFAP-FEH Pooling group																							
0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
Station Number	999022	27073	20002	26802	25019	72014	73015	33054	44008	45816	33032	26803	76811	26003											
Distance SDM	0	0.56938	1.5266	2.02519	2.15515	2.25	2.31358	2.35343	2.42769	2.51323	2.5262	2.61503	2.63594	2.6439											
AREA	10.62	8.06	26.31	15.85	15.07	28.99	30.06	48.51	20.17	6.81	56.18	32.43	33.97	59.4											
SAAR	660	721	616	757	830	1183	1158	686	1012	1210	688	721	1428	698											
FPEXT	0.203	0.237	0.128	0.031	0.019	0.082	0.075	0.118	0.015	0.011	0.116	0.016	0.072	0.106											
FARL	1	1	0.996	1	1	0.975	0.976	0.944	1	1	0.983	1	0.999	0.987											
URBEXT 2000	0.057	0.008	0.002	0	0.004	0.006	0.003	0.005	0.004	0.005	0.006	0.007	0	0.004											
BFIHOST	0.906	0.887	0.471	0.959	0.525	0.443	0.486	0.906	0.811	0.59	0.968	0.949	0.457	0.88											
SPRHOST	11.2	17.77	32.18	5.67	38.58	35.96	35.79	9.73	19.55	31.27	6.01	6.51	36.34	10.32											
LCV		0.197	0.292	0.261	0.347	0.193	0.156	0.214	0.395	0.324	0.315	0.215	0.144	0.243											
Lskew		-0.022	0.015	0.199	0.394	0.059	0.001	0.069	0.332	0.434	0.099	0.069	0.047	-0.015											
Years		##	##	##	##	##	##	##	##	##	##	##	##	##											
Qmed		0.813	3.299	0.109	5.539	17.703	12.239	1.129	0.420	3.456	0.461	0.684	54.706	1.739											
Permeable catchment?	PERMEABLE	PERMEABLE		PERMEABLE				PERMEABLE	PERMEABLE		PERMEABLE	PERMEABLE		PERMEABLE											

ARUP	Job No.	Sheet No.	Rev.
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	Member/Location		
Job Title: Permeable catchment calculation template	Drg. Ref.		
Calculation: Permeable catchment adjustments to growth curve - Inputs	Made by LRJB	Date 20/05/2011	Chd.

Hydrological year	Imported flow record (m3/s)																							
1941																									
1942																									
1943																									
1944																									
1945																									
1946																									
1947																									
1948																									
1949																									
1950																									
1951																									
1952																									
1953																									
1954																									
1955																									
1956																									
1957																									
1958																									
1959														2.38											
1960														2.86											
1961														2.09											
1962														2.09											
1963														1.42											
1964														0.54											
1965			7.17											2.77											
1966			4.69			17.49					0.41			1.76											
1967			3.69			23.48					0.74			1.02											
1968			3.08			19.04					0.74			2.91											
1969			1.80			12.72					0.83			2.38											
1970			2.61			15.12					0.38			1.19											
1971			1.83		6.22	15.12					0.28			1.25											
1972			0.17		3.09	21.20					0.16			0.37											
1973			0.13		2.18	15.20					0.18			0.84											
1974			2.05		4.23	21.47			0.47		0.57														
1975			1.17		25.18	12.51			0.06		0.16			1.27											
1976			4.51		4.09	5.67		2.14	0.42		0.96			2.95											
1977			2.79		6.34	25.69		1.16	0.64		0.45			1.92											
1978			3.30		7.17	13.10		2.14	0.85		1.11			2.54											
1979			3.73		6.58	13.91		1.13	0.51		1.20			2.71											
1980		1.04	2.75		7.28	24.77		2.07	0.63		0.82			2.70											
1981		1.17	5.86		3.63	14.85		0.99	0.48		0.31			1.23											
1982		0.65	3.77		7.54	11.67		1.54	0.34		0.71			1.61											
1983		1.10	3.81		7.64	27.41		0.99	0.26		0.42			2.19											
1984		0.63	4.86		3.99	15.93		0.97	0.26		0.50			1.69											
1985		0.92	4.68		9.36	12.20		0.95	0.28		0.42			1.95											
1986		0.69	2.08		15.50	21.83		0.97			0.43			1.55											
1987		0.81	3.53		3.49	14.92		1.45			0.87			1.79											
1988		0.20	0.35		1.14	21.27		0.62			0.22			0.42											
1989		0.30	0.47		3.55			0.57			0.14			0.45											
1990		0.74	4.09		3.99	10.70		0.40			0.13			1.27											
1991		0.41	5.67		3.98	13.22	9.49	0.36	0.33		0.08			0.27											
1992		0.53	4.36		15.97	19.15	9.43	0.84	0.33					1.14											
1993		0.98	3.85		6.09	13.74	10.23	1.87	1.02	2.38				2.68											
1994		0.73	1.92		4.99	25.19	12.33	1.24	0.94	4.02	0.74			1.66											
1995		0.55	2.79		4.30	6.26	5.31	1.23	0.25	1.64	0.18			1.22											
1996		0.57	3.30			16.96	7.69	1.13	0.13	5.79	0.19			0.91											
1997		0.95	2.68	0.20		11.17	8.28	1.39	0.88	3.23	0.59			1.72											
1998		1.32	4.26	0.11		23.06	12.76	1.36	0.41	11.66	0.80	0.64		2.22											
1999		0.74	3.49			17.70	13.64	1.10	0.29	3.93	0.47	0.50		1.71											
2000		0.84	3.59	0.26		24.84	12.14	1.67	0.95	7.87	0.77	1.01	44.81	2.94											
2001		0.68	2.06			18.34	13.48	1.13	0.18	3.62	0.53		76.62	1.87											
2002		1.06	5.83	0.15		10.21	7.59	1.53	1.99	3.02	0.74	0.89	30.34	2.78											
2003		1.27	2.59	0.13	7.45	30.08	14.39	1.49	0.30	2.73	0.54	0.68	52.50	1.81											
2004		0.72	1.76	0.08	18.88	22.53	13.01	1.06	0.12	2.04	0.41	0.33	78.75	1.36											
2005		0.65	1.64	0.10	4.92	20.23	12.24	0.58	0.18	3.79	0.22	0.89	59.05	1.55											
2006		1.16		0.07	9.52	12.53	10.32	1.90	0.54	2.83	0.73	1.21	52.69	2.20											
2007		1.27		0.14	4.87	18.07	14.63	1.12	0.45	10.20	0.45	1.13	47.82	3.21											
2008		0.87		0.07	8.70	28.32	16.87	1.01	0.60	3.46	0.96	0.53	42.35	2.02											
2009		1.10		0.14	10.33	20.21	9.45	1.41	0.60	2.44	0.57	1.16	56.72	2.56											
2010		1.12		0.04	3.85	31.40	17.99	0.87	0.17	2.15	0.31	0.58	57.45	1.58											
2011		0.82		0.11	4.87	20.64	12.42	1.60	1.45	4.56	0.34	0.61	64.19	1.33											
2012																									
2013																									
2014																									
2015																									

ARUP	Job	Sheet No.	Rev
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	Member/Location		
Job Title: Permeable catchment calculation template	Drg.		
Calculation: Permeable catchment adjustments to growth curve - Outputs	Made: LRJB	Date: 20/05/2011	Chd

Subject site name:	999200 Mill Beck at Norton

>>> Step 1 - press [Calculate permeable adjustment] button to right>>>

Calculate permeable adjustment

>>> Step 2 - select approach to urban adjustment of growth curve
(select Option 3 as default)

Urban adjustment method	3)	Kjeldsen (2009)

Pooling Group: Before permeable adjustment

Pooled L-CV	0.253
Pooled L Skew	0.125
NUMBER OF YEARS OF RECORD:	395

	Subject Site	Pooling Group																								
Rank	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
Station Number		27073	20002	26802	25019	72014	73015	33054	44008	45816	33032	26803	76811	26003												
Distance SDM	0	0.57	1.53	2.03	2.16	2.25	2.31	2.35	2.43	2.51	2.53	2.62	2.64	2.64												
LCV		0.197	0.292	0.261	0.347	0.193	0.156	0.214	0.395	0.324	0.315	0.215	0.144	0.243												
Lskew		-0.022	0.015	0.199	0.394	0.059	0.001	0.069	0.332	0.434	0.099	0.069	0.047	-0.015												
Years of Record		32	41	13	34	45	21	36	33	19	44	13	12	52												
Qmed		0.81	3.30	0.11	5.54	17.70	12.24	1.13	0.42	3.46	0.46	0.68	54.71	1.74												

ARUP	Job: 000000-00	Sheet No.	Rev
	Member/Location		
Job Title: Permeable catchment calculation template	Drg.		
Calculation: Permeable catchment adjustments to growth curve - Outputs	Made: LRJB	Date: 20/05/2011	Chd

Generalised Logistic Growth curve adjustment for urbanisation at Subject Site - with no adjustment for permeable record

Notes: - urban adjustment only applicable for 2 years < Tr < 1,000years.
- permeable adjustment is only documented for the Generalised Logistic Distribution

Year of interest:	2015

SPRHOST	11.20	(%)	(copied from inputs)
$URBEXT_{2000}$	0.06	(fraction)	(copied from inputs)
$URBEXT_{adj}$	0.06	(fraction)	(calculated from $URBEXT_{2000}$ and year of assessment, this page)
UAF	1.37	(factor)	(calculated from URBEXT and PRUAF, this page)
PRUAF	1.15	(factor)	(calculated from SPRHOST and URBEXT, this page)

$L\text{-}CV_{URBAN}$	0.2443	$= L\text{-}CV \cdot 0.5547^{URBEXT}$
$L\text{-}SKEW_{URBAN}$	0.1345	$= [(L\text{-}SKEW + 1) \cdot 1.1545^{URBEXT}] - 1$
k_{URBAN}	-0.1345	$= -L\text{-}SKEW$
β_{URBAN}	0.2505	$= \dfrac{LCV.k.\sin(\pi.k)}{k.\pi.(k+LCV) - LCV.\sin(\pi.k)}$

Q / Qmed (rural) $= 1 + b/k.(1-(T-1)^{-k})$

Q / Qmed (urban)

$= Tr.UAF^{-[(LN(Tr)-LN(2)) / (LN(1000)-LN(2))]}$ (method 1)

$= 1 + [(Tr-1)^*(z_{1000}/UAF-1) / (z_{1000}-1)]$ (method 2)

$= 1 + \beta_{URBAN}/k_{URBAN}.(1-(T-1)^{-k_{URBAN}})$ (method 3)

z_{1000} =	3.9

Flood Frequency Curves (before permeability adjustment)

Return period (years)	Annual Exceedence probability (%)	Q / Qmed ('z') Before urban adjustment	Q / Qmed ('z') After urban adjustment
2	50.000	1.000	1.00
5	20.000	1.393	1.38
10	10.000	1.657	1.64
25	4.000	2.014	1.99
50	2.000	2.303	2.28
100	1.000	2.613	2.59
200	0.500	2.950	2.93
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L-Moments based on Flood Years

For sites denoted as permeable (SPRHOST>20%), the non-flood years (where Q<Qmed/2) have been removed from the flow record.
The L- Moments have been recalculated on the basis of the flood years only.

	Subject Site	Pooling Group																							
Rank	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
Station Number		27073	20002	26802	25019	72014	73015	33054	44008	45816	33032	26803	76811	26003												
Flood Years		30		12				34	27		34	12		46												
LCV'		0.17		0.23				0.19	0.33		0.22	0.19		0.18												
Lskew'		0.05		0.26				0.13	0.38		0.14	0.11		0.08												
Qmed'		0.8		0.1				1.1	0.5		0.6	0.8		1.8												

Pooling Group: After permeable adjustment
The L-Moments have then been rescaled for the missing years using the approach from FEH chapter 19, equations 19.1 - 19.9.

Pooled L-CV	0.240
Pooled L Skew	0.146

Pooled k*	-0.146
Pooled β*	0.245

Number of Flood years:	367

	Subject Site	Pooling Group																							
Rank	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
Station Number		27073	20002	26802	25019	72014	73015	33054	44008	45816	33032	26803	76811	26003												
k*		-0	-0	-0.2	-0.4	-0.1	-0	-0.1	-0.4	-0.4	-0.1	-0.1	-0	-0.1												
β*		0.2	0.3	0.2	0.3	0.2	0.2	0.2	0.4	0.3	0.3	0.2	0.1	0.2												
LCV*		0.18	0.29	0.24	0.35	0.19	0.16	0.20	0.37	0.32	0.28	0.20	0.14	0.21												
Lskew*		0.04	0.01	0.25	0.39	0.06	0.00	0.12	0.36	0.43	0.09	0.10	0.05	0.06												

ARUP	Job	Sheet No.	Rev
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	Member/Location		
Job Title: Permeable catchment calculation template	Drg.		
Calculation: Permeable catchment adjustments to growth curve - Outputs	Made: LRJB	Date: 20/05/2011	Chd

Generalised Logistic Growth curve adjustment for urbanisation at Subject Site

Notes: urban adjustment only applicable for 2 years < Tr < 1,000years.

permeable adjustment is only documented for the Generalised Logistic Distribution

$L\text{-}CV_{URBAN}$	0.2316	= $L\text{-}CV{*}0.5547^{URBEXT}$
$L\text{-}SKEW_{URBAN}$	0.1562	= $[\,(L\text{-}SKEW + 1) * 1.1545^{URBEXT}\,] -1$
k_{URBAN}	-0.1562	= $-L\text{-}SKEW$
β_{URBAN}	0.2363	= $\dfrac{LCV.k.\sin(\pi.k)}{k.\pi.(k+LCV) - LCV.\sin(\pi.k)}$

Q / Qmed = $1 + \beta/k.(1-(T-1)^{-k})$

Q / Qmed (URBAN) = $Tr.UAF^{-[\,(LN(Tr)-LN(2))\,/\,(LN(1000)-LN(2))\,]}$ (method 1)

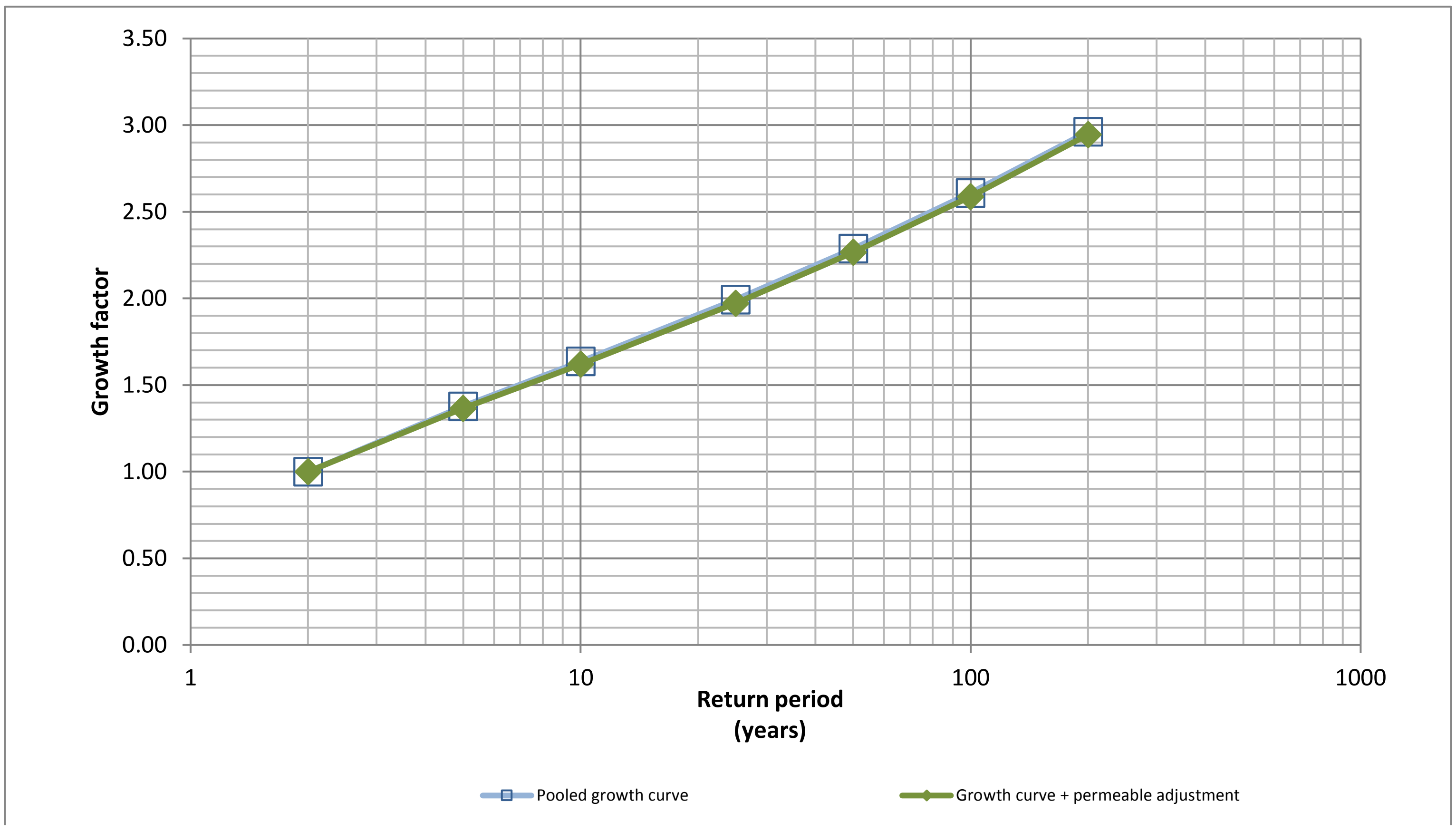
= $1 + [\,(Tr-1)*(z_{1000}/UAF-1)\,/\,(z_{1000}-1)\,]$ (method 2)

= $1 + \beta_{URBAN}/k_{URBAN}.(1-(T-1)^{-k_{URBAN}})$ (method 3)

z_{1000} =	3.9

Flood Frequency Curves:

Return period (years)	Annual Exceedence probability (%)	Permeability adjusted growth curve Q / Qmed ('z'): Before urban adjustment	After urban adjustment	Permeability adjustment ratios $z_{(adjusted)}$ / $z_{(unadjusted)}$: Before urban adjustment	After urban adjustment
2	50.000	1.00	1.00	1.00	1.00
5	20.000	1.38	1.37	0.99	0.99
10	10.000	1.64	1.62	0.99	0.99
25	4.000	1.99	1.97	0.99	0.99
50	2.000	2.29	2.27	0.99	0.99
100	1.000	2.61	2.59	1.00	1.00
200	0.500	2.96	2.95	1.00	1.00
0	#DIV/0!	#NUM!	#NUM!	#NUM!	#NUM!
0	#DIV/0!	#NUM!	#NUM!	#NUM!	#NUM!
0	#DIV/0!	#NUM!	#NUM!	#NUM!	#NUM!
0	#DIV/0!	#NUM!	#NUM!	#NUM!	#NUM!
0	#DIV/0!	#NUM!	#NUM!	#NUM!	#NUM!
0	#DIV/0!	#NUM!	#NUM!	#NUM!	#NUM!



ARUP	Job 000000-00	Sheet No.	Rev
	Member/Location		
Job Title: Permeable catchment calculation template	Drg.		
Calculation: Permeable catchment adjustments to growth curve - Outputs	Made: LRJB	Date: 20/05/2011	Chd

MODIFIED RATIONAL METHOD **Malton**

Design and analysis of urban storm drainage : The Wallingford procedure (1983)

Qp = CiA Pg 57, Eq 7.18

where Qp = Peak discharge (l/sec)
C = runoff coefficient dimensionless
i = average rainfall intensity during the time of concentration (mm/hr) (from FEH rainfall parameters)
A = Area (ha) of total catchment assessed (pervious and impervious)

and C = CvCr Eq 7.19

where where Cv is the volumetric runoff co-efficient and Cr is the routing co-efficient.
Cv is defined as the proportion of the rainfall on the catchment which appears as surface runoff in the system
This depends if the whole catchment, or just the impervious urban areas are being included.
if the whole catchment is being considered;

Cr = 1.3 Recommended value see pg 58
and Cv = PR/100 Eq 7.2

where PR = 0.829*PIMP+0.25*SOIL+0.078*UCWI-20.7 Eq 7.3
and PIMP is the Percentage of catchment area covered by impervious surfaces
SOIL = Soil Type (broadly analogous to Standard Percentage Runoff)
UCWI = Antecedent wetness condition (based on SAAR)

FEH rainfall parameters

c	d1	d2	d3	e	f
-0.023	0.33	0.354	0.243	0.293	2.402

	Total catchment (M4)	To pumping station	To combined system, leaving catchment	M2	M3	M1
A (ha)	36	2.15	22.6	0.921	0.964	11
Run off coefficient:						
PIMP	46.9	95.0	46.9	40.0	32.1	26.9
SOIL	0.089	0.089	0.089	0.089	0.089	0.089
SAAR	656	656	656	656	656	656
UCWI	96.08	96.08	96.08	96.08	96.08	96.08
PR =	28	68	28	22	16	11
Cv	0.28	0.68	0.28	0.22	0.16	0.11
Cr	1.3	1.3	1.3	1.3	1.3	2.3
C =	**0.36**	**0.88**	**0.36**	**0.29**	**0.20**	**0.26**
CA	13.07	1.89	8.20	0.27	0.20	2.86

Rainfall:																	
Duration (hrs)	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	1	2	5	8	12	24	48	72
Return period (years)	2	5	10	25	30	50	75	100	2	2	2	2	2	2	2	2	2
Reduced variate, y	0.37	1.50	2.25	3.20	3.38	3.90	4.31	4.60	0.37	0.37	0.37	0.37	0.37	0.37	0.37	0.37	0.37
R12	27.34	35.72	42.64	53.32	55.71	62.95	69.32	74.21	27.34	27.34	27.34	27.34	27.34	27.34	27.34	27.34	27.34
R48	44.15	55.63	64.83	78.66	81.70	90.80	98.69	104.69	44.15	44.15	44.15	44.15	44.15	44.15	44.15	44.15	44.15
Rainfall depth (mm)	9.8	14.0	17.6	23.6	25.0	29.3	33.3	36.4	9.8	12.3	15.4	20.6	24.0	27.3	34.7	44.1	48.6
Average intensity (mm/hr)	19.7	27.9	35.2	47.2	50.0	58.7	66.6	72.8	19.7	12.3	7.7	4.1	3.0	2.3	1.4	0.9	0.7
Areal Reduction factor	0.961	0.961	0.961	0.961	0.961	0.961	0.961	0.961	0.961	0.97	0.975	0.98	0.9825	0.986	0.9905	0.9925	0.9925
i	18.913	26.843	33.847	45.367	48.047	56.379	63.97	69.952	15.13	9.542786	5.993498	3.24	2.358049	1.797346	1.147113	0.730263	0.535419
Flow:																	
Qp (m3/s) M1 Total catchmt	0.247	0.351	0.443	0.593	0.628	0.737	0.836	0.915	0.198	0.125	0.078	0.042	0.031	0.023	0.015	0.010	0.007
Qp (m3/s) Towards combined syste	0.155	0.220	0.277	0.372	0.394	0.462	0.524	0.573	0.124	0.078	0.049	0.027	0.019	0.015	0.009	0.006	0.004
Combined system capacity, based on assumption of 30yr flow, 0.5hr design storm = 0.39m3/s																	
Combined system flow out	0.155	0.220	0.277	0.372	0.390	0.390	0.390	0.390	0.124	0.078	0.049	0.027	0.019	0.015	0.009	0.006	0.004
Qp (m3/s) To Yates Yard PS	0.036	0.051	0.064	0.086	0.091	0.107	0.121	0.133	0.029	0.018	0.011	0.006	0.004	0.003	0.002	0.001	0.001
Yates Yard flow out	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.006	0.004	0.003	0.002	0.001	0.001
M2	0.005	0.007	0.009	0.012	0.013	0.015	0.017	0.019	0.004	0.003	0.002	0.001	0.001	0.000	0.000	0.000	0.000
M3	0.004	0.005	0.007	0.009	0.009	0.011	0.013	0.014	0.003	0.002	0.001	0.001	0.000	0.000	0.000	0.000	0.000
Ground flow	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.03	0.025	0.025	0.025	0.025	0.025
Chandlers Wharf Out	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007
TOTAL IN (M4)	0.247	0.351	0.443	0.593	0.628	0.737	0.836	0.915	0.198	0.125	0.078	0.042	0.031	0.023	0.015	0.010	0.007
TOTAL OUT (M4)	0.162	0.227	0.284	0.379	0.397	0.397	0.397	0.397	0.131	0.085	0.056	0.033	0.024	0.018	0.012	0.007	0.005
Net inflow	0.085	0.124	0.158	0.214	0.231	0.340	0.439	0.518	0.067	0.040	0.022	0.010	0.007	0.005	0.003	0.002	0.002
TOTAL IN (M4 + M2, + M3)	0.281	0.388	0.483	0.639	0.675	0.788	0.891	0.972	0.230	0.154	0.106	0.069	0.057	0.049	0.041	0.035	0.032
TOTAL OUT (M4 + M2, + M3)	0.169	0.234	0.291	0.386	0.404	0.404	0.404	0.404	0.138	0.092	0.063	0.040	0.031	0.025	0.019	0.014	0.012
Net inflow	0.112	0.154	0.192	0.253	0.271	0.384	0.487	0.568	0.092	0.062	0.043	0.029	0.026	0.024	0.022	0.021	0.020
										223.024	309.6047	525	752.352	1045.083	1896.63	3545.115	5143.691

MODIFIED RATIONAL METHOD **Norton**

Design and analysis of urban storm drainage : The Wallingford procedure (1983)

Qp = CiA Pg 57, Eq 7.18

where Qp = Peak discharge (l/sec)
C = runoff coefficient dimensionless
i = average rainfall intensity during the time of concentration (mm/hr) (from FEH rainfall parameters)
A = Area (ha) of total catchment assessed (pervious and impervious)

and C = CvCr Eq 7.19

where where Cv is the volumetric runoff co-efficient and Cr is the routing co-efficient.
Cv is defined as the proportion of the rainfall on the catchment which appears as surface runoff in the system
This depends if the whole catchment, or just the impervious urban areas are being included.
if the whole catchment is being considered;

Cr = 1.3 Recommended value see pg 58
and Cv = PR/100 Eq 7.2

where PR = 0.829*PIMP+0.25*SOIL+0.078*UCWI-20.7 Eq 7.3
and PIMP is the Percentage of catchment area covered by impervious surfaces
SOIL = Soil Type (broadly analogous to Standard Percentage Runoff)
UCWI = Antecedent wetness condition (based on SAAR)

FEH rainfall parameters

c	d1	d2	d3	e	f
-0.023	0.33	0.354	0.243	0.293	2.402

	Total catchment	Total catchment	Total catchment	Total catchment													
A (ha)	231.6	42.4	42.4	42.4			8.3										
Run off coefficient:																	
PIMP	18.3	100.0	95.0	64.0													
SOIL	0.262	0.262	0.262	0.262													
SAAR	653	653	653	653													
UCWI	95.54	95.54	95.54	95.54													
PR =	8	76	72	46													
Cv	0.08	0.76	0.72	0.46													
Cr	1.3	1.3	1.3	1.3													
C =	**0.11**	**0.99**	**0.94**	**0.60**													
CA	25.529	42.003	39.718	25.553													
Rainfall:																	
Duration (hrs)	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9
Return period (years)	2	5	10	25	30	50	75	100	30	2	5	10	25	30	50	75	100
Reduced variate, y	0.37	1.50	2.25	3.20	3.38	3.90	4.31	4.60	3.38	0.37	1.50	2.25	3.20	3.38	3.90	4.31	4.60
R12	27.34	35.72	42.64	53.32	55.71	62.95	69.32	74.21	55.71	27.34	35.72	42.64	53.32	55.71	62.95	69.32	74.21
R48	44.15	55.63	64.83	78.66	81.70	90.80	98.69	104.69	81.70	44.15	55.63	64.83	78.66	81.70	90.80	98.69	104.69
Rainfall depth (mm)	18.4	24.8	30.3	38.9	40.8	46.8	52.2	56.3	40.8	15.1	20.7	25.5	33.2	35.0	40.4	45.3	49.1
Average intensity (mm/hr)	5.3	7.1	8.6	11.1	11.7	13.4	14.9	16.1	11.7	8.0	10.9	13.4	17.5	18.4	21.3	23.8	25.8
Areal Reduction factor	0.96	0.96	0.96	0.96	0.96	0.96	0.96	0.96	0.96	0.97	0.97	0.97	0.97	0.97	0.97	0.97	0.97
i	5.05	6.81	8.30	10.66	11.20	12.84	14.31	15.44	11.20	7.72	10.58	13.03	16.97	17.87	20.64	23.13	25.06
Qp	0.13	0.17	0.21	0.27	0.29	0.33	0.37	0.39	0.29	0.20	0.27	0.33	0.43	0.46	0.53	0.59	0.64
										0.324	0.444	0.548	0.713	0.751	0.867	0.971	1.053
						0.699											
						0.349											

MODIFIED RATIONAL METHOD **Old Malton**

Design and analysis of urban storm drainage : The Wallingford procedure (1983)

Qp = CiA Pg 57, Eq 7.18

where Qp = Peak discharge (l/sec)
C = runoff coefficient dimensionless
i = average rainfall intensity during the time of concentration (mm/hr) (from FEH rainfall parameters)
A = Area (ha) of total catchment assessed (pervious and impervious)

and C = CvCr Eq 7.19

where where Cv is the volumetric runoff co-efficient and Cr is the routing co-efficient.
Cv is defined as the proportion of the rainfall on the catchment which appears as surface runoff in the system
This depends if the whole catchment, or just the impervious urban areas are being included.
if the whole catchment is being considered;

Cr = 1.3 Recommended value see pg 58
and Cv = PR/100 Eq 7.2

where PR = 0.829*PIMP+0.25*SOIL+0.078*UCWI-20.7 Eq 7.3
and PIMP is the Percentage of catchment area covered by impervious surfaces
SOIL = Soil Type (broadly analogous to Standard Percentage Runoff)
UCWI = Antecedent wetness condition (based on SAAR)

FEH rainfall parameters

c	d1	d2	d3	e	f
-0.023	0.33	0.354	0.24	0.29	2.4

	Total catchment (OM9)	Total catchment (OM5)
A (ha)	17.6	16.5
Run off coefficient:		
PIMP	29.4	33.9
SOIL	0.12	0.17
SAAR	647	643
UCWI	94.46	93.74
PR =	14	19
Cv	0.14	0.19
Cr	1.3	1.3
C =	**0.18**	**0.25**
CA	3.22	4.07

Rainfall:

Duration (hrs)	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Return period (years)	2	5	10	15	20	25	30	50	75	100
Reduced variate, y	0.37	1.50	2.25	2.67	2.97	3.20	3.38	3.90	4.31	4.60
R12	27.34	35.72	42.64	47.12	50.53	53.32	55.71	62.95	69.32	74.21
R48	44.15	55.63	64.83	70.68	75.08	78.66	81.70	90.80	98.69	104.69
Rainfall depth (mm)	9.8	14.0	17.6	20.1	22.0	23.6	25.0	29.3	33.3	36.4
Average intensity (mm/hr)	19.7	27.9	35.2	40.1	44.0	47.2	50.0	58.7	66.6	72.8
Areal Reduction factor	0.961	0.961	0.96	0.96	0.96	0.96	0.96	0.96	0.96	0.96
i	18.913	26.843	33.8	38.6	42.3	45.4	48	56.4	64	70
Flow:										
Qp (m3/s)	0.061	0.109	####	####	####	####	####	####	####	####

Duration (hrs)	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5
Return period (years)	2	5	10	15	20	25	30	50	75	100
Reduced variate, y	0.37	1.50	2.25	2.67	2.97	3.20	3.38	3.90	4.31	4.60
R12	27.34	35.72	42.64	47.12	50.53	53.32	55.71	62.95	69.32	74.21
R48	44.15	55.63	64.83	70.68	75.08	78.66	81.70	90.80	98.69	104.69
Rainfall depth (mm)	18.4	24.8	30.3	33.8	36.6	38.9	40.8	46.8	52.2	56.3
Average intensity (mm/hr)	5.3	7.1	8.6	9.7	10.5	11.1	11.7	13.4	14.9	16.1
Areal Reduction factor	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98
i	5.13	6.91	8.43	9.43	10.2	10.8	11.4	13	14.5	15.7
Flow:										
Qp (m3/s)	####	####	####	####	####	####	####	####	####	####

Duration (hrs)	15.5	15.5	15.5	15.5	15.5	15.5	15.5	15.5	15.5	15.5
Return period (years)	2	5	10	15	20	25	30	50	75	100
Reduced variate, y	0.37	1.50	2.25	2.67	2.97	3.20	3.38	3.90	4.31	4.60
R12	27.34	35.72	42.64	47.12	50.53	53.32	55.71	62.95	69.32	74.21
R48	44.15	55.63	64.83	70.68	75.08	78.66	81.70	90.80	98.69	104.69
Rainfall depth (mm)	29.9	38.8	46.1	50.8	54.4	57.3	59.8	67.4	74.0	79.1
Average intensity (mm/hr)	1.9	2.5	3.0	3.3	3.5	3.7	3.9	4.3	4.8	5.1
Areal Reduction factor	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99
i	1.9	2.47	2.93	3.23	3.46	3.64	3.8	4.28	4.71	5.03
Flow:										
Qp (m3/s)	####	####	####	####	####	####	####	####	####	####

Appendix D

Hydrogeology

Subject Malton Initial Hydrogeology Desk Study

Date 4 July 2015 Job No/Ref

1 Topography

The topography of the study area is relatively flat to the north of Malton, between the River Rye and River Derwent, and to the northeast upstream on the River Derwent. The River Derwent in Malton is located at approximately 20mOD. The topography rises to the north of the river, up to 50mOD in the centre of Malton. The land rises to the west of Malton, towards the Howardian Hills. The A64 carriageway is located within a cutting to the north west of the town, natural ground level at the cutting is approximately 45 and 50mOD. The nearest hill is 123mOD, approximately 2km to the west of the A64. Norton, to the south of the river, is much flatter, with the built up area located predominately between 20 and 30mOD. The land then rises up beyond Norton to a topographic high of 90mOD at Langton Wold, approximately 3km to the south.

2 Rainfall

Rainfall data was provided by the Environment Agency (EA) for 4 tipping bucket rain gauges. The nearest rain gauge to Malton and Norton is located at Scampston Hall (SE 86375 75693, ground level c.30mOD), 8km to the northeast of Malton. The annual and monthly total rainfall, between 1961 and 2011, for this gauge is presented in Figure D1. This indicates that the annual average rainfall over this period was 641mm. The lowest rainfall over this period was recorded in the drought years of 1991 and 1995 (414 and 394mm respectively), whereas the highest rainfall was in 2000 (923mm), which corresponds to a severe flooding event in the town which included flooding from groundwater.

3 Geology

3.1 Superficial Geology

The British Geological Survey (BGS) 1:50,000 geological mapping indicates that superficial deposits are largely absent from the town of Malton (Figure D2) and the Howardian Hills to the west. Glacial Till (red-brown and grey, pebbly clay) laid down in the Mid-Pleistocene and overlying Lacustrine Deposits (clay and sand, locally with peat), deposited by the pro-glacial Lake Pickering, overlie the Vale of Pickering to the north and extend to the River Derwent upstream of Malton (Figure D3). Small strips of Lacustrine Deposits are also present along the northern bank of the River Derwent in Malton and running north-south through the town centre (Figure D2). The River Derwent itself was created by Lake Pickering as the level rose and overflowed southwards, cutting an exit between the Howardian Hills and Yorkshire Wolds at Kirkham Priory.

To the south of the river, including Norton, the superficial deposits are predominantly Sands and Gravels of uncertain age and origin. A thin strip of these deposits are also present along the northern edge of the Howardian Hills running from the A64 westwards through Broughton, Amotherby and Slingsby. Superficial Deposits are again absent from the higher ground to the south of Norton. Head deposits (clay, silt, sand and gravel) are present in a dry valley running to the south of Howe Hill on the Corallian outcrop to the south of Norton.

Alluvium (clay, silt sand and gravel, mainly clay) is present in the channels of the Rivers Derwent and Rye.

3.2 Bedrock Geology

The BGS 1:50,000 scale bedrock geology mapping is presented as Figure D4. The study area is located on Upper Jurassic strata. Malton and Norton are situated on the eastern portion of the Corallian Ridge, which runs between Gilling East (~17.5km to the WNW of Malton) to North Grimston (~5km to the southeast of Norton), forming the Howardian Hills. This ridge is near continuous, comprising a sequence of limestones and calcareous sandstones of the Corallian Group. Three formations make up the solid geology of the Corallian Ridge, namely the Upper Calcareous Grit, Coralline Oolite Formation and Lower Calcareous Grit, which are described in Wright (2009) [ref] as follows:

- **Upper Calcareous Grit:** largely argillaceous calcareous strata, namely the North Grimston Cementstone (9-15m thick).
- **Coralline Oolite Formation:** series of oolitic and fine-grained limestones with subordinate calcareous sandstones and sandy limestones (50-58m thick).
- **Lower Calcareous Grit:** succession of fine-grained, calcareous or specular, siliceous sandstones (40-50m thick).

The Corallian Group is underlain by the Oxford Clay Formation, also from the Upper Jurassic Period, which is described by the BGS as a slightly silty silicate-mudstone, with sporadic beds of argillaceous limestone nodules.

The towns of Malton and Old Malton are located on the Corallian Oolite Formation, which is up to 40m thick (Wright, 2009[1]) whereas to the south of the River Derwent, Norton is underlain by the Kimmeridge Clay Formation. The Kimmeridge Clay comprises mudstone and thin limestones up to 297m thick. The formation also dates from the Upper Jurrassic but is younger that the Corallian Group. The Kimmeridge clay also outcrops to the north of the Corallian Ridge in the Vale of Pickering.

3.3 BGS Borehole

The BGS online borehole database contains scanned records of boreholes drilled within the study area. A search of this database revealed that there are relatively few deep borehole records available for the area. In particular, there is no borehole log available for the EA groundwater monitoring well at Broughton, which is used by the EA to indicate groundwater flood risk in Malton. A summary of the most useful borehole logs in the area is provided in Table D1 below.

[1] Wright, J.K. 2009. The geology of the Corallian ridge (Upper Jurassic) between Gilling East and North Grimston, Howardian Hills, North Yorkshire. Proceedings of the Yorkshire Geological Society, Vol. 57, Parts 3 – 4, pp 193-216

Table D1 Summary of BGS Borehole Logs in the Malton and Norton area

Name/ Ref.	Location	Year	Depth (m)	Ground Level (mOD)	Geology	Rest Water Level (mOD)
Amotherby P.S. (SE77SE95)	475360 473150	1913	50.29	45.57	Corallian Group to 48.5mBGL Oxford Clay to base	14.6
Low Farm Swinton (SE77SE21)	476235 473925	1903	21.34	~25.00	Superficials to >3.7mBGL Kimmeridge Clay encountered at unknown depth.	No info
Malton By Pass 11 (SE77SE30/J)	477776 472427	1972	15.50	~48.00	Corallian Group proven to 14.5mBGL	No info
Malton (SE77SE97)	478810 471540	1939	61.72	~20.00	Made Ground to 1.8mBGL Superficial to 3.7mBGL Corallian Group proven to 61.8mBGL	~16.2
Old Brewery Malton (SE77SE100)	478800 471650	1949	76.2	~30.00	Made Ground to 2mBGL Corallian Group proven to 76.2mBGL	~19.3
Malton Station 6 (SE77SE160)	478740 471350	1992	5.5	~20.00	Made Ground to 1.8mBGL Sand proven to 5.5mBGL	~18.1
Lakeside Village Norton Malton 4 (SE77SE123)	479136 470918	1994	6.1	~20.00	Made Ground to 0.3mBGL, Sandy stony clay to 1.0mBGL, Sand and Gravel to 4.6mBGL, Laminated clay proven to 6.1mBGL	~19.0
Norton (SE87SW2)	480522 470195	1883 1964	20.4	31.09	Sand to 5mBGL Corallian Group to 21.95mBGL, Green Sand to 22.56mBGL, Oxford Clay proven at base	23.0
Highfield Farm, Norton on Derwent (SE86NW7)	480800 469990	2006	45	~30.00	Topsoil to 0.2mBGL Stoney clay to 1.0mBGL Corallian Group proven to 45mBGL	~18.0

3.4 Structure

The Howardian Hills are located in the southwestern sector of the Vale of Pickering/ Flamborough Head Fault Zone (Wright, 2009), which was active in the Upper Jurassic Period. There are two main faults in the study area (Figure D5), namely the Malton Fault and the Gilling Fault, which trend in a west-east direction.

The Malton Fault corresponds to the River Derwent valley as it flows through Malton, and downthrows the Kimmeridge Clay underlying Norton (south of the fault) relative to the Corallian Oolite underlying Malton (to the north of the fault). A further fault to the south of Norton (off the area mapped in Figure D5) downthrows to the north, with Corallian Group strata at rockhead to the south in a continuation of the Corallian Ridge. The Kimmeridge Clay Formation between these two faults forms the Norton Trough.

The Gilling Fault downthrows to the north and represents the northern edge of the Corallian Ridge, with Kimmeridge Clay at rockhead to the north of the fault, in the Vale of Pickering, and Corallian Oolite to the south forming the Howardian Hills.

There are also numerous minor faults mapped within the Corallian Group strata to the west of Malton. Notably the Braygate Fault, which trends west-east, downthrows to the south, and intercepts the Malton Fault at the River Derwent in Malton.

The 1:50,000 geologocal mapping indicates that the Corallian Group dips gently to the north in the vicinity of Broughton by 2° though there are no mapped dips for the south of the Corallian Ridge at Malton. A gentle anticline was identified in the Corallian Ridge to the north of Malton from examination of sections through Malton Bypass (Wright, 2009). This is shown in Figure D5 by the opposing dip arrow along the A64.

The dip on the Corallian Ridge to the south of Norton, is indicated on the 1:50,000 mapping as 3° to the north of the ridge at Howe Hill and 10 to 30° to the south at the southern side of the ridge beyond Langton Wold. An excerpt from the BGS borehole log for the Yorkshire Water abstraction at Howe Hill (ref SE87SW2, BGS ID 132715) suggests that there is an anticline structure (not shown on the 1:50,000 map) to the south of Howe Hill. This would explain the variation in dip across the Corallian Ridge at this location.

The interpreted geological structure of the Malton area is summarised in Figure D6.

4 Hydrogeology

4.1 Aquifer classification

The EA provides a classification system for aquifers in England based on their ability to transmit water (permeability) and support water supply abstractions, surface water flows and wetland ecosystems. Table D2 presents the EA aquifer classification for each geological unit presented in Figure D6.

Table D2 Environment Agency classification of aquifers around Malton and Norton

Strata	EA Aquifer Classification
Superficial Deposits	
Alluvium	Secondary A Aquifer
Sand and Gravel of unknown age and origin	Secondary A Aquifer
Lacustrine Deposits	Secondary (undifferentiated) Aquifer
Glacial Till	Unproductive Strata
Head	Secondary (undifferentiated) Aquifer

Bedrock	
Kimmeridge Clay	Unproductive Strata
Upper Calcareous Grit	Principal Aquifer
Corraline Oolite	Principal Aquifer
Lower Calcareous Grit	Principal Aquifer
Oxford Clay	Unproductive Strata

The Glacial Till, Kimmeridge Clay and Oxford Clay are all classified as Unproductive Strata. This classification is applied to superficial deposits and bedrock with low permeability and negligible significance for water supply of river baseflow.

The Lacustrine Deposits are classified as a Secondary (undifferentiated) Aquifer, which is the designation applied where it has not been possible to attribute either category A or B. In most cases, this means that the strata in question has previously been designated as both minor and non-aquifer in different locations due to the variable characteristics of the rock type.

The Alluvium Deposits along the rivers Derwent and Rye are classified as Secondary A Aquifers. This is the designation for permeable superficial deposits capable of supplying water on a local scale and supporting baseflow to rivers.

The bedrock of the Corallian Group (Upper and Lower Calcareous Grit and Coralline Oolite Formations) has been classified as a Principal Aquifer. This means that the rock is highly permeably and provides water supply and/or river baseflow.

Two Water Framework Directive (WFD) groundwater bodies are defined in the study area: the Derwent Malton Corallian Limestone (ID: GB40401G702500), which corresponds to the Corallian Ridge to the northwest of Malton; and The Derwent (south) Mercia Mudstone, Lias, Ravenscar and Norton Corallian (ID: GB40402G702200), which includes the Corallian Ridge to the south of Norton. The former is classed as have poor Quantitative and Chemical Status, whereas the latter is classed as having Good Quantitative and Chemical Status.

4.2 Aquifer Properties

The BGS aquifer properties manual provides information on the hydraulic properties of bedrock aquifers. The properties of the Corallian Group are summarised in Table 3.

The associated description of the Corallian states that:

'The Corallian is highly fractured, with fracture flow being well developed. Transmissivities can be high (up to 3,800m^2/d) and large yields are obtained close to major springs and faults. The highest yielding boreholes are in or close to the confined zone. It is underlain by Oxford Clay and overlain by Kimmeridge Clay, both of which are impermeable. Both the River Rye and River Riccal originate as springs issuing at the basal junction of the Corallian with the Oxford Clay.' p.132.

Table 3 Summary of aquifer properties for the Corallian Group [BGS aquifer properties manual]

Property	Range	Mean	Source

Bulk Hydraulic Conductivity (m/d)	4.6 x 10^{-6} to 0.25	1.8 x 10^{-4}	Laboratory analysis
Transmissivity (m^2/d)	0.2 to 16,000	318	Pumping tests
Storage Coefficient	4.0 x 10^{-7} to 2 x 10^{-2}	unknown	Pumping tests
Porosity (%)	6.0 to 37.4 (Coralline Oolite)	17.4 (Coralline Oolite)	Laboratory analysis

4.3 Groundwater Levels

The EA monitors groundwater levels at three boreholes within the Corallian aquifer near Malton. The locations of these boreholes are presented in Figure D7. There are no monitoring boreholes located on the Corallian outcrop to the south of Norton.

Monthly manual dip data from these three boreholes is available from the period 1983 to 2015, and is presented in Figure D8. This data indicates that the water levels in all three boreholes show similar trends and that they are broadly between 15 and 26.5mOD, and that peak groundwater levels correlate to high monthly rainfall. Rainfall and groundwater levels are both highest in winter months and lowest in summer months. The highest water levels recorded over the period were in autumn 2000, which was a major flood event in the UK. Lower than normal summer groundwater levels are shown in known drought years of 1992 and 1996/97.

The water levels at Broughton and Amotherby are very similar. These boreholes are only 1.7km apart and located in the centre of the Corallian outcrop. Water levels at Barton-le-Street, which is 6.6km from Malton town centre, are 1 to 2.5m higher than at the other two boreholes.

The borehole at Broughton closest to Malton, approximately 2km to the northwest of the town centre, is used by the EA predict when groundwater flooding is likely to occur in the town. Groundwater level data from this borehole is shows as Figure D8.1. In addition to the monthly manual dips, a pressure transducer with data logger was installed in the Broughton borehole in December 2012. There is now instantaneous 15 minute data available for this borehole. This data indicates that the fluctuation in water level observed at this borehole between December 2012 and February 2015 was 5.3m (range 17.32mOD to 22.62mOD).

4.4 Groundwater Flow

There are insufficient EA monitoring wells coverage to determine the detailed direction of groundwater flow. Given the difference in water levels between Barton-le Street and Amotherby/Broughton, it could be that groundwater flows in an easterly direction. However, further monitoring points would be required to verify this.

Groundwater is expected to flow in the direction of geological dip. The Corallian Group in the vicinity of Malton is shown to be horizontal on the 1:10,000 mapping (Figure D5). To the north of the Corallian Ridge, near Broughton, the dip is marked as 2° to the north on the 1:50,000 mapping.

The BGS Aquifer Properties Manual notes that springs issue from the base of Corallian aquifer because the underlying Oxford Clay is low permeability. Groundwater outflows from the Corallian Ridge are likely to be related to changes in geology, such as along fault lines and at the base of permeable strata.

Both historical and modern OS maps have been examined to determine the location of springs close to the River Derwent at Malton and Norton. These show that the location of many of the springs in Malton and Norton appear to be related to the bedrock geology, specifically the faults which downthrow the Kimmeridge Clay relative to the Corallian Group in the valley of the River Derwent. There are two springlines that can be identified, one appearing to correspond to the Malton Fault and the other to the fault to the south of Norton. A significant spring is marked on the OS maps at Auburn Hill, approximately 500m to the west of the Yorkshire Water groundwater abstraction at Howe Hill. This spring feeds into a fish hatchery in Norton and ultimately into the River Derwent. The spring corresponds to the fault to the south of Norton, and also to the edge dry valley filled with head deposits above the Corallian Group (Figure D2). Groundwater flow within the Corallian Group is significantly controlled by faulting and fracture zones.

Groundwater flow within the superficial deposits is expected to be within the more permeable strata, the Alluvium and Sand and Gravel. Both of which are likely to be in hydraulic continuity with the River Derwent. Where these deposits overly the Corallian Group, they are likely to be in hydraulic continuity with the underlying bedrock.

The groundwater flow direction in the superficial deposits would be expected to follow topography, and is thus likely to be toward the River Derwent.

4.5 Groundwater Abstraction

Abstraction licence information has been obtained from the EA, which covers a large area and includes live, revoked and expired licences, as well as abstractions from the Corallian, Chalk and superficial aquifers. Figure D9 shows the locations of all abstraction licences identified by the EA, whereas Figure D10 shows the location of live licences.

Figure D11 indicates the largest live groundwater abstraction licences are Yorkshire Water public water supply boreholes at East Ness (NE/027/0025/021, 11.5km to northwest of Malton town centre), Keld Head (2/27/25/128, 12.5km to north of Malton town centre) and Howe Hill (2/27/27/002, 0.3km to the south of Norton). All three abstractions are from the Corallian Group.

The actual annual volume of licensed abstraction for the live abstraction licences are presented in Figure D12, these indicate the level of groundwater abstraction has been relatively steady during the last 10 years. The indicative scale of actual abstraction volume compared to other components of the water balance suggest that these will not have a significant level of impact on estimates of flow.

5 Conceptual Model

5.1 Overview

Our conceptual model of potential contributions of groundwater flow to flooding, based on the cross-section presented in Figure D6, uses the hydraulic gradients between water levels at boreholes and the spring lines as the basis for estimates of groundwater flow. A range of Transmissivity measurements are used, based on a pumping test carried out at the Malton Norton public water supply borehole and values from the BGS Aquifer Properties Manual. The aquifer thickness is inferred as 5m thick, based on the assumed active fracture zone, shallow spring and surface water discharge zone and the role of the Kimmeridge Clay bedrock in restricting onward flow.

5.2 Malton

The conceptual model for Malton uses the hydraulic gradient between the borehole at Broughton and the Castlegate spring line. It is noted that the Malton Norton pumping test resulted in implied hydraulic conductivity that was a factor of 10 in excess of the conductivity rates from the Aquifer Properties Manual. However, in application in the calculation (presented overleaf), use of the pump test rates suggested a rate of discharge of 0.3l/s/m in wet conditions. Assuming this is applied across a discharge width of 150m (the assumed width of discharge at Castlegate, Malton), this would result in a flow of 46 l/s. Comparing this to accounts by Yorkshire Water of dry weather groundwater flows of 20-30 l/s in the Castlegate surface water drainage system.

Multipliers of this rate of 0.3l/s/m have been used to estimate the groundwater component of inflow to any individual flood cell, dependent on the estimated width of discharge along the spring line. It is acknowledged within the main hydraulic modelling report that the above figure is an average throughput, and there may be significant spatial variation in flow associated with fractures in the rock. Solutions that address greater extents of the spring line are likely to have greater robustness by virtue of averaging such uncertainty.

Hydraulic modelling has demonstrated that the scale of solutions for Malton is particularly sensitive to the estimate of groundwater flow, the accumulated volume of which is a much greater component of flooding than surface water run-off. It is therefore recommended that further monitoring data is gathered in Malton to further understand and validate groundwater levels and flow.

5.3 Norton

The Malton Norton pumping test is more likely to be of direct relevance to the Norton catchment. Its use here is however complicated in that the surface water based hydrological models also make an estimate of baseflow; the level of overlap between such models, and estimates of flow from the groundwater model is not clear.

The conceptual model uses water levels from the Malton Norton Yorkshire Water abstraction borehole, and the spring at the fault line as an estimate for hydraulic gradient, finding a steeper gradient than Malton. The implied inflow to the system (assuming a 200m discharge length) is 140l/s, which is broadly comparable with the estimates of baseflow from the hydrological calculations. Moreover, it is a relatively small figure compared to the scale of peak flows from the hydrological analysis, and therefore the level of uncertainty with regards to overlap and accuracy of the conceptual model is of less concern.

Malton – Conceptual groundwater flow model.

Water Levels (mOD)

	Max	Average
Broughton BH	22.75	17.45
Spring at fault line	17	17

Hydraulic Gradient (i)

	Max WL	Average WL
Horizontal Distance (m)	1125	1125
Difference in Water Level (m)	5.75	0.45
Hydraulic Gradient	0.0051	0.0004

Hydraulic Conductivity (K)

	Malton Norton Pump Test	Interquartile Max (APM)	Interquartile Min (APM)
Transmissivity (m2/d)	16,000	2,100	32
Aquifer thickness	15.33	15.33	15.33
Hydraulic Conductivity (m/d)	**1,043.7**	**137.0**	**2.1**

Groundwater Flow per m width (Q)

Q = K x i x A

5m thick aquifer, max i

K	1,043.7	137.0	2.1	
i	0.0051	0.0051	0.0051	
A	5	5	5	
Q (m3/d)	**26.67**	**3.50**	**0.05**	
Q (m3/s) x 150m length	0.046	0.006	0.000	m3/s

Norton – conceptual groundwater flow model

Water Levels (mOD)

	Max from SRO	19/12/2006
Malton Norton YW	25.33	24.48
Spring at fault line	23.65	23.65

Hydraulic Gradient (i)

	Max WL	Average WL
Horizontal Distance (m)	150	150
Difference in Water Level (m)	1.68	0.83
Hydraulic Gradient	0.011	0.0055

Hydraulic Conductivity (K)

	Malton Norton Pump Test	Interquartile Max (APM)	Interquartile Min (APM)
Transmissivity (m2/d)	16,000	2,100	32
Aquifer thickness	15.33	15.33	15.33
Hydraulic Conductivity (m/d)	1,043.7	137.0	2.1

Cross sectional area perpendicular to flow (A)

	Malton Norton YW	Top flow zone
Width (m)	1	1
Aquifer thickness (m)	15.33	5
Area (m2)	15.33	5

Groundwater Flow per m width (Q)

Q = K x i x A

5m thick aquifer, max i

K	1,043.7	137.0	2.1	
i	0.0112	0.0112	0.0112	
A	5	5	5	
Q (m3/d)	**58.45**	**7.67**	0.12	
Q (m3/s) x 200m length	0.14	0.02	0.00	m3/s

Figure D1: Environment Agency Scampston Hall Rain Gauge (1961 - 2011)

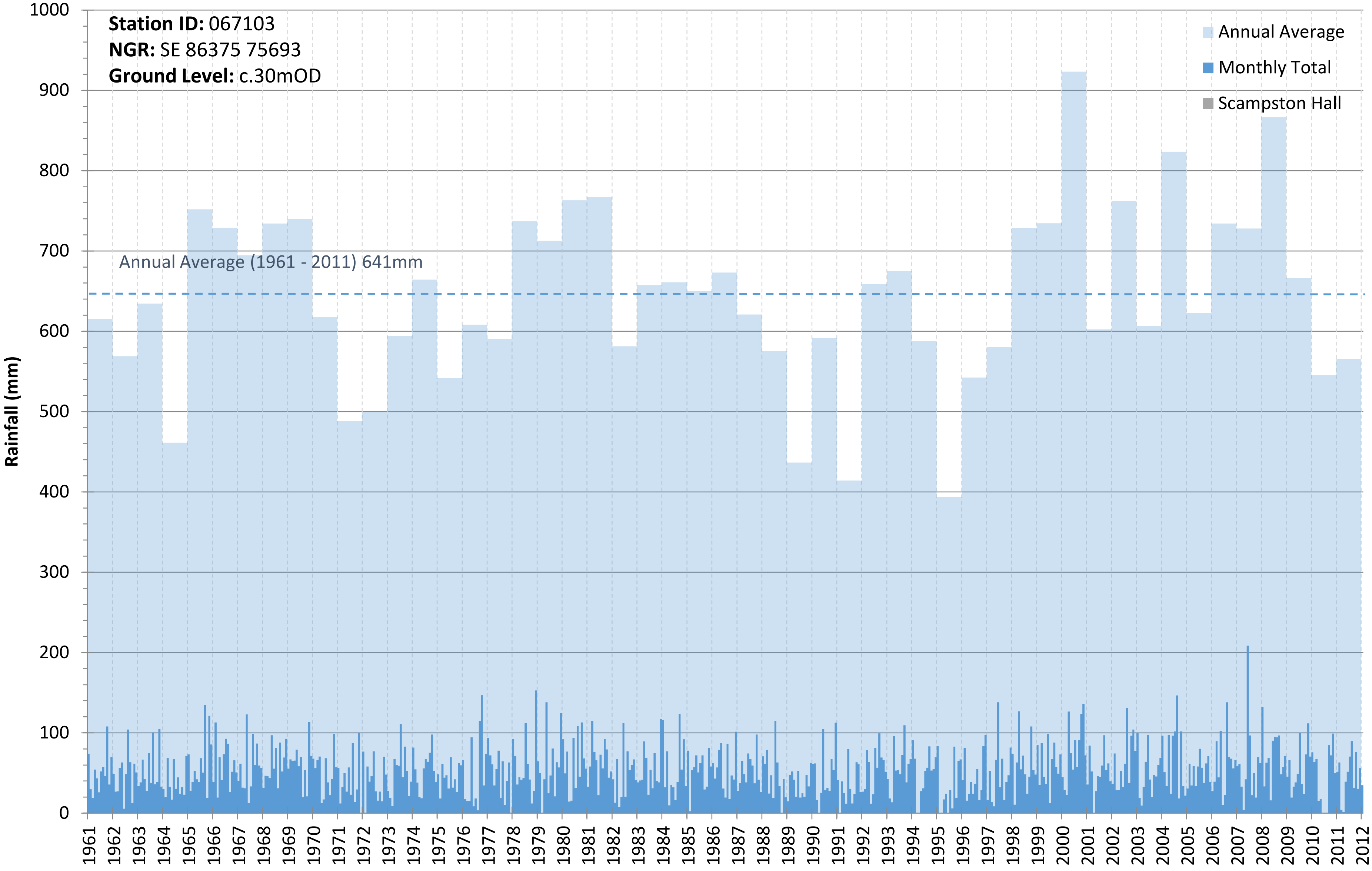


Figure D2: 1:50,000 superficial geology (local)

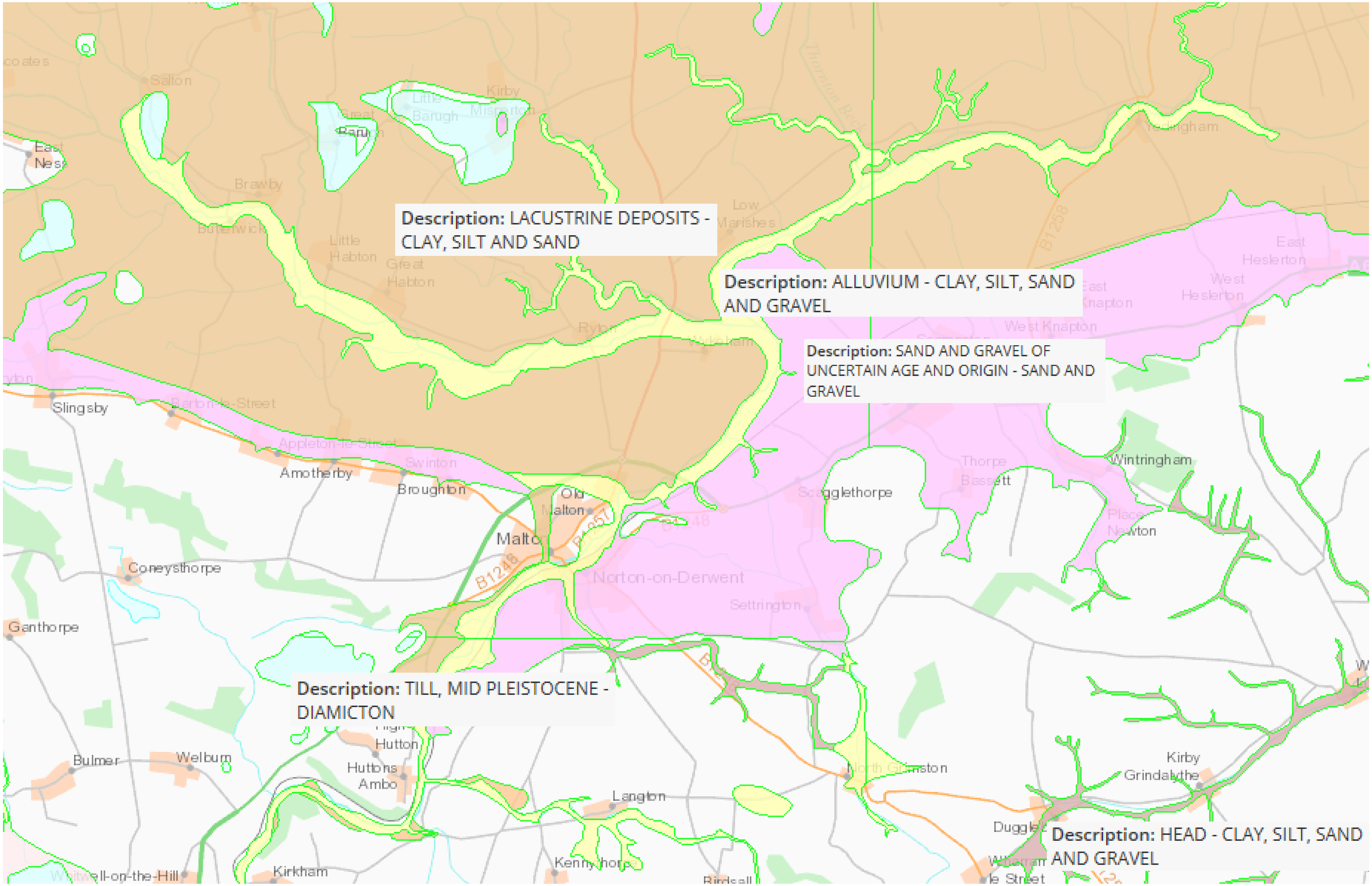


Figure D3: 1:50,000 superficial geology (region)

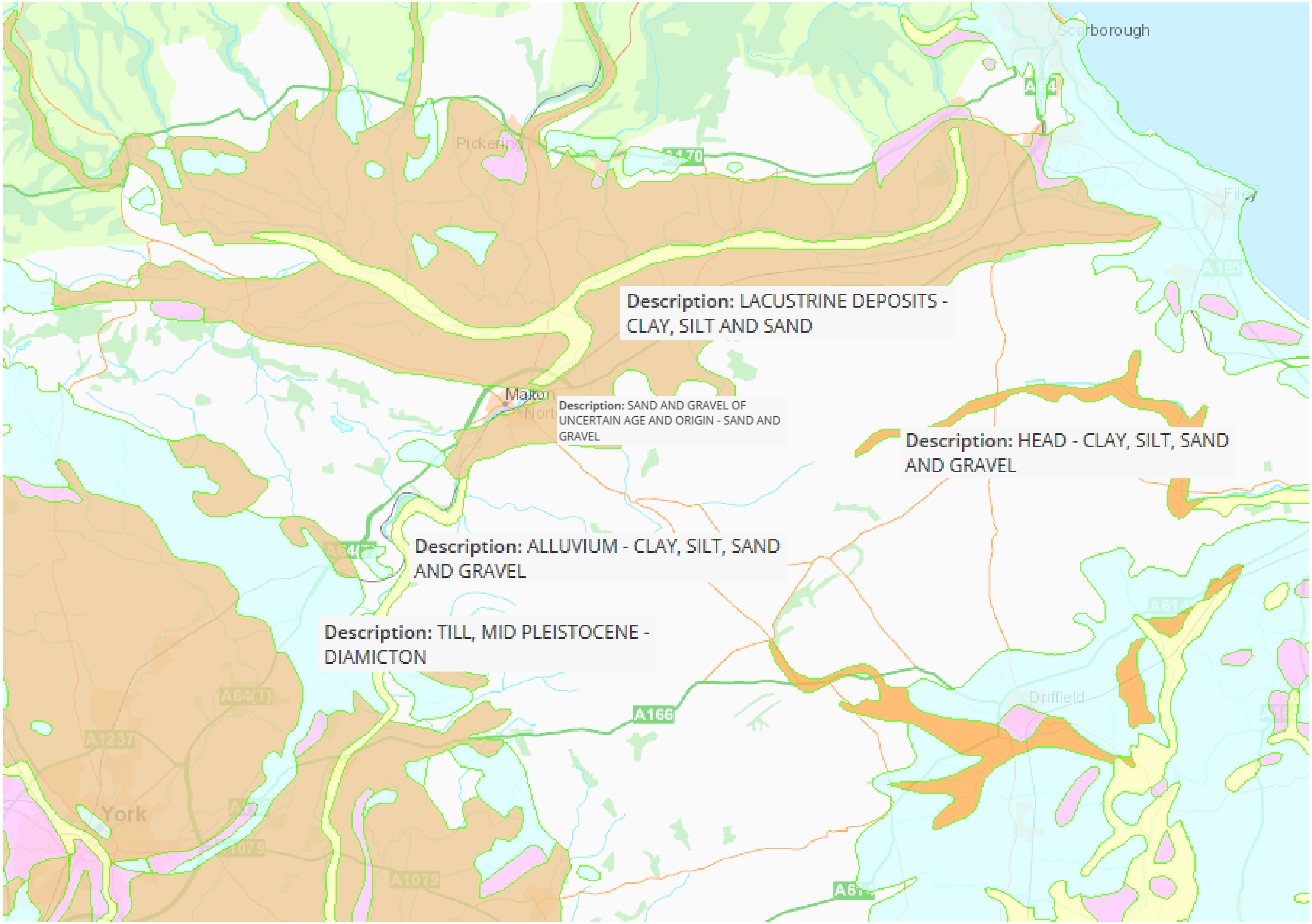
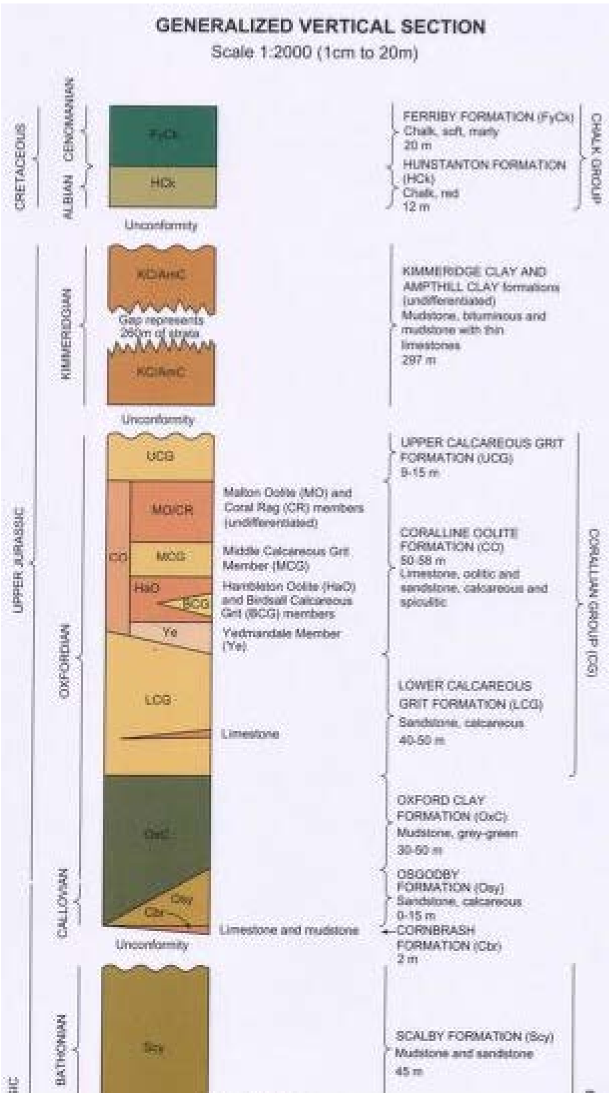


Figure D4: 1:50,000 Bedrock geology



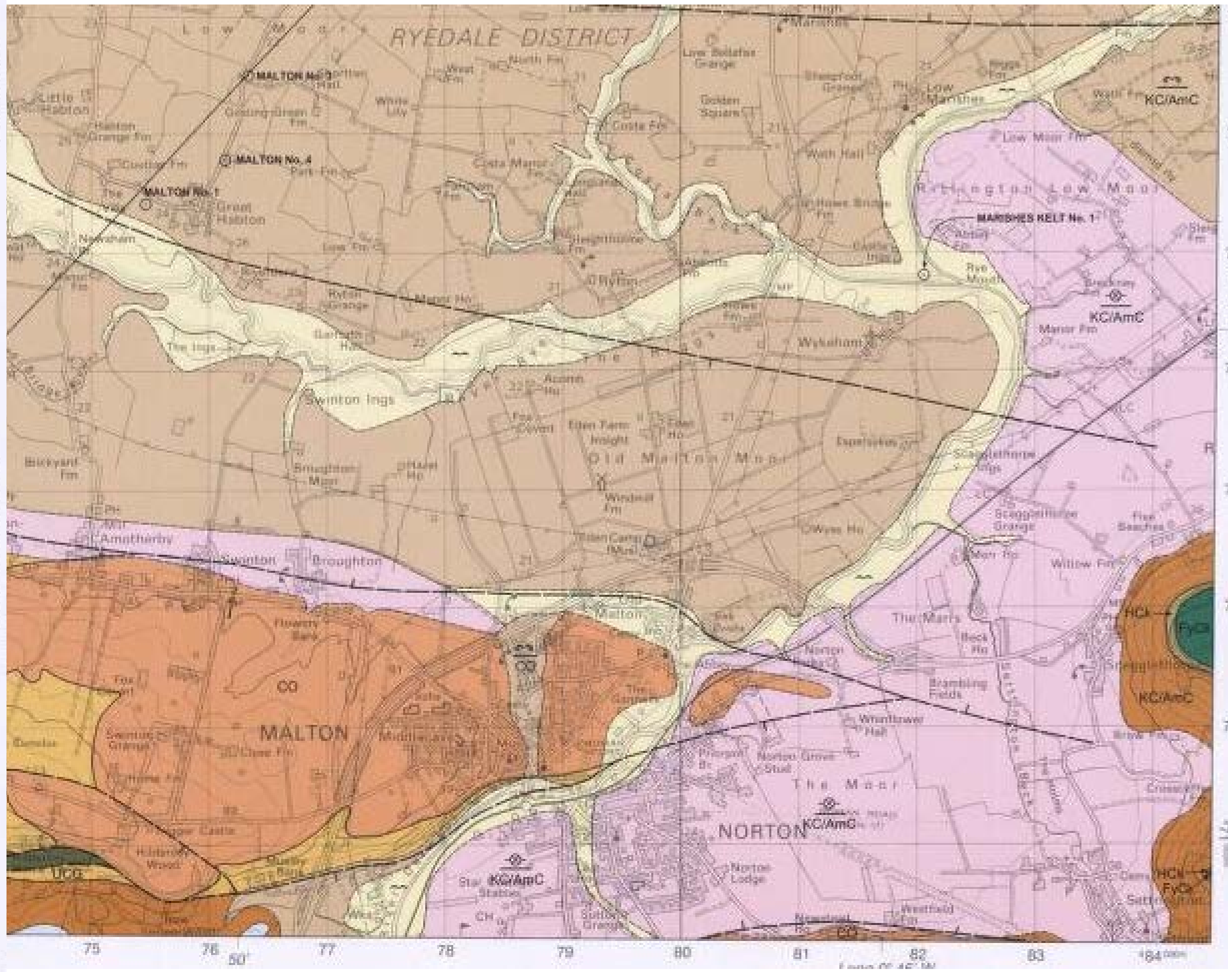
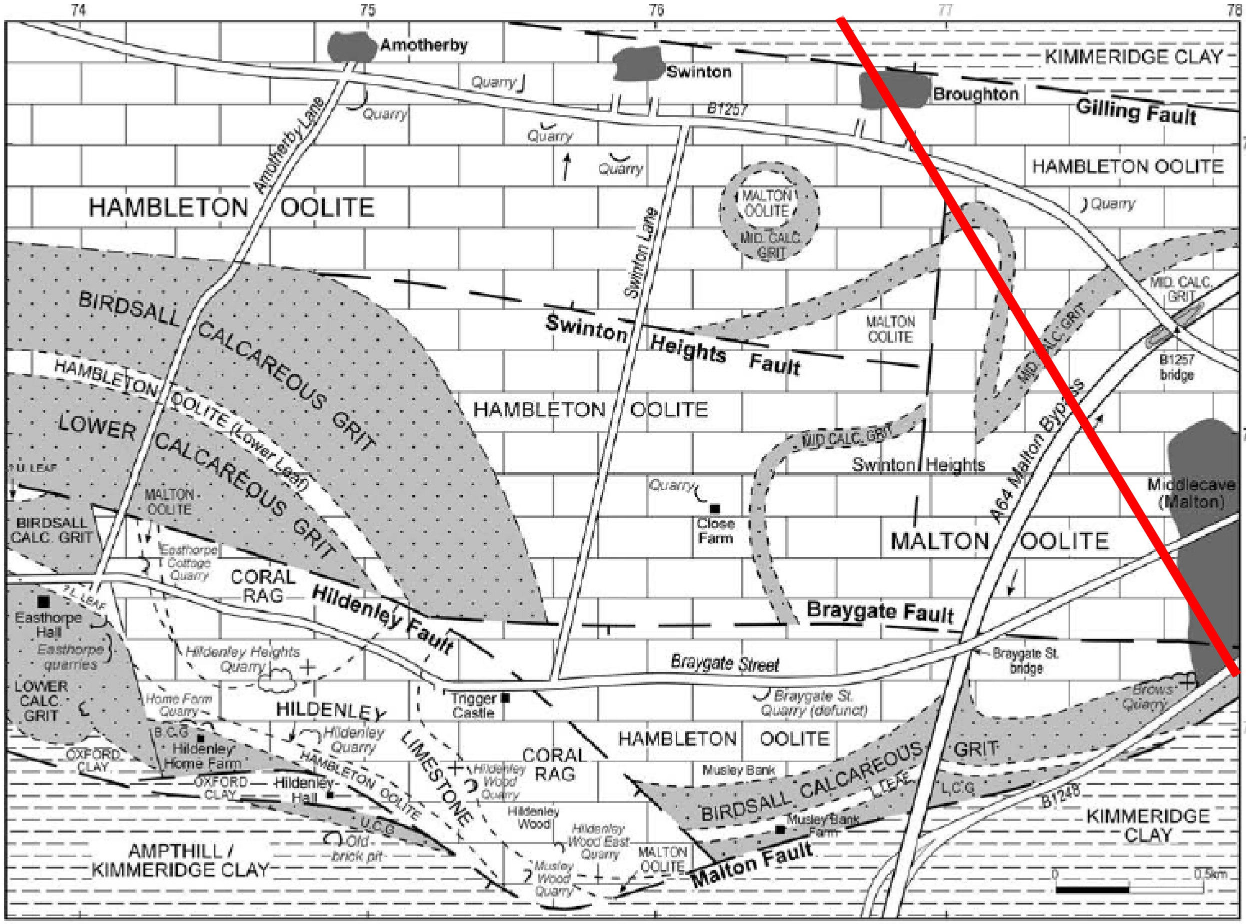


Figure D5: Geological map of Malton area – extract from Wright (2004)

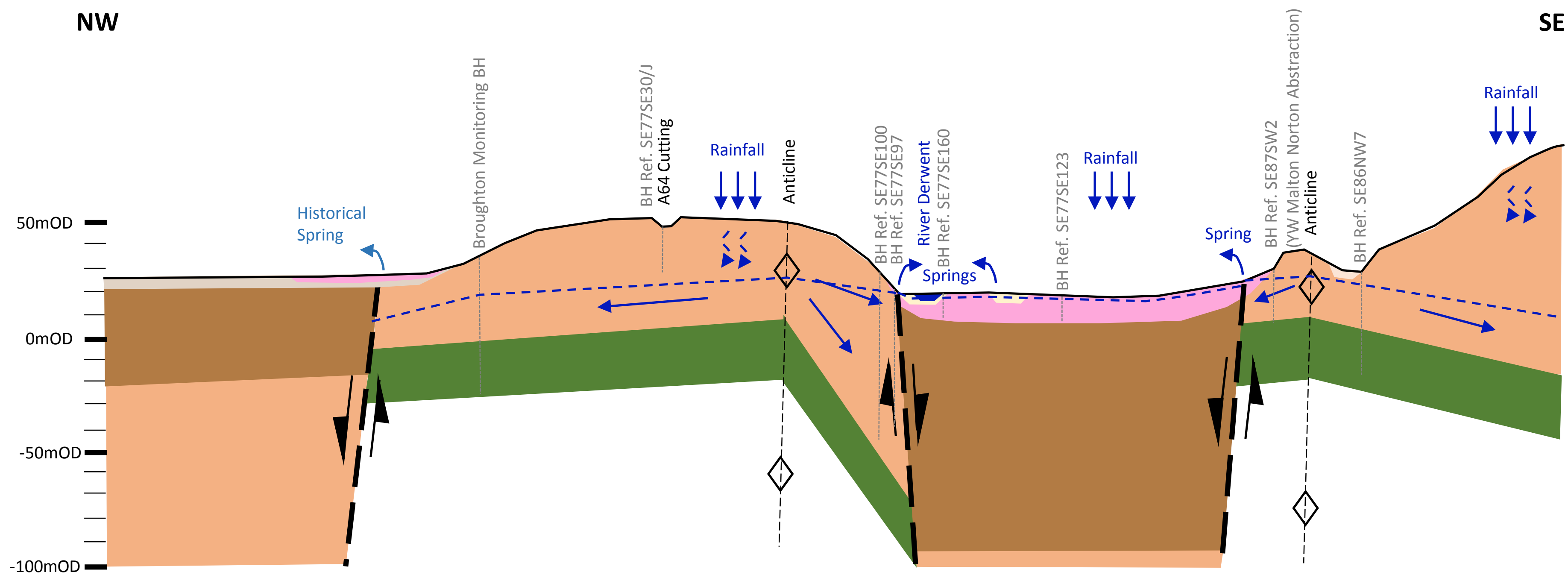
Approximate line of cross section

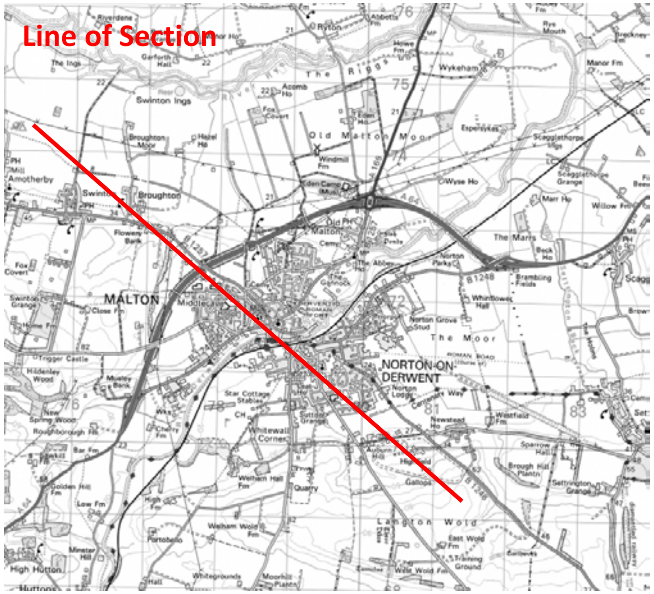


Approximate line of cross section

Fig. 3. Geological map of the area west of Malton. Based on field mapping on a 1:10,000 scale by the author. Thick, dashed lines are faults, tick on the down-throw side. Arrows indicate the dip direction. + sign = horizontal strata. British National Grid co-ordinates at 1 km spacing. The

Figure D6: Section through Malton





Bedrock

- Corallian Group
- Kimmeridge Clay
- Oxford Clay

Superficial Deposits

- Sand and Gravel of unknown age and origin
- Lacustrine Deposits
- Alluvium
- Head

Figure D7: Hydrometric monitoring locations

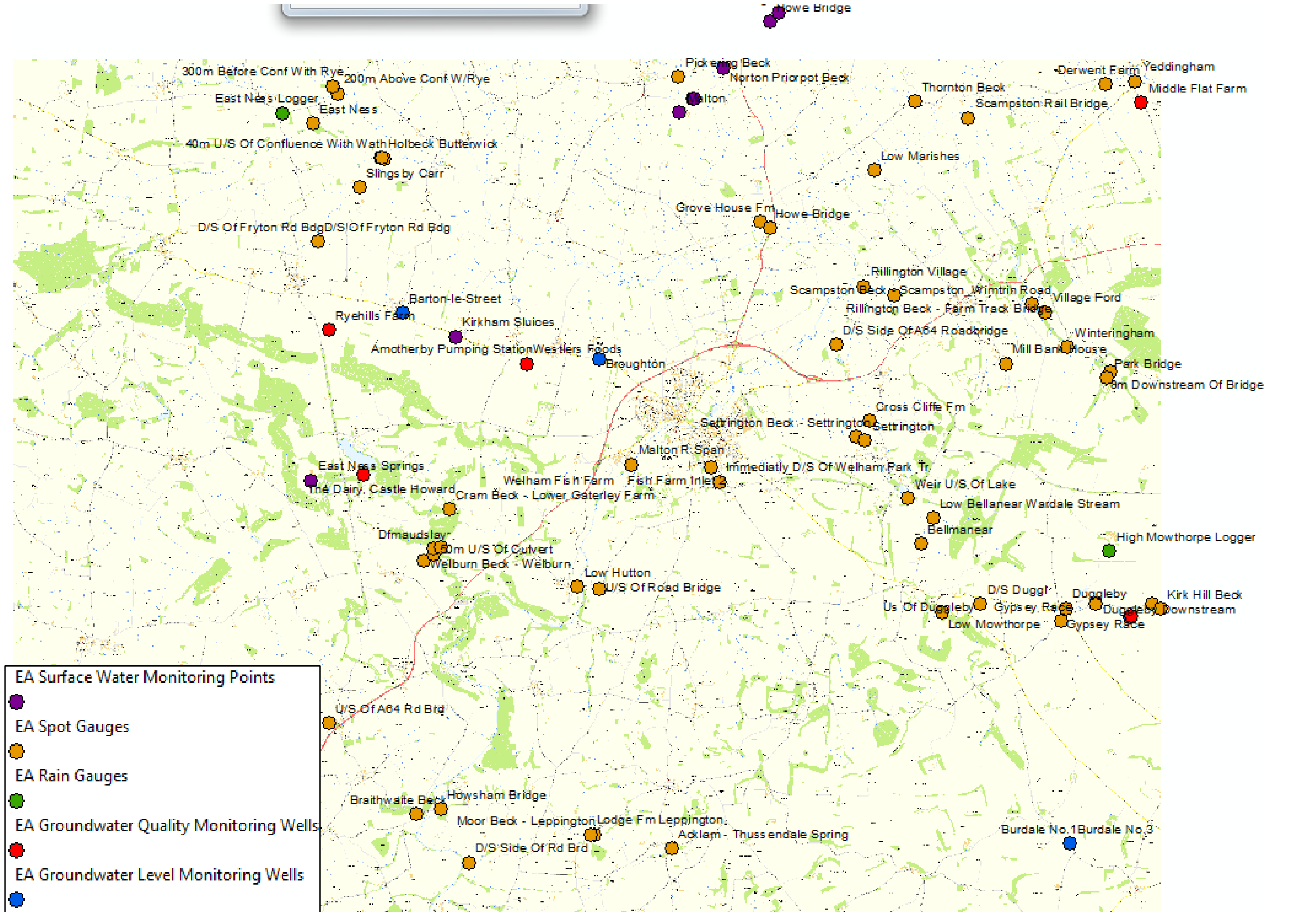


Figure D8: Environment Agency groundwater level monitoring

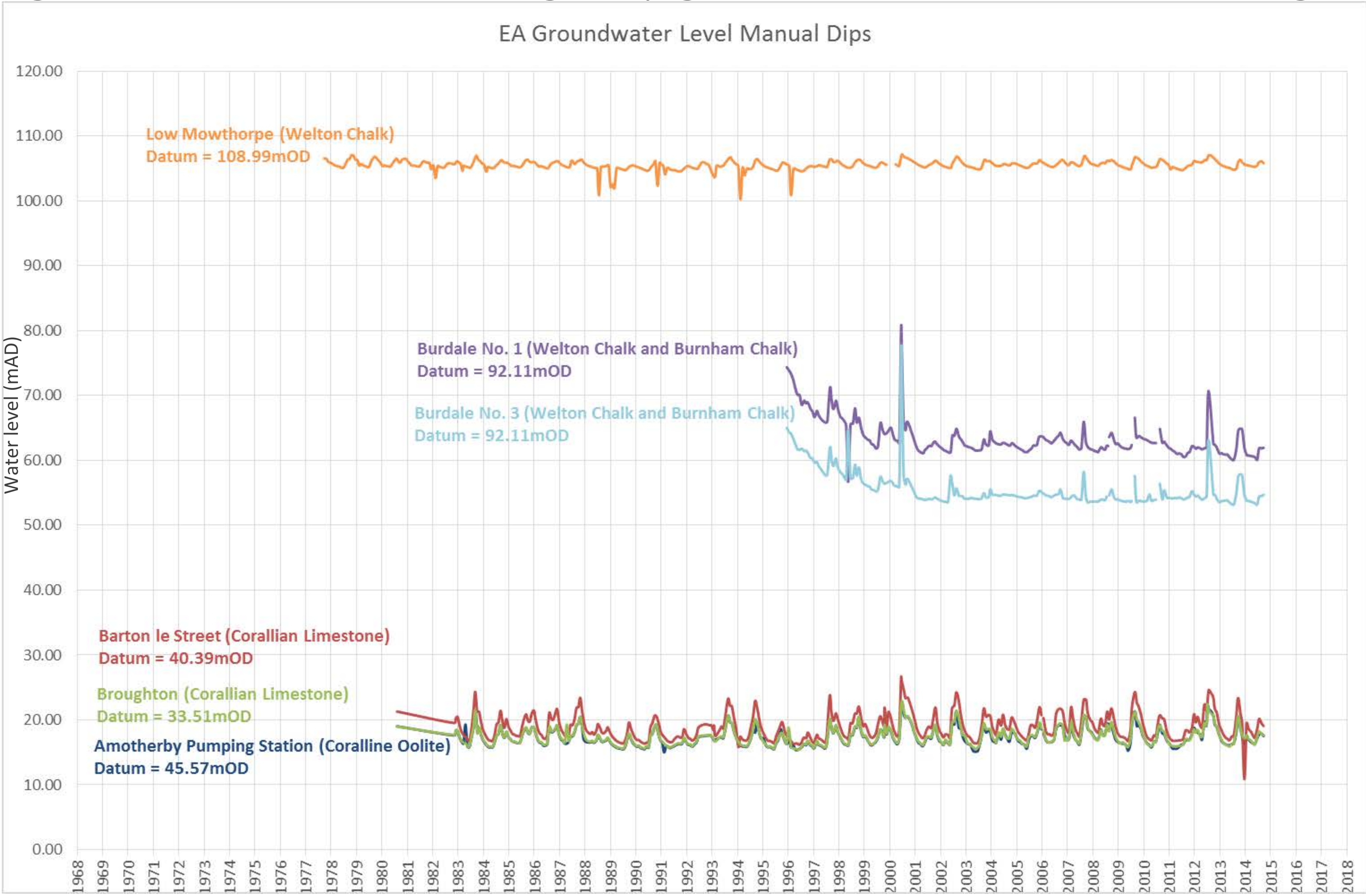


Figure D8.1: EA Broughton monitoring borehole water level data

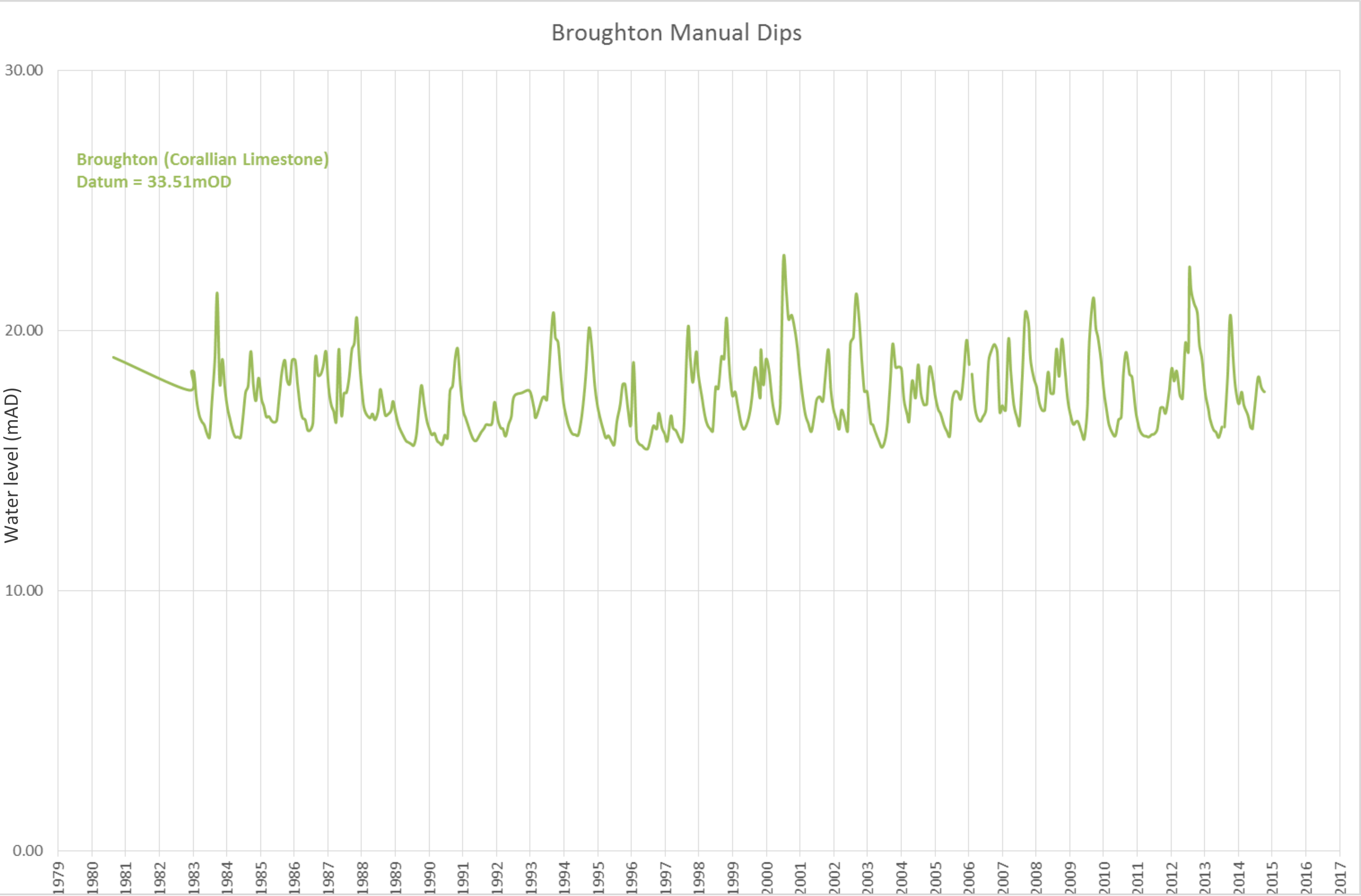


Figure D9: All abstraction licence locations

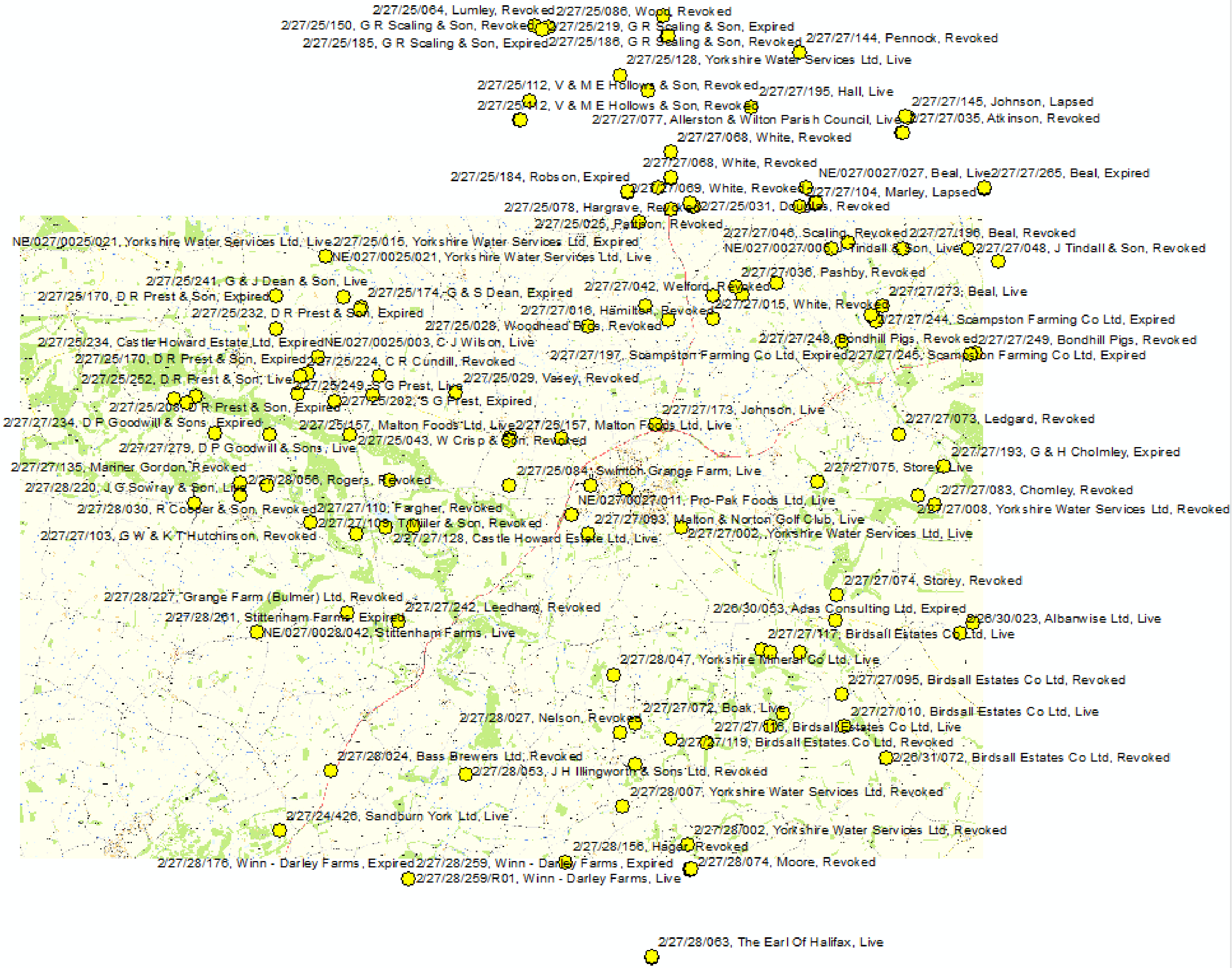


Figure D10: Live abstraction licence locations

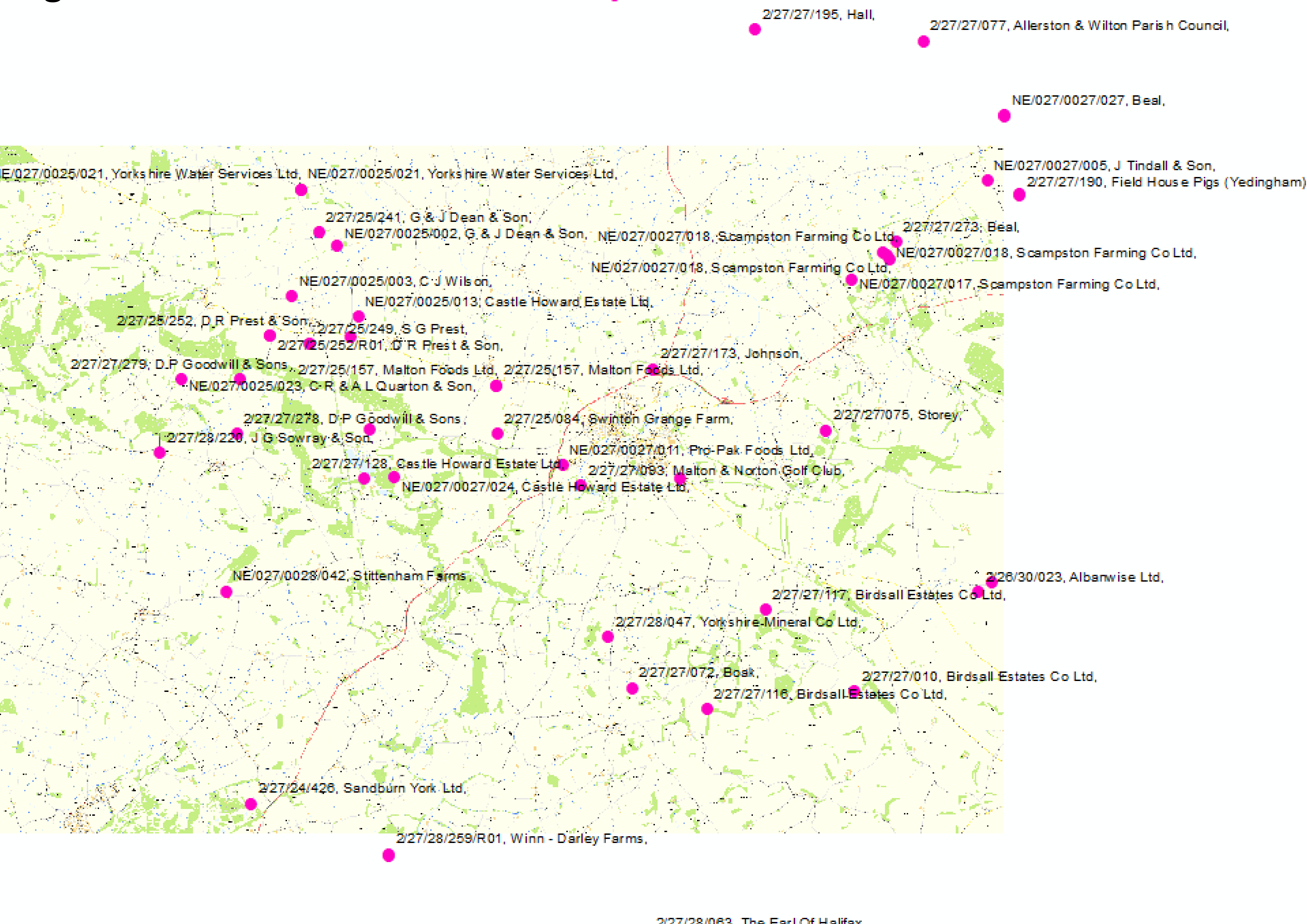


Figure D11: Live abstraction licence volumes

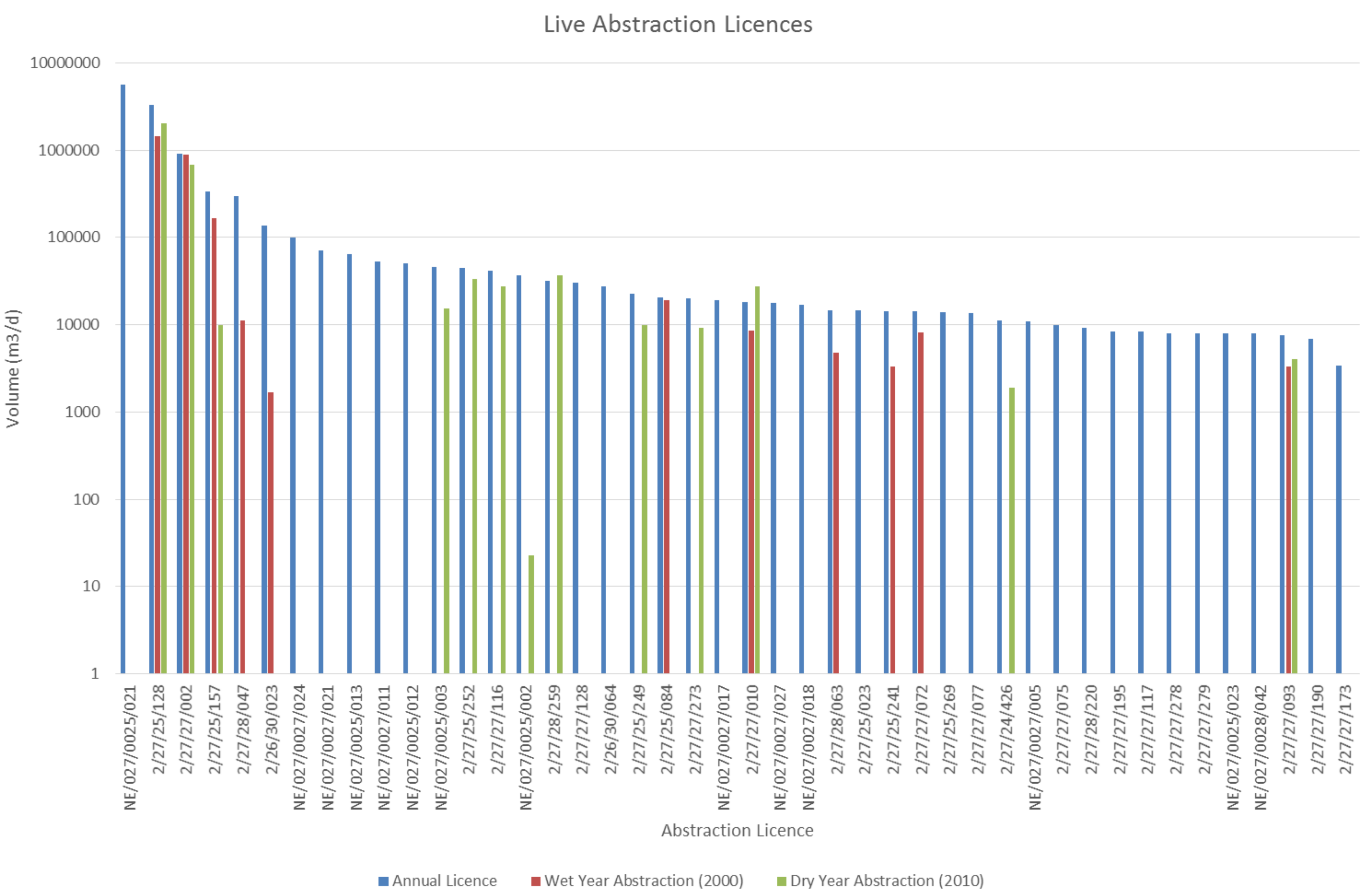
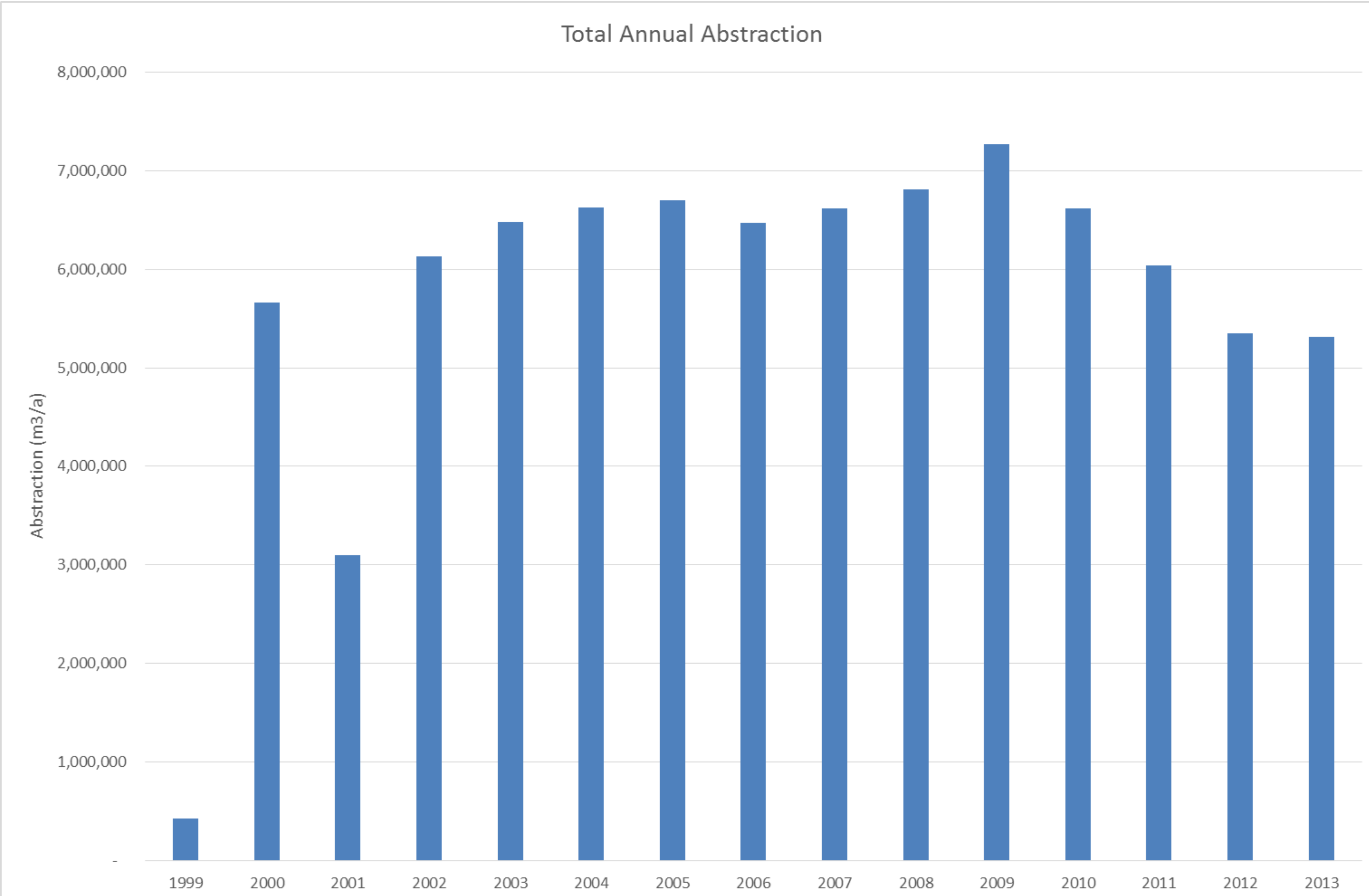


Figure D12: Actual annual groundwater abstraction



Appendix E

Joint probability

Contents

E1 Overview

The towns of Malton, Norton and Old Malton are sited on the banks of the River Derwent, and benefit from a flood defence scheme built to protect from the Derwent in 2003. However, since the construction of the flood scheme, significant levels of flooding have still occurred.

The dominant mechanism, as understood from the pattern of flooding in the November 2012 event, and from discussion with professional partners, is of flood-locking, ie while water levels are high on the River Derwent, watercourses and drainage systems behind the Derwent defences are unable to discharge to the Derwent.

This is a joint probability problem, in which the outcome (the peak water level on the landward side of the flood defences for a given joint probability) is a consequence of the degree of coincidence of (high water levels on the Derwent) and (high volumes of flow in the drainage systems).

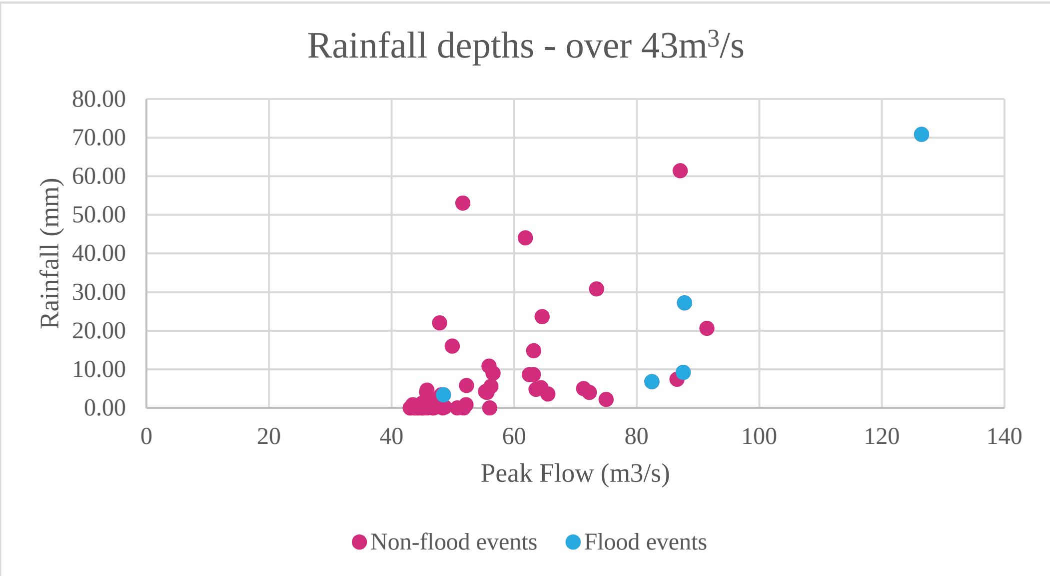
Within this, there are further subtleties –

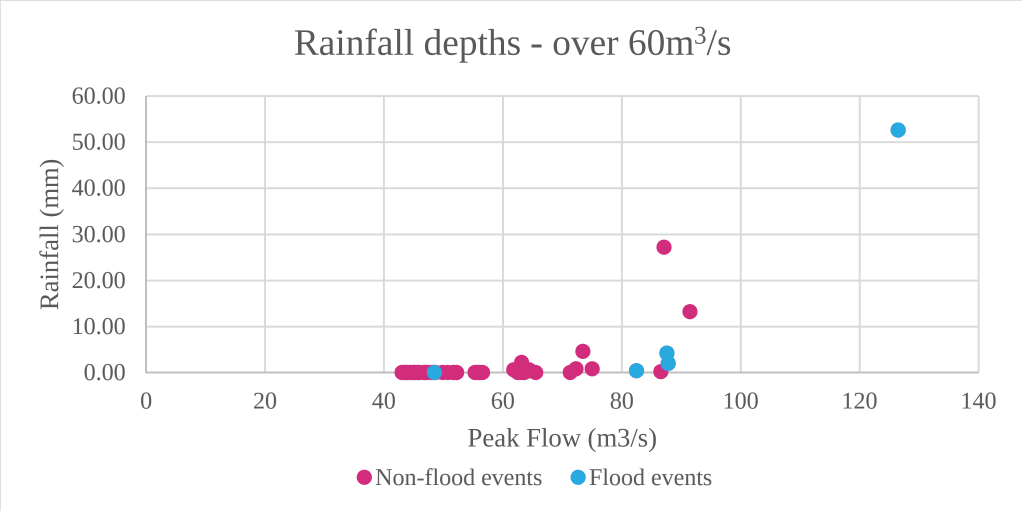
- the threshold at which the drainage systems are unable to freely discharge against high levels on the Derwent, and
- the degree to which there is a trade off between high intensities of flow in the drainage systems and the overall volumes of discharge.

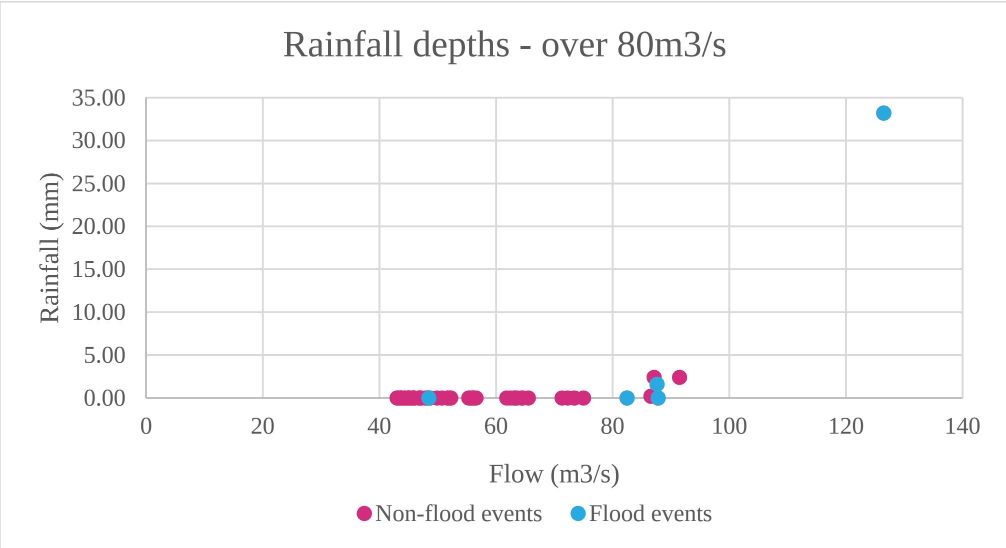
E2 Investigation

E2.1 Comparison of rainfall and flow

Hydrographs on the Derwent have been extracted for events in excess of 43m^3/s (from data for the A64 flow gauge). We have extracted from this data the times at which flow thresholds have been exceeded in these events and identified the amount of rainfall that fell while these thresholds were exceeded.







E2.2 Threshold of flood locking

To investigate the degree to which the drainage systems may be able to discharge against the Derwent, historic flood events have been investigated, and plotted against within the data to identify a plausible threshold of flood locking.

It is notable that most flood incidents following the construction of the 2003 River Derwent Flood Alleviation Scheme seem to coincide with flows in the River Derwent in excess of 80m^3/s (a return period of ~ 4 years according to the Malton Data Improvements Study), and this corresponds broadly with the threshold at which local water courses and drainage systems cannot discharge to the Derwent.

This is not a perfect relationship and there are notable counterfactuals:

There are three events when flows> 80m^3/s occurred on the Derwent and flooding is not recorded as happening.

> December 2012 - Jan 2013 and February 2013. It is considered that the magnitude and political ramifications of the November 2012 flood event would have meant that all parties were on high alert for these latter two events. Prompt, and heavy deployment of pumps prevented flooding.

January 2010 – flooding

There are three events recorded as occurring while Derwent < 80m^3/s.

November 2014, Jan 2003. Events identified as being due to intense rainfall surcharging an element of the combined drainage system and resulting in overland flow along Malton road into Malton (and as such is a localised drainage issue).

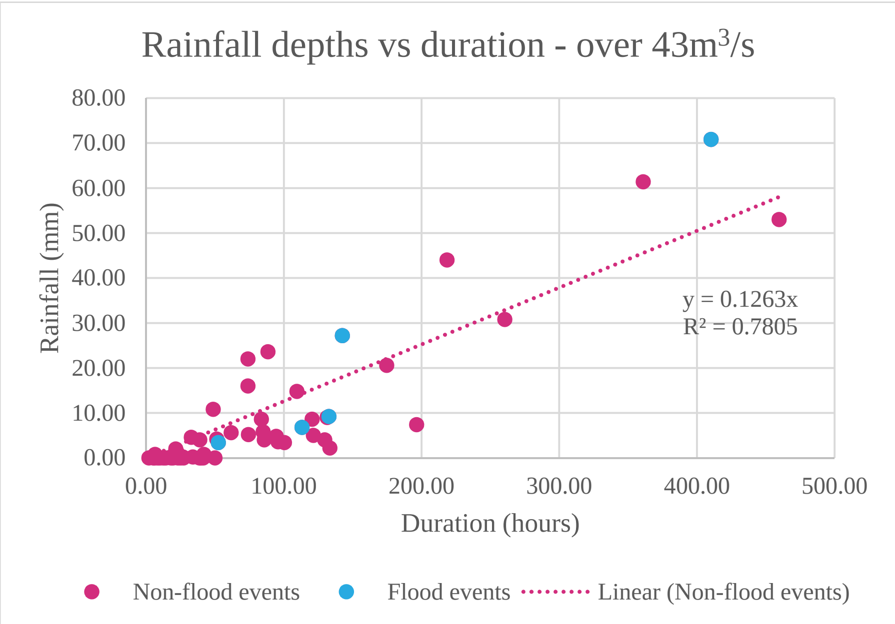
2005. An event was identified in the Derwent catchment Management Plan as causing flooding to 170 properties in 2005. There appears to be no record of this however in on-line searches or in the knowledge of this projects professional partners. While Environment Agency staff note that flood gates in Malton & Norton were closed during an event in 2005, it seems improbable that they wouldn't also have noted the flooding of so many properties and it is therefore considered that the Plan refers to flooding elsewhere.

E2.3 Influence of rainfall on flood events

It can be seen above in E2.1 that for a lot of high flow events on the Derwent, only small amounts of rainfall fell in the study area during the high flow period

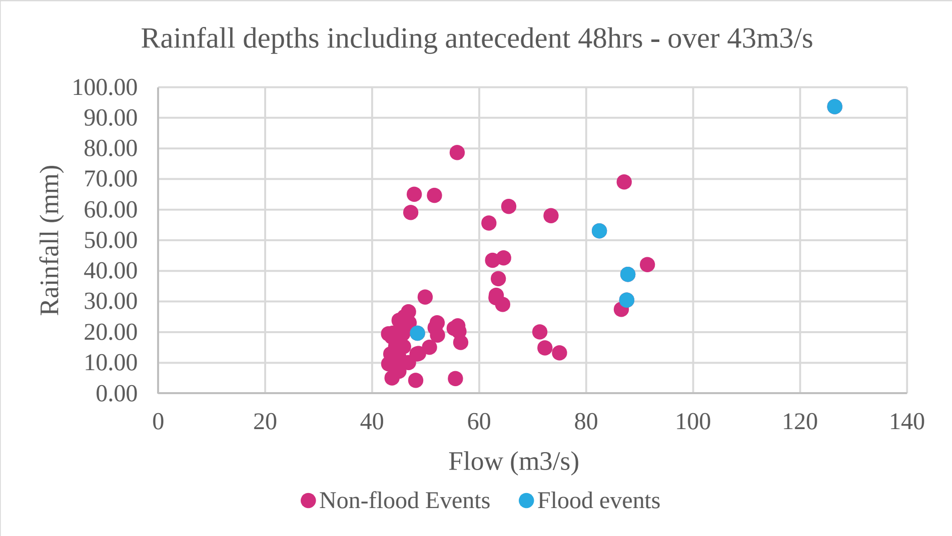
It can also be seen that (while November 2012 is a strong example of rainfall and high flows combining), for most events there is not a particularly strong connection between the depth of rainfall in a high flow period and the likelihood of a flood event.

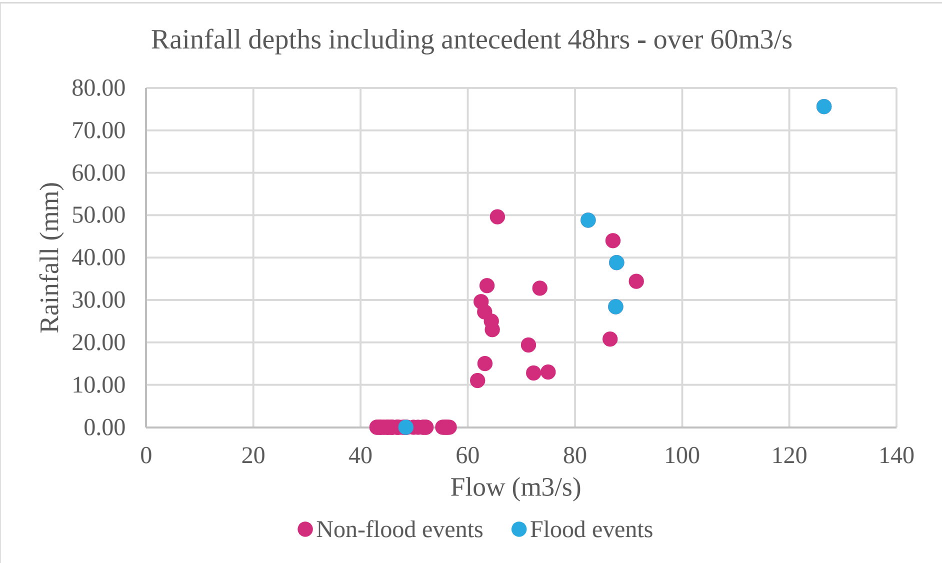
The graph below illustrates that there is (logically enough) a moderate relationship between rainfall depths and the duration of high flows. This does not of itself allow interpretation of dependency.

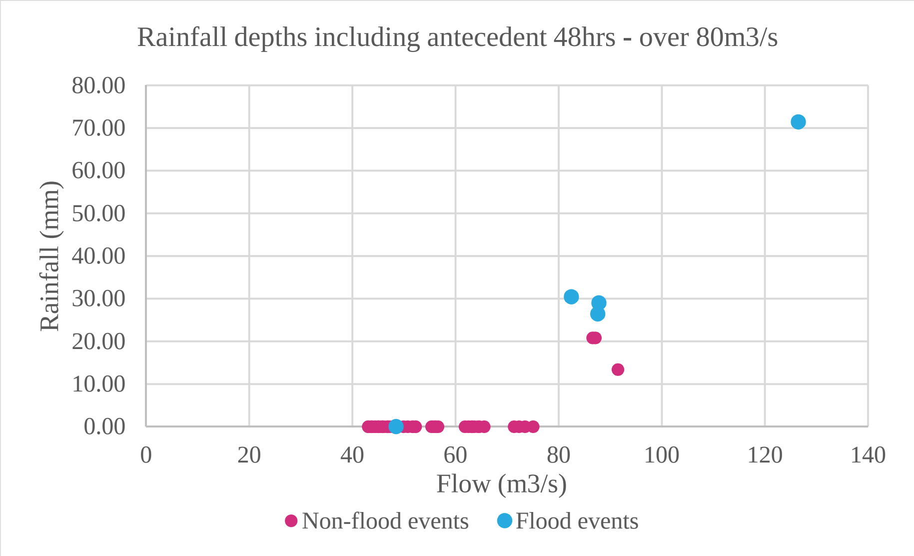


E2.4 Influence of antecedent rainfall on flood events

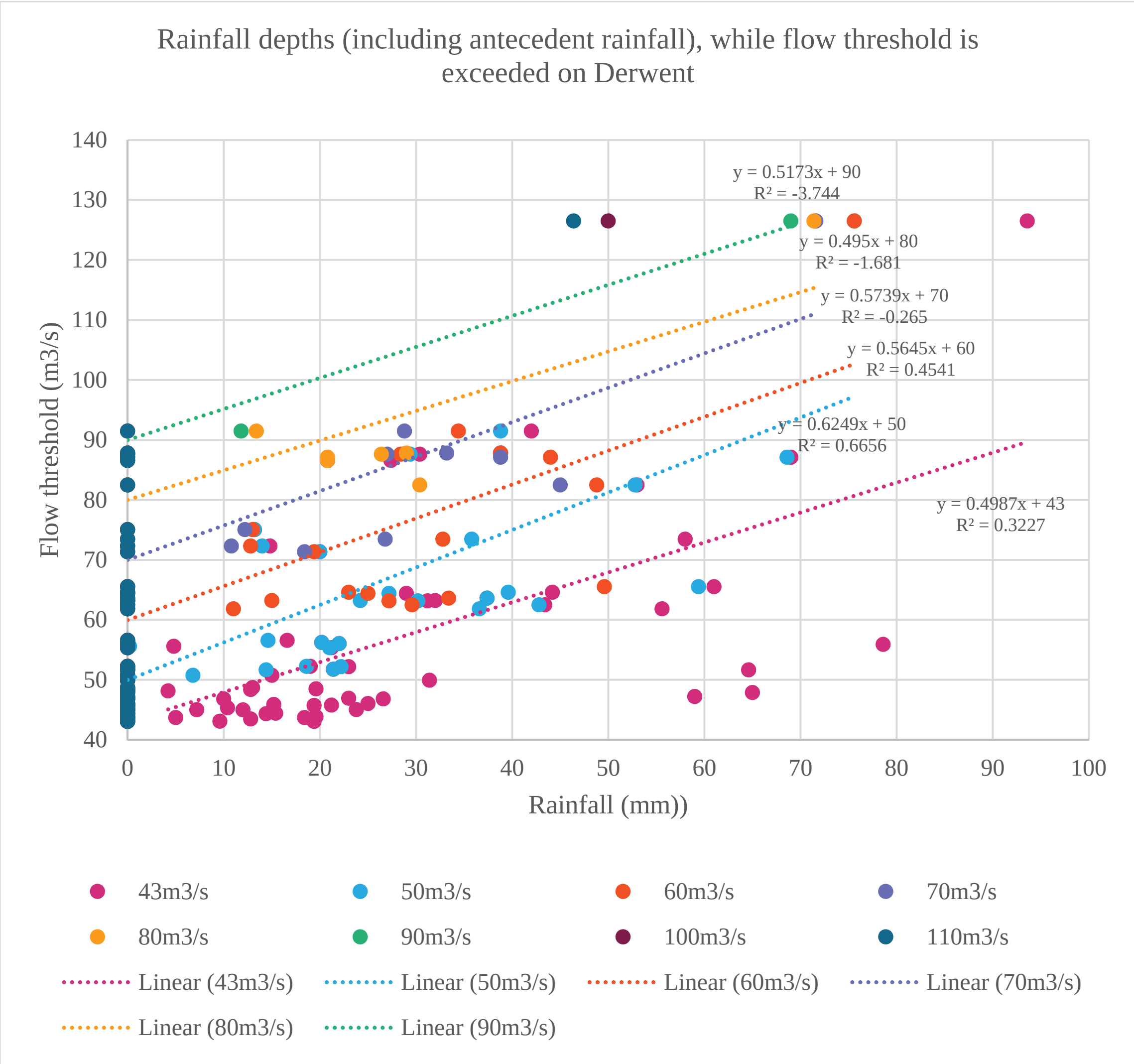
Theoretically, on flat catchments like Old Malton, or catchments that are heavily influenced by groundwater (like Malton and Norton), antecedent rainfall should have a significant role to play in the generation of flows. A range of durations of antecedent rainfall were added to the rainfall depths used in E2.1. Through a process of trial and error, this appeared to suggest that the preceding 2 days of rainfall to a flood event could explain some of the observed flood behaviour.



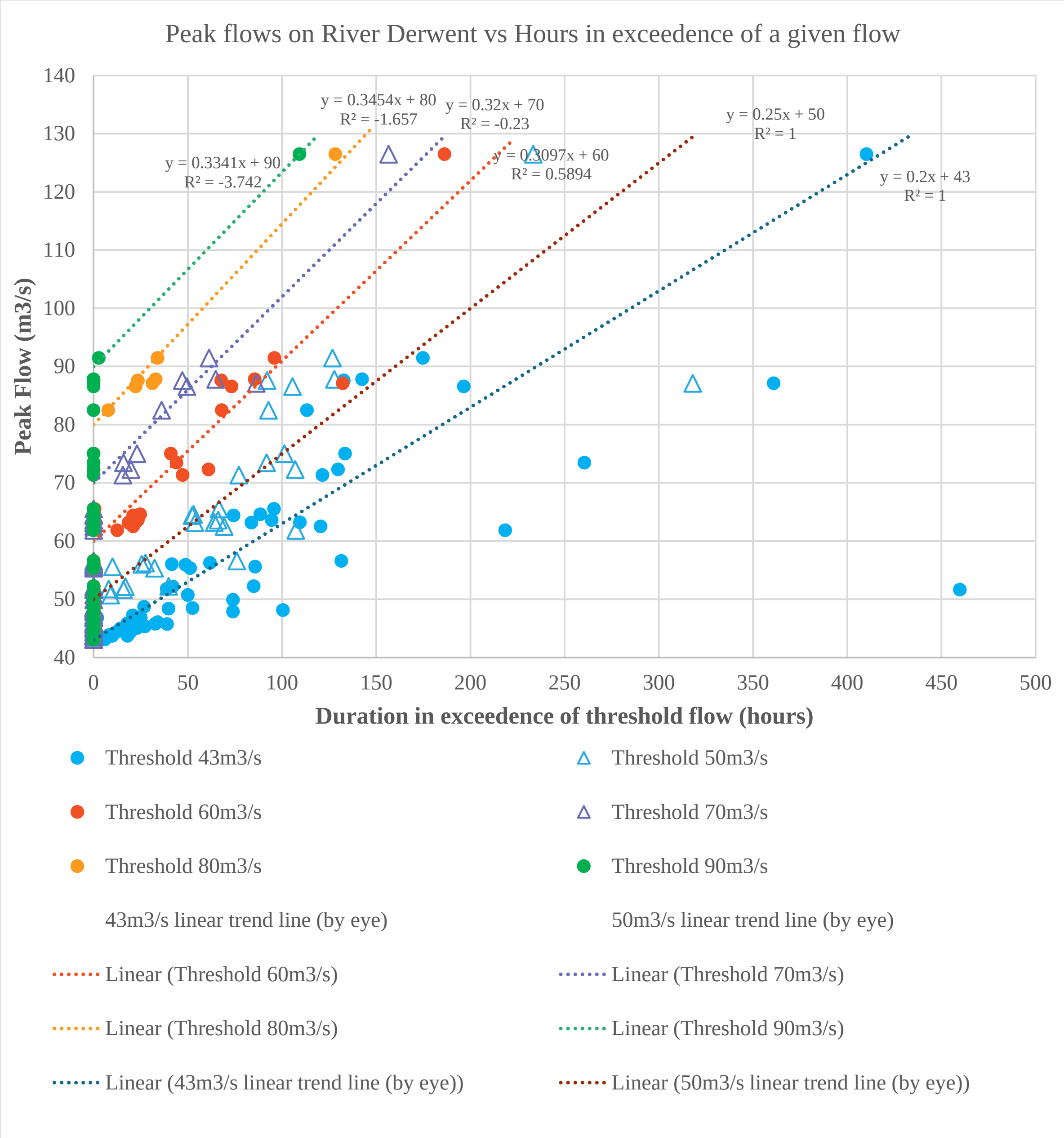




Using this information, an approximate pattern can be built up between antecedent rainfall and Derwent flow thresholds.



And this can be used in conjunction with a relationship between flow exceedence, duration and peak flow.



While the individual relationships are not strong (mainly a function of the short record available), the combination of the two relationships does allow the composition of Table E2.4, focussed on the apparent threshold of flood locking of the River Derwent.

Table E2.4 – approximate relationships between high flows on the Derwent and rainfall on the study area.

Return period (years)	2	5	10	25	50	75	100	200
Peak flow (m3/s)	64.6	83.5	96.1	113.4	127.3	136.0	142.4	158.2
Average duration flows exceed threshold of $80m^3/s$ (hrs / days)	0 hrs 0d	10 hrs 0.4d	47 hrs 1.9d	97 hrs 4.0 d	137 hrs 5.7 d	162 hrs 6.8 d	181 hrs 7.5 d	227 hrs 9.4 d
Average rainfall while flows exceed threshold of 80m3/s, plus preceding 48hrs (mm)	0	6	29	61	86	102	114	142
Implied return period of rainfall (years)	0.02	0.15	0.5	2.4	9.3	20	32	95

It should be noted that these are implied and highlight best estimate relationships only – it does not mean that for, say, every 10yr return period event on the Derwent, that 29mm will fall on the Malton catchment.

It can be seen that the ratio between the return periods of the different flood sources decreases with higher return periods. This is logical – higher return period events on the Derwent will result in longer durations of flood-locking, increasing the chance of a significant rainfall event locally. Furthermore, because this is a relationship between a long duration rainfall event and flows on the Derwent, it has to be recognised that the same rainfall event that causes high flows on the Derwent is, to a great extent, responsible for flooding over the study catchments. It is however recognised that the degree to which this effect is exhibited here appears to be exaggerated, and this may be a function of the short dataset (15years) behind the underlying relationships. The table above is used therefore as a guide to a working relationship between rainfall and flow.

Most of the economic benefit of the proposals is associated with joint events lesser than a 50year return period in magnitude; for events in excess of this, flooding is dominated by the Derwent alone (Malton / Norton), or the economic influence of such events is reduced by dwindling probability. To this end, the 50 year return period is used as the focus of the joint probability assessment, and the table above indicates a 1:5 relationship of event significance.

This approximate relationship will be used for all events, hence for the assessment of flood events on the minor watercourses, if they occur during a flood locked period, the joint return period is 5 times what it would have been assumed to be if the watercourses had been able to discharge freely to the Derwent. Table E2.4.b illustrates this.

Table E2.4b – relationship between free discharge and flood locked return periods.

Return period - free discharge (years)	Return period - flood locked (years)
2	10
5	25
10	50
15	75
20	100

Appendix F

Hydraulic modelling

Contents

F1 Introduction

This appendix outlines the work carried out in assessment of flood levels in Norton, Malton and Old Malton, and restates water levels due to flooding from the River Derwent from the “Malton Data Improvements study” (Halcrow 2009).

The Do Nothing assumption is that the River Derwent flood defences remain intact, but the penstocks and flaps protecting drainage systems from ingress by the Derwent fail in the open position. The Do Nothing water levels are therefore set by levels from the Derwent, covered in Section F2.

In the Do Something options, the River Derwent defences function as designed, complemented by correctly functioning and operated flap valves and penstocks. The water levels presented in Sections F3, F4 and F5 were calculated on the assumption that the Derwent never overtops those defences. However, in the economic analysis, water levels in excess of local standards of protection (50yr at Malton & Norton, 200yr at Old Malton) are taken from the River Derwent water levels instead.

For Malton and Old Malton, spreadsheet models have been used. While such an approach may appear unsophisticated, it is perfectly capable of modelling the main flood-locking mechanism under consideration. Taking into account the lack of explicit survey data for drainage assets in these areas, and the underlying uncertainties of hydrological methods and joint probability, these models are entirely appropriate.

For Norton, updates have been made to the existing Mill Beck numerical hydraulic models, built in ISIS, an industry standard hydraulic modelling programme.

Flood maps have been developed in GIS from model flood levels in conjunction with LiDAR information. These accompany the main report.

F2 Derwent

The most recent flood mapping project in the area was the "Malton Data Improvements study" (Halcrow 2009). Documentation from that study reports the following flood levels:

Model section locations	Old Malton	Norton 1	Norton 2	Norton	Malton 1, Malton 1.1	Malton 2	Malton 3	Malton 4
	Riggs Road outfall	Mill Beck outfall	Skatepark	Mill Beck - from Mill Beck conceptual model	US of Castlegate Br	DS of Castlegate Br	Chandler's Wharf	Morrisons car park
	MN3888	MN2084	MN1914		MN2118	MN2084	MN1968	MN1860
Return periods (years)	Water Levels (mOD)							
2	17.94	17.61	17.57	17.61	17.64	17.61	17.59	17.55
5	18.42	18.11	18.06	17.61	18.14	18.11	18.08	18.03
10	18.70	18.38	18.33	18.07	18.43	18.38	18.35	18.30
20	18.96	18.63	18.58	18.37	18.69	18.63	18.60	18.54
25	19.05	18.71	18.66	18.46	18.78	18.71	18.68	18.62
50	19.38	19.01	18.96	18.79	19.12	19.01	18.98	18.91
75	19.60	19.21	19.15	18.88	19.34	19.21	19.18	19.11
100	19.76	19.35	19.29	18.97	19.50	19.35	19.32	19.24
200	19.91	19.49	19.43	19.11	19.66	19.49	19.46	19.38
395 (100yr + cc)	20.21	19.74	19.68	19.74	19.94	19.74	19.71	19.63
1000	20.62	20.08	20.03	20.08	20.32	20.08	20.05	19.99

The Do Nothing assumption is that the River Derwent flood defences remain intact, but the penstocks and flaps protecting drainage systems from ingress by the Derwent fail in the open position. In Malton, and Old Malton, the flood cells behind the defences do not permit outflow, and so (because the Derwent can stay at height for so long), it is reasonable to assume that flood levels behind the defences effectively reach the water levels in the Derwent.

At Norton, overland flow can occur out of Norton via overland flow to Bark Knots field. The levels above highlighted in green are derived by

1) calculating the flow into the Welham Road area due to surcharging to the level of the River Derwent over the spill at the upstream end of the Mill Beck culvert

2) calculating the water level required to pass the same flow out of the Welham Road area via overland flow in the vicinity of LidL. This water level is used as the water level in Norton town centre.

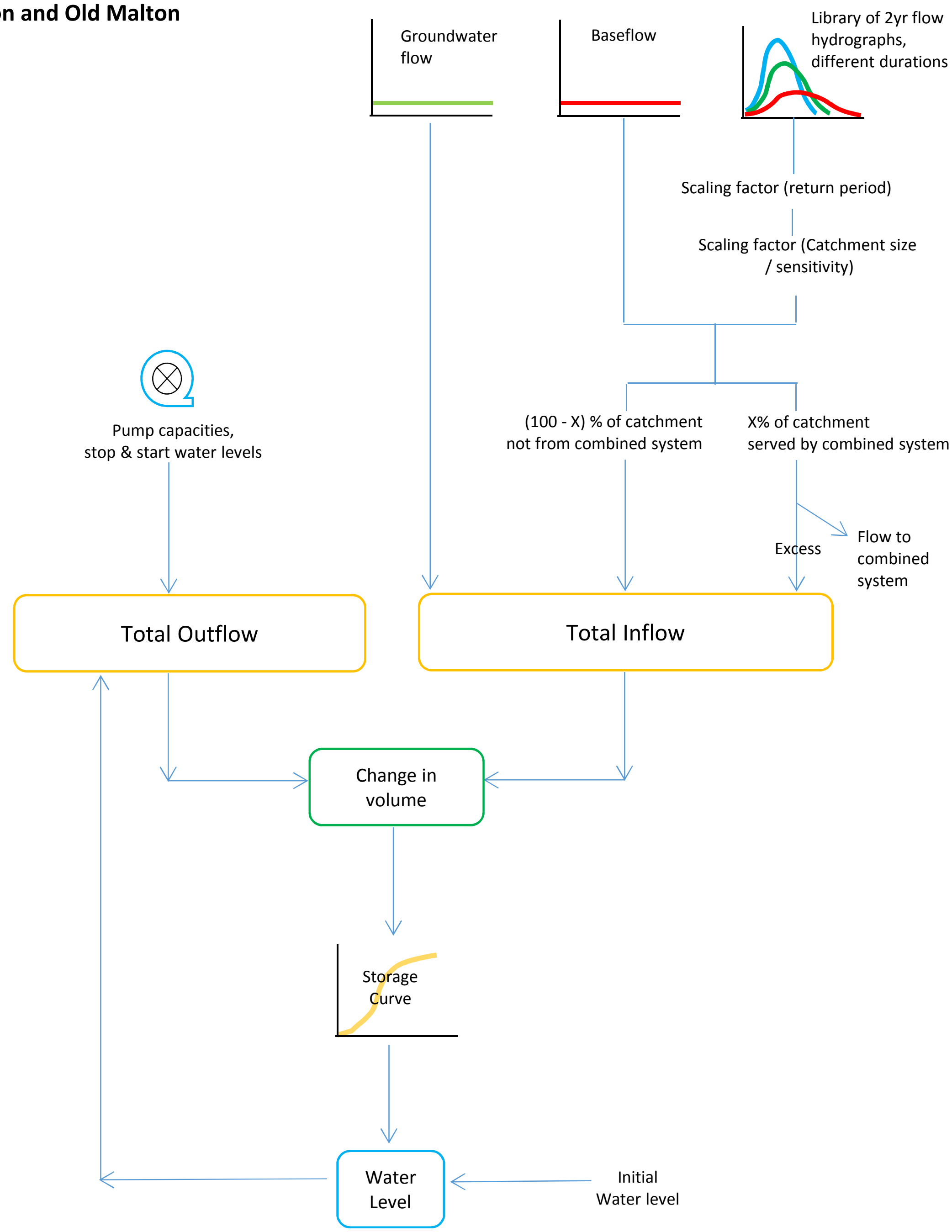
F3 Malton

F3.1 Methodology

The hydraulic model of the Malton flood cells is a series of spreadsheet mass-balance models representing the amount of inflow expected from each catchment, assumed ground water flows, inflows diverted by the combined sewerage system, the storage associated with each flood cell, and outflows provided by the pumping system.

A schematic of the routing model is shown overleaf in Figure F3.1.a

Schematic of spreadsheet models of Malton and Old Malton



The flood cells represented are shown below in Figure F3.1b. The storage curves associated with these are presented in Table F1.

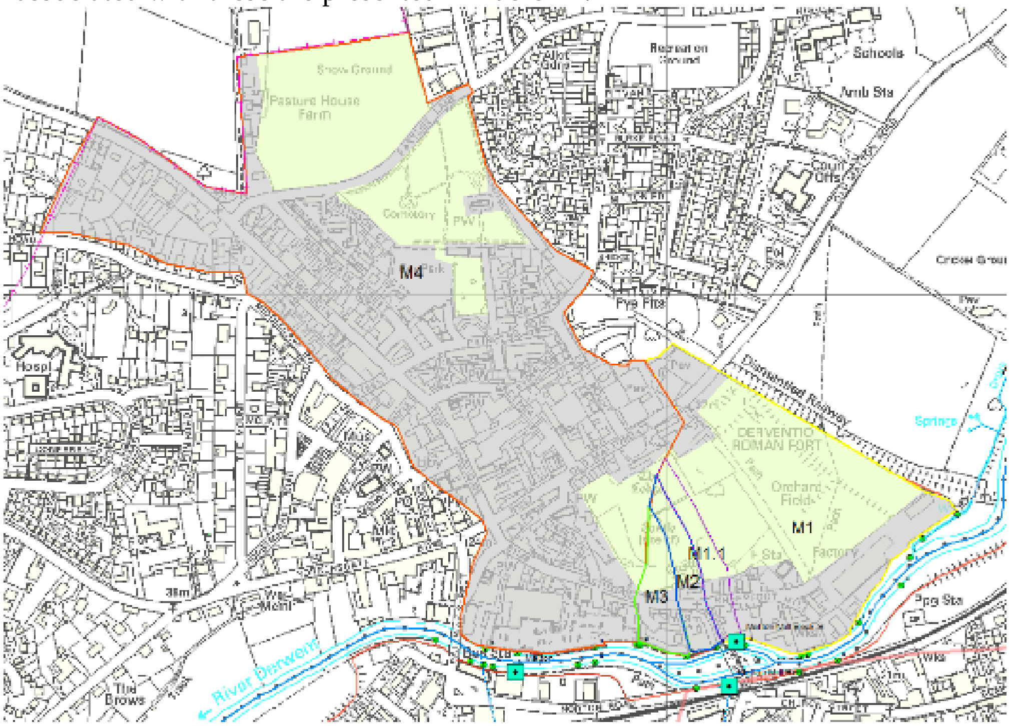


Figure F3.1b: Malton Flood cells

The models have been run for a range of storm magnitudes and pump capacities.

The results are shown in F7, assuming that no overtopping occurs due to the Derwent.

F3.2 Interpretation of results

These have allowed a number of conclusions to be drawn:

Groundwater flows in the surface water system alone (at the Chandlers Wharf outfall) have been reported by Yorkshire Water to be of the order of 20-30l/s. The pumping stations at Sheepfoot, Yates Yard, and Chandler's Wharf each have a capacity of 7l/s, giving them a combined capacity of 21l/s, potentially 9l/s too small to cope with a flood-locked situation, even in dry weather flows.

Modelling shows that, in extended flood events, it is the groundwater flow that is the dominant influence on peak water levels – doubling the scaling factor for rainfall based hydrographs has little effect (+/-0.02m) on peak water levels, whereas small changes in ground water flows (if in excess of pumping capacity) can have a large impact. This is particularly notable on the smallest flood cells, where the available storage capacity accentuates the differences.

In assessment of required pumping station capacities therefore, it is largely a matter of ensuring that pumping station capacity is in excess of the groundwater flow. The difficulty therefore lies in accurate assessment of groundwater flow values. Groundwater flows can vary greatly from location to location, dependent on subsurface fractures in the rock. Solutions that capture flow from a wider area are more likely to average out this effect and therefore have less sensitive outcomes. To this end, it is considered more robust to have a solution that will address Flood Cells 1.1, 2 and 3 together, rather than separate solutions.

F3.3 Implications for solutions.

Option 3 – Frequent deployment of temporary pumping (<every 4 years on average) would still be necessary to prevent significant disruption to businesses and homes. These would not necessarily prevent traffic disruption associated with overland flow on Castlegate. The lack of guidance to flow paths mean that there would be reduced certainty that all flood water could be ‘captured’ by temporary measures.

Option 2 – In addition to the resilience provided by property level protection, the proposed suite of measures would guide flow to formalised sumps for pumping, which would reduce disruption to property and traffic. Measures guiding flow away from the entrance to Castlegate will allow the YWS pumping station to deal with its own design flow. It is important however that there is the facility to divert flow from the Castlegate surface water system and combined system overflow towards the Castlegate sump – otherwise it will not cope.

Option 3 – Option 3 replaces reliance on emergency deployed pumps with permanent pumps. Costs of pumping stations (and the vulnerability of assumptions) can be reduced by linking flood cells together as far as possible. The required pumping capacities for a joint 50 year standard of protection are estimated as

M1:	100l/s
M1.1, M2 and M3 (combined):	50l/s
M4:	55l/s

These capacities are estimated in addition to the existing pump capacities.

F3.4 Recommendations

The main conclusion is that pumping capacities do not have to be great, but they do have to be in excess of the groundwater component of flooding. Uncertainty in groundwater flow values is therefore the main driver of potential pumping station size.

It is therefore recommended that monitoring of groundwater flows is carried out in greater detail than before. Extraction of pumping capacities deployed as part of the emergency response in November 2012 will also help understand the peak values of flow observed during that event.

F4 Old Malton

F4.1 Model build

The hydraulic model for Old Malton is a spreadsheet model similar to those presented for Malton.

The diversion structure is considered to divert 88% of the catchment's flows (the proportion assumed from the ratio of Qmed for this portion of the catchment compared to the overall catchment).

The results are shown in Table F4.1, assuming that no overtopping occurs due to the Derwent.

F4.2 Interpretation of results

The results show that diverting the catchment inflowing from upstream of the A64 allows a significant reduction in water levels in Malton. However, it can not prevent flow to Town Street in its entirety, and a low level of pumping (150l/s) would still be required to achieve the 200year standard of protection implied by the Derwent flood defences.

Without diversion, the system would be reliant on significantly larger pumps – capacity 2.5m^3/s, and at an estimated capital cost of £0.5m per m^3/s, there would be significant expense involved in the provision of this capacity.

F4.3 Implications for solutions

The diversion measure appears to be the most cost effective measure achieveable for Old Malton.

The modelling does not simulate the overland flow mechanism from Old Malton Road via Town Street, this being a different mechanism to the flood-locking problem. It appears that this is a frequent occurrence and suggests a blockage or capacity shortfall in drainage along Old Malton Road. One reasonable solution might be to install interception measures towards the east end of Old Malton Road that divert this flow into drainage ditches to the south of the road leading down to The Cut.

F5 Norton

F5.1 Model build

The study has used and adapted the Malton Data Improvements (MDI) Mill Beck model files (Halcrow 2009). The MDI Mill Beck model is a 1D ISIS model, based on the earlier Mill Beck Phase 2 model (Atkins 2005), with minor amendments to the channel cross-sections, node labelling, and versions for specific scenarios. Because of stability issues, Halcrow had not incorporated the Mill Beck model into the main ISIS-Tuflow 1D-2D hydrodynamic model of the River Derwent, though it does reference the resultant water levels for the downstream boundary. See Appendix B for more details.

The scenario-specific versions provided in the MDI study needed to be adapted for use:

- 01_MDI_MillBeck.DAT – with Derwent defences – with 2 pumps, penstock closed, no flood zone reservoir units;

- 02_MDI_MillBeck_Shortened.DAT - without Derwent defences – only modelled as far downstream as Mill Pond (i.e. no Mill Beck Pump Station, no representation of Mill Beck long culvert, and no flood zone reservoir units);
- 03_MDI_MillBeck_withoutd.DAT - without Derwent defences – with 2 pumps, penstock closed, 2 flood zone reservoir units.

Arup have developed a new 01_MDI_MillBeck_WithD.DAT model as follows:

- The model nodes have been taken from the 03_MDI_MillBeck_withoutd.DAT model, which includes minor channel cross-section changes to the 01_MDI_MillBeck.DAT model, and includes two reservoirs and associated spills representing flood zones in the Church Street and Welham Road area.
- The pump and sluice details and logic control have been copied from the 01_MDI_MillBeck.DAT model.
- The sluice is set to permanently closed, representing full flood-locking by the River Derwent behind the Derwent defences.

Specific changes between model versions during development and runs are detailed in the Model Log. Relevant sections have been copied in below:

Scenario	Model file name	Description
1 - With Defences, model development	01_MDI_MillBeck_WithD.DAT	Model development. Mill Beck can flood into 2 reservoirs at culvert inlet. This is taken from the MillBeck_withoutD model. Only one of the pumps is set to work.
001 With defences, model dvmt	01_MDI_MillBeck_WithD_001.DAT	Model development. Updated previous to have both pumps working. This model needs to work for up to 50 yr event. After that, the flood levels should be replaced by the Derwent overtopping levels and a modified model could be used (like 02_MDI shortened).
002 - pump on level reduced to 16.5	01_MDI_MillBeck_WithD_002.DAT	Testing pump on/off level optimisation. Both pumps changed, reducing on level from 16.7 and 16.72 mAD to 16.1mAD and 16.12.
003 - one pump only	01_MDI_MillBeck_WithD_003.DAT	Original pump on/off levels, but only one pump working. Will be used to test whether changing pump 2 on/off level only would be a useful optimisation.
004 - duty / assist arrangement	01_MDI_MillBeck_WithD_004.DAT	Pump 1 on level lowered to 16.1mAD. Pump 2 on level same as in original (001).
005 - With Derwent Defence, 2 pumps working	01_MDI_MillBeck_WithD_005.DAT	Model development. With Derwent Defences. 2 reservoir flood zones for the flooded areas on Church Street and Bark Knots. PS working with 2 pumps (2 * 0.4 m3/s). On levels at 16.7 mAD. Sluice permanently closed.
006 - With Derwent Defence, 1 pump working	01_MDI_MillBeck_WithD_006.DAT	Model development. With Derwent Defences. 2 reservoir flood zones for the flooded areas on Church Street and Bark Knots. PS working with 1 pumps (1 * 0.4 m3/s). On levels at 16.7 mAD. Sluice permanently closed.

007 - With Derwent Defence, no pumps working	01_MDI_MillBeck_WithD_007.DAT	Model development. With Derwent Defences. 2 reservoir flood zones for the flooded areas on Church Street and Bark Knots. PS not working with both pumps deleted and references in junctions removed. Sluice permanently closed.
008 - With Derwent Defence, 2 pumps@300l/s	01_MDI_MillBeck_WithD_008.DAT	Model development. Same as 005 but with amended pump rates to match EA information of 300l/s pumps, despite not matching previous reports and studies. With Derwent Defences. 2 reservoir flood zones for the flooded areas on Church Street and Bark Knots. PS working with 2 pumps (2 * 0.3 m3/s as per indication from EA). On levels at 16.7 mAD. Sluice permanently closed.
009 - With Derwent Defence, 2 pumps, start level 16.2mAD	01_MDI_MillBeck_WithD_009.DAT	Model development. Same as 005 but with lower pump start levels. With Derwent Defences. 2 reservoir flood zones for the flooded areas on Church Street and Bark Knots. PS working with 2 pumps (2 * 0.4 m3/s). On levels reduced to 16.2 mAD, hunting range also lowered to 15.9mAD. Sluice permanently closed.
010 - With Derwent Defence, 2 pumps, start level 16.5mAD	01_MDI_MillBeck_WithD_010.DAT	Model development. Pump start levels mid way between 005 and 008 models. With Derwent Defences. 2 reservoir flood zones for the flooded areas on Church Street and Bark Knots. PS working with 2 pumps (2 * 0.4 m3/s). On levels set to 16.5 mAD, hunting range also lowered to 15.9mAD. Sluice permanently closed.
005 OSD - Optimal storm duration	01_MDI_MillBeck_WithD_005_OSD.DAT	Swapped QTBDY for FEH BDY to enable Optimal Storm Duration tool to work. 2 pumps. FEH BDY is the Q50
005 OSD 2 - Optimal storm duration	01_MDI_MillBeck_WithD_005_OSD2.DAT	OSD reveals anything over 5-6 hrs is critical, and remains at a high level for the Q50 storm. Limited by pump capacity. Because the pump capacity equates to peak flows somewhere between Q2 and Q5, then another OSD is tested on a smaller event to identify max stage when not completely overwhelmed. FEHBDY is replaced by the Q2 event.
011 - 3 pumps	01_MDI_MillBeck_WithD_011.DAT	Addition of a pump 3 connected along with the existing 2 pumps. Set and run to test various pump rates and start / stop levels, outputting the results into a relevant sub-folder, but just keeping this one Model DAT.
012 - 3 pumps	01_MDI_MillBeck_WithD_012.DAT	Addition of spill from Bark Knots going to a sink - to avoid Bark Knots storage area from biasing results at Norton. Re ran sequence of flows. Multiplier used in pump unit to allow for different capacities. Mostly run with 2 pumps rather than 3.

F5.2 Interpretation of results

F5.2.1 Do Nothing

The overland spill mechanism to Bark Knots provides a 0.30m relief in flood levels for events below the flood defence capacity. Depths of flooding are however quite considerable.

F5.2.2 Existing situation

The existing pumping station capacity is 0.6m^3/s, provided by 2no 300l/s pumps.[1] This pump capacity is however just slightly less than the estimated 2yr flow on the Mill Beck. Taking into account the 1:5 ratio from the joint probability analysis

[1] Environment Agency email, 22 May 2015.

(Appendix E), this implies that the pumping station provides an approximate 10yr standard of protection.

F5.2.3 Reconfiguration of Mill Beck PS start levels.

Currently the interaction of the Mill Beck pumping station and the Welham Road CSO causes flooding to YWS sewer systems if the CSO is not closed off via a penstock. This is apparently because the start level of the Mill Beck pumping station is 16.7mOD – the soffit of the Mill Beck culvert. It therefore undeniably would cause flooding to the YWS system as soon as the Mill Beck penstock is closed.

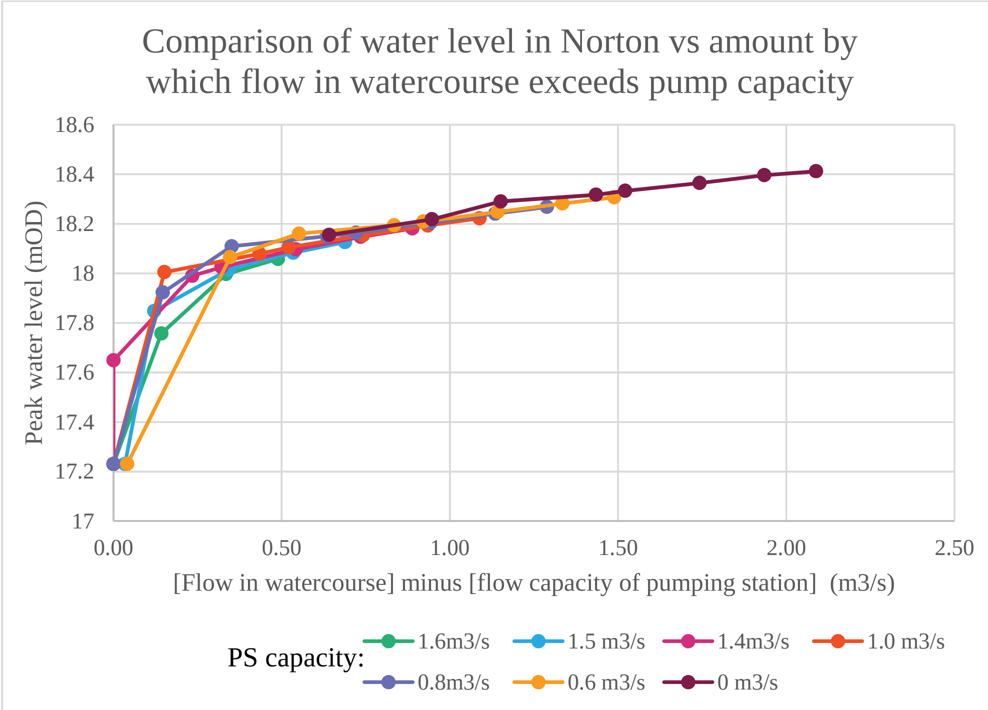
While YWS were not able to report the level of the CSO, it is noted that the existing pumping arrangement is well capable of retaining the water level in the Mill Beck culvert to 16.4mOD or potentially lower. The trade-off for this is the numbers of stops and starts in operation (theoretically reducing the start water level to half the culvert height will double the number of stops and starts), and a mechanical engineering opinion would be required to advise on the implications of this for the particular pumps in the Mill Beck Pumping Station.

However, as above, the existing pumps can only achieve this up to a 10year joint probability. For events in excess of that, water levels will start to rise in excess of the pump start level. Improvements to the pump start levels alone will not therefore remove the need for Yorkshire Water to close the CSO penstock; such an exercise would have to be carried out in conjunction with pumping station upgrades.

F5.2.4 The benefits of pumping capacity on the Mill Beck

The model results are given in F7.3

There is a strong relationship between the degree to which an event's peak flow exceeds the capacity of the Mill Beck pumping station, and the peak water level it will reach.



The existing pumping capacity will result in flooding in events little greater than the 2year event (joint return period, 10yrs). A 50yr standard of protection can be achieved with a pumping capacity of 1.2m^3/s, but cognisance would need to be taken of the underlying uncertainty in hydrological estimates.

F5.3 Recommendations

Further hydraulic modelling may still be necessary to fully understand flood mechanisms associated with the Yorkshire Water combined sewerage system in the vicinity of Church Street and Welham Road (Norton). It is however understood that Yorkshire Water are carrying out a flood modelling exercise in the area, for which the flow surveys are intended to have started in June 2015, with an expected project duration of 9 months.

It is nonetheless apparent that, with the Mill Beck penstock closed, the system has little residual capacity to deal with additional rainfall, potentially due to high infiltration when the water table is raised. If a higher capacity is to be provided, either additional pumping capacity needs to be provided at Welham Road north pumping station, or a pumped CSO facility is needed in the vicinity of Church Street.

An allowance of 0.30m head difference on top of the water levels from the Mill Beck modelling have been used to simulate the impact of the Yorkshire Water Sewer system within the economic analysis. This figure is based on the inferred minimum head difference between the two systems in the November 2012 event.

There is some inconsistency between the levels of a number of different data sources used in the Norton analysis (LiDAR, the Mill Beck hydraulic model, the

Derwent hydraulic model and Yorkshire Water sewer data). It is recommended that topographic survey be carried out of key features to confirm levels.

F6 Conclusions and recommendations

Hydraulic modelling has represented the flood locking mechanisms of Malton and Old Malton, and the free flow and flood locking mechanisms along the Mill Beck in Norton.

Further hydraulic modelling may still be necessary to fully understand flood mechanisms associated with the Yorkshire Water combined sewerage system in the vicinity of Church Street and Welham Road (Norton). It is however understood that Yorkshire Water are carrying out a flood modelling exercise in the area, for which the flow surveys are intended to have started in June 2015, with an expected project duration of 9 months.

Results are particularly sensitive to assumed values of groundwater flows, and monitoring is required to establish these values with greater confidence.

There is some unconsistency between the levels of a number of different data sources used in the Norton analysis (LiDAR, the Mill Beck hydraulic model, the Derwent hydraulic model and Yorkshire Water sewer data). It is recommended that toporgaphic survey be carried out of key features to confirm levels.

F7 Tables

F7.1 Storage Curves

F7.1.1 Malton Storage Curves

	Morrisons (M4)	Chandlers Wharf (M3)	Castlegate (M2)	Boathouse (M1.1)	Sheepfoot (M1)	Morrisons + Chandlers Wharf + Castlegate	Chandlers Wharf + Castlegate	Boathouse + Sheepfoot
Level	Volume	Volume	Volume	Volume	Volume	Volume	Volume	Volume
(mOD)	(m3)	(m3)	(m3)	(m3)	(m3)	(m3)	(m3)	(m3)
16.7	-10000	-10000	-10000	-10000	0	-10000	-10000	0
16.8	0	-10000	0	-10000	1.8	0	0	1.8
16.9	1.4	-10000	2.2	-10000	4.8	3.6	2.2	4.8
17	4.6	-10000	8.6	-10000	9.4	13.2	8.6	9.4
17.1	10.4	-10000	20.8	-10000	15.6	31.2	20.8	15.6
17.2	19.2	-10000	39.4	-10000	23.6	58.6	39.4	23.6
17.3	31.4	-10000	65.8	-10000	33.6	97.2	65.8	33.6
17.4	46.6	-10000	100.8	-10000	46.4	147.4	100.8	46.4
17.5	65.8	-10000	144.6	0	64.6	210.4	144.6	64.6
17.6	92.8	0	198.6	7.6	90.8	291.4	198.6	98.4
17.7	142	0.8	267.6	29.6	132.2	410.4	268.4	161.8
17.8	244	3.4	358.4	74.2	208.8	605.8	361.8	283
17.9	428.4	10.2	469.4	142.2	354.6	908	479.6	496.8
18	701.4	26	597.2	227.2	604	1324.6	623.2	831.2
18.1	1051.2	57.2	744	324.2	983.6	1852.4	801.2	1307.8
18.2	1474	107.6	908.4	431.6	1544	2490	1016	1975.6
18.3	1976.6	175.4	1090	551.6	2407.8	3242	1265.4	2959.4
18.4	2569	260.6	1294.2	690	3659.2	4123.8	1554.8	4349.2
18.5	3258.2	373.6	1520	844.6	5270.4	5151.8	1893.6	6115
18.6	4039.8	535.2	1766.4	1011	7157.2	6341.4	2301.6	8168.2
18.7	4904	751.4	2034.6	1188	9233.8	7690	2786	10421.8
18.8	5847.6	1009.4	2322.4	1372	11445	9179.4	3331.8	12817
18.9	6867.6	1294.4	2627.2	1559.8	13738.6	10789.2	3921.6	15298.4
19	7954	1593.2	2942.2	1750.4	16079.8	12489.4	4535.4	17830.2
19.1	9103.4	1900.6	3261.6	1944.6	18461.2	14265.6	5162.2	20405.8
19.2	10316	2215.2	3584	2141.6	20882	16115.2	5799.2	23023.6
19.3	11582.6	2536.8	3908.4	2341	23333.4	18027.8	6445.2	25674.4
19.4	12897.6	2866.2	4234	2542.4	25804.8	19997.8	7100.2	28347.2
19.5	14261.4	3203.2	4560.8	2745.8	28291.4	22025.4	7764	31037.2
19.6	15674	3548.6	4888.6	2951	30791.8	24111.2	8437.2	33742.8
19.7	17138.4	3900.8	5216.6	3156.6	33302.4	26255.8	9117.4	36459
19.8	18658	4255.8	5544.6	3362.2	35820.2	28458.4	9800.4	39182.4
19.9	20235.8	4614.2	5872.6	3567.8	38345.2	30722.6	10486.8	41913
20	21875.2	4977	6200.6	3773.4	40877.4	33052.8	11177.6	44650.8

F7.1.2 Old Malton storage curve

Level	Volume
(mOD)	(m3)
15.4	0
16	112.5
16.2	150
16.4	187.5
16.6	225
16.8	262.5
17	300
17.2	337.5
17.4	375
17.6	595
17.8	815
18	1259.244
18.1	1714.234
18.2	2169.224
18.3	2624.214
18.4	3079.204
18.5	3905.761
18.6	4849.656
18.7	5793.551
18.8	7563.581
18.9	9350.471
19	11137.36
19.1	13722.99
19.2	17016.95
19.3	20310.9
19.4	23604.85
19.5	27128.89
19.6	32057.35
19.7	36985.8
19.8	42224.57
19.9	47891.88
20	58851.55
20.1	70672.77
20.2	82494
20.3	94315.22
20.4	106136.4
20.5	117957.7
20.6	129778.9
20.7	132431.3
20.8	133071.1
20.9	133710.8
21	134350.6

F7.2 Malton Hydraulic modelling results

Results tabulated from the hydrological flood model developed for Malton and for Old Malton. Except where otherwise indicated, all values in the tables are water levels (mAD).

F7.2.1 Malton

F7.2.1.1 Malton 1

Baseflow (i.e. groundwater) = 0.042 m^3/s

Existing pump capacity 0.007m3/s at Sheepfoot Hill

Qmed = 0.250 m^3/s

Return Period	Pump capacity 0 m^3/s (DoN)	Pump capacity 0.007 m^3/s (DoM)	Pump capacity 0.007 +0.045 m^3/s	Pump capacity 0.007 +0.06 m^3/s	Pump capacity 0.007 + 0.075 m^3/s
2	18.66	18.58	17.63	16.87	16.82
5	19.03	18.93	17.74	17.29	17.27
10	19.23	19.17	17.81	17.50	17.49
15	19.48	19.32	17.83	17.59	17.59
20	19.61	19.43	17.85	17.65	17.64
25	19.71	19.51	17.88	17.70	17.69
30	19.77	19.57	17.90	17.73	17.71
50	20.07	19.82	17.94	17.81	17.78

F7.2.1.2 Malton 1.1

Baseflow (i.e. groundwater) = 0.020 m^3/s

Start water level = 17.50 mAD

Return Period	Pump capacity 0 m^3/s (DoN)	Pump capacity 0.025 m^3/s (groundwater + 0.050)	Pump capacity 0.0150 m^3/s (groundwater – 0.050)
2	-same as river level-	17.55	18.91
5	-same as river level-	17.59	19.71
10	-same as river level-	17.61	20.35
15	-same as river level-	17.62	20.75
20	-same as river level-	17.63	21.05
25	-same as river level-	17.64	21.28
30	-same as river level-	17.65	21.43
50	-same as river level-	17.65	22.14

Sensitivity to flow = 0.04 (max event)

F7.2.1.3 Malton M2+M3

Baseflow (i.e. groundwater) = 0.046 m^3/s

Existing pump capacity 0.007m3/s at Chandlers Wharf

Start water level = 16.8 mAD

	Storage in M2 + M3	Storage in M2 + M3	Storage in M2 only, flow from M2 & M3	Storage in M2 only	Storage in M2 only	Storage in M2 only
Return Period	Pump capacity 0 m^3/s (DoN)	Pump capacity 0.007 m^3/s (DoM)	Pump capacity 0.046 m^3/s	Pump capacity 0.051 m^3/s	Pump capacity 0.066 m^3/s	Sensitivity Pump capacity 0.046 m^3/s **Qmed increased to 0.45m3/s**
2	19.64	19.46	16.98	16.80	16.80	16.80
5	20.92	20.57	17.04	16.91	16.80	16.92
10	21.96	21.46	17.10	16.98	16.80	17.04
15	22.60	22.02	17.13	17.02	16.80	17.10
20	23.10	22.44	17.15	17.04	16.80	17.14
25	23.46	22.75	17.17	17.06	16.80	17.17
30	23.72	22.98	17.18	17.07	16.80	17.20
50	24.88	23.97	17.23	17.12	16.80	17.26

F7.2.1.4 Malton 2 + 3 + 1.1

Representing the scenario with thrust bored pipe through Castlegate Bridge to join flood cells.

Existing pump capacity 0.007m3/s at Chandlers Wharf

Baseflow (i.e. groundwater) = 0.060 m^3/s

NB:- sewer baseflow not needed to be included in this scenario.

Return Period	Pump capacity 0.080 m^3/s	Pump capacity 0.100 m^3/s	Full Qmed sensitivity
2	16.80	16.70	16.80
5	16.80	16.70	16.92
10	16.80	16.98	17.04
15	16.80	17.19	17.10
20	16.84	17.33	17.14
25	16.89	17.42	17.17
30	16.92	17.48	17.20
50	17.10	17.63	17.26

F7.2.1.5 Malton 4

Existing pump capacity 0.007m3/s at Yates Yard

Peak flow capacity of combined system: 0.39m3/s

Return Period	Water level (m^3/s)					
	Pump capacity 0 m^3/s	Pump capacity 0.007 m^3/s (existing at Yates Yard)	Pump capacity = ground water + 0.005 m^3/s	Pump capacity = ground water + 0.010 m^3/s	Pump capacity = ground water – 0.005 m^3/s	Sensitivity analysis: Pump capacity = ground water + 0.005 m^3/s **Qmed increased to 0.45m3/s**
2	19.07	18.97	17.72	17.69	17.99	17.90
5	19.74	19.58	17.80	17.79	18.10	17.99
10	20.18	19.98	17.86	17.85	18.15	18.06
15	20.42	20.20	17.90	17.88	18.18	18.11
20	20.60	20.36	17.92	17.91	18.21	18.14
25	20.72	20.47	17.94	17.92	18.23	18.17
30	20.82	20.55	17.95	17.93	18.24	18.20
50	21.21	20.90	18.00	17.98	18.28	18.27

F7.2.2 Old Malton

Combined probability analysis gives an assumed ratio of 1:5, i.e. for a 200 year Derwent event, we can expect ~40 year rainfall event over Old Malton (likely to be conservative).

F7.2.2.1 Pump, no diversion

Return Period	Storm duration (hr)	Pump capacity 2 m^3/s
2		15.4 (no flood)
5		15.4(no flood)
10		15.4(no flood)
15		15.49(no flood)
20	15.5	17.97 (no flood)
25	15.5	18.35
30	15.5	18.56

50	15.5	18.96

F7.2.2.2 Pump and divert

Return Period	Storm duration (hr)	Pump capacity 0.150 m^3/s
10		No damages
15		No damages
20		No damages
25	19.5	18.21
30	19.5	18.29
50	21.5	18.47
75	21.5	18.56

F7.2.2.3 Diversion, no pump

Diversion peak flow:

- 50 year event = 2.40 m^3/s
- 75 year event = 2.64 m^3/s
- 100 year event = 2.82 m^3/s

Return Period	Storm duration (hr)	Pump capacity 0 m^3/s
2	49.5	18.59
5	49.5	18.78
10	49.5	18.90
15	49.5	18.97
20	49.5	19.02
25	49.5	19.05
30	49.5	19.08
50	49.5	19.16

F7.3 Norton Results

Peak Water levels in Norton flood cell (mOD)

Design event			Pump capacity (m3/s)		
Return period (yrs)	Joint Return Period (yrs)	Design flows (m3/s)	0	0.6	1.2
0002	0002	0.64	18.16	17.23	17.23
0005	0005	0.95	18.22	18.07	17.23
0010	0010	1.15	18.29	18.16	17.65

0025	0025	1.43	18.32	18.19	17.99
0030	0030	1.52	18.33	18.21	18.03
0050	0050	1.74	18.36	18.25	18.10
0075	0075	1.93	18.40	18.28	18.15
0100	0100	2.09	18.41	18.31	18.18

Appendix G

Economics

Contents

G1 Introduction

This appendix details the economic appraisal undertaken in support of the Malton & Norton Flood Study. It sets out the options appraised, how benefits have been calculated, how costs have been calculated and what the resulting benefit cost ratios suggest.

The project brief is clear in stating that this study is to include “coarse” cost benefit, and the level of detail carried out in our analysis reflects the brief.

G2 Assessment of benefits

G2.1 Overview

The options benefits have been calculated in terms of flood damages avoided relative to a baseline, following the principles of the FCERM-AG. Arup’s in house flood damage calculation tool, “Floodlight,” has been used to calculate flood damages in line with the processes of the Middlesex University Flood Hazard Research Centre “Multi-Coloured Manual,” 2013 (MCM).

G2.2 Baseline

The “Do Nothing” baseline assumes that the penstocks, and flap valves on local watercourses are not operated or maintained and therefore will fail in an open position. High river levels on the River Derwent will therefore result in high water levels on the landward side of the current river defences. Given that the Derwent can remain high for a number of days, it is assumed that the water levels on the landward side will match the peak water levels on the Derwent.

An alternative, harsher baseline was considered in which the penstocks and flap vales failed in the closed position, resulting in water level build up to the defence height, which would have resulted in write off of all property behind defences. This was however dismissed for being unrealistic, and reliant on the Derwent defences retaining water on their landward side (which they would not have been designed for).

G2.3 Treatment of multiple sources

It is assumed in all options that flood levels revert to the river level for events in excess of the stated standard of protection of the river defences. The surface water and ground water mechanisms are highly dependent on the level of the Derwent, and therefore it would not be appropriate to add the benefits associated with separate mechanisms.

G2.4 Damages assessed

The following damages have been calculated:

- Damages to residential and non-residential properties (including costs of clean-up and dehumidifiers)

- Costs of evacuation
- Intangible damages
- Vehicle damages
- Emergency Services (assumed at 5.6% of direct damages)
- Utilities damages (assumed at 10% of direct damages)

The following damages were not assessed:

- Risks to life – it is assumed that flood levels in the study area rise too slowly to be of concern for risks to life.
- Traffic disruption – it is recognised that loss of transport over the Castlegate bridge and associated south bank junction is a significant element of concern to local residents. Given the length of occurrence, prevention of this disruption has potentially high benefit. However, the calculation of traffic damages is a lengthy procedure, and therefore considered to be outside the scope of "coarse" assessment.
- Rail disruption – similar to traffic disruption.
- Loss of business – conventionally, economic analysis for the purposes of securing Flood and Coastal Erosion Risk Management Grant in Aid (GiA) does not consider loss of business, unless significant international exports are involved. This may however prove useful in identifying key beneficiaries of any proposals

G2.5 Key assumptions

G2.5.1 Property threshold

Calculated from LiDAR; assumed to be 0.30m above local ground level

G2.5.2 Flood Warning

There is currently no flood warning in the study area for groundwater or surface water flooding. It is therefore assumed that Flood Warning is not available in Options 1 and 2. For Options 3,4 and 5, Flood Warning > 6 hours is assumed.

G2.5.3 Reliability of pumping regimes

Option 2: It is assumed that the current emergency pumping regime may fail to protect 20% of the time (approximately once in 20 years). This is related to potential lack of pump availability, but also to the lack of formal infrastructure to place pumps in. When the pumping regime fails, damages revert to the Option 1 value.

It is assumed that provision of formal infrastructure to place pumps in may halve the failure percentage to 10% (Options 3 and 4). The provision of permanent pumps is assumed to have 0% failure (Options 5).

G2.5.4 Effectiveness of property level protection

Property level protection is assumed to be provided to all properties subject to the 50year flood in Options 3, 4 and 5 for each area.

Property level protection is reliant on appropriate installation, and on householders being present and having enough time to implement any protection measures. Property level protection can also be overwhelmed by flooding in excess of 0.9m. It has assumed that property level protection reduces the residual damages of Options 3, 4 and 5 by 50%.

G2.5.5 Treatment of climate change

To avoid remodelling of scenarios or reassessment of damages, climate change has been calculated on the basis of reassigning probability. The probabilities of the modelled events have been recalculated, based on the underlying growth curves of flow (for the Derwent, applicable to the Do Nothing) and rainfall (for the Mill Beck and drainage systems), and the percentages of uplift from Environment Agency Guidance, as follows:

Reassignment of flow return periods (years) with climate change

Present Day	2025 - 2039	2040 - 2069	2070 +
2	1.8	1.6	1.5
5	3.9	3.3	2.4
10	7	6	4
25	17	13	8
50	33	26	16
75	50	38	23
100	66	50	30
200	128	96	56
1000	739	606	429

Reassignment of rainfall return periods (years) with climate change

Present Day	2025 - 2039	2040 - 2069	2070 +
2	1.8	1.6	1.4
5	5	4	3
10	9	8	5
15	14	12	8
20	19	15	11
25	24	19	13
30	28	23	16
50	47	38	26

G2.5.6 Capping of property values

Annual average damages have been calculated for each option at each property assessed, for the four EA climate change scenarios.

The annual average damages for each property, for each year are calculated based on the appropriate climate change scenario, and multiplied by discount factors as based on Treasury Green Book guidance (Table 6.1, Annex 6)

Treasury Green Book Discount rates

Start year of period	End year of period	Discount rate (%)
0	30	3.5
31	75	3
76	125	2.5
126	200	2
201	300	1.5
301	1000	1

This provides the net present damage per property for each given year. These are then summed and capped so that they do not exceed the market value of that property in total.

The property values used were as follows:

Residential:

Property type	Property value
Detached	273,493
Semi-detached	155,388
Terraced	131,176
Bungalow	125,074
Flat	125,074

Non-residential:

MCM lower band	Bulk Class	Rental Yield (%)	Rateable value £/m2	Market Value £/m2
200	Retail	6.7	93	1,388
300	Offices	6.7	68	1,015
400	Factories	8.09	27	334
500	Other	8.09	59	729
800	Warehouses	8.09	37	457

G2.6 Flood Damages results

The Do Nothing damages are summarised in Table 1 at the end of this appendix.

G3 Costs

G3.1 Costs overview

A rough Bill of Quantities has been built up for Options 3, 4 and 5, and evaluated by a Quantity Surveyor.

Project team members have built up some allowances for whole life costs associated with maintenance of pumps and other assets.

G3.2 Allowances

The following allowances have been made on top of the core capital works figure:

Main contractor's preliminaries incl access	25%
Traffic management	Sum, estimated by QS
Ground Risk – rock and contamination	5%
Main contractor's construction risk	10%
Consultants costs	10%
Site Investigation and survey	5% (or sum, where necessary for consistency)
Compensation	5%
Optimism Bias	40%

G3.3 Do Minimum costs

Costs associated with Option 2 are based on an estimate of 5 non-emergency services staff being in full time attendance for 3 days per flood event at each area. Emergency services costs are not assessed within costs, because they are assumed to be included in the damages estimates. It is recognised that such an assessment may be an underestimate of the true costs of the current regime, since it ignores (for instance) costs of upkeep of pumps, post flood clearance work and post flood reviews.

G3.4 Optimism Bias

The Optimism bias allowance of 40% has been built up by reference to the 2013 Supplement to the Treasury Green Book. This has been achieved by identifying what percentage of the standard 66% optimism bias is likely to be applicable in Malton, as follows:

Contributary Factors to Capital Expenditure		**Non-Standard Projects (%)**	**Malton & Norton (%)**
Procurement	Other (specify)	2	2
Project Specific	Design Complexity	8	4
	Degree of Innovation	9	4
	Environmental Impact	5	2
Client Specific	Inadequacy of the Business Case	35	28
	Funding Availability	5	5
	Project Management Team	2	0
	Poor Project Intelligence	9	1
Environment	Site Characteristics, Permits / Consents / Approvals	5	3
External Influences	Economic	3	3
	Legislation/Regulations	8	4
	Technology	8	4
	Other (specify)	1	1
Total		100	61

	Non-Standard Projects	**Malton & Norton**
Upper Bound Optimism Bias:	**66**	**40 (61% of 66)**

Costs of +/- 20% (approximately equivalent to optimism bias 68% / 17%) have been used in sensitivity analyses.

G3.5 Costs Build up

Table 2 presents the costs build up for Options 3, 4, 5 for each area.

G4 Benefit Cost Ratios

The benefit cost ratios of the individual options are presented below, together with indicative results from the Partnership Funding calculator, which indicate the level of funding that would be available from FCERM Grant in Aid, and the residual that would have to be sourced from Partnership Funding Contributions.

G4.1 Best estimates

	Malton Options				
	M1	M2	M3	M4	M5
NPV Damages (£)	10,188,745	4,527,152	1,900,570.98	1,867,929.29	1,555,876.63
Benefits (£)	-	5,661,594	8,288,174.30	8,320,815.99	8,632,868.65
Costs (£)	-	42,033	1,310,960.00	1,103,704.00	1,090,572.00
BCR		134.7	6.32	7.54	7.92
Costs eligible for FCERM GiA (£)			724,446.26	726,259.69	743,595.95
PF contribution required (£)			586,513.74	377,444.31	346,976.05

	Norton Options				
	N1	N2	N3	N4	N5
NPV Damages (£)	15,427,826	12,046,668	5,410,455.42	5,168,352.61	4,773,542.10
Benefits (£)	-	3,381,158	10,017,370.18	10,259,472.99	10,654,283.50
Costs (£)	-	42,033	2,277,758.00	2,176,216.00	2,544,969.00
BCR		80.4	4.40	4.71	4.19
Costs eligible for FCERM GiA (£)			1,006,860.08	1,020,310.24	1,042,244.16
PF contribution required (£)			1,270,897.92	1,155,905.76	1,502,724.84

	Old Malton Options				
	OM1	OM2	OM3	OM4	OM5
NPV Damages (£)	3,758,799	2,671,431	1,276,386.45	506,418.26	485,030.70
Benefits (£)	-	1,087,368	2,482,412.54	3,252,380.73	3,273,768.29
Costs (£)	-	84,066	1,003,870.00	745,752.00	1,150,464.00
BCR		12.9	2.47	4.36	2.85
Costs eligible for FCERM GiA (£)			388,316.11	431,092.12	432,280.32
PF contribution required (£)			615,553.89	314,659.88	718,183.68

G4.2 Sensitivity testing

Sections G4.2.1 to G4.2.4 below provide additional information designed to illustrate the impact of combining the schemes, reducing costs and increasing benefits – all of which may or may not be possible, depending on the outcome of more detailed appraisal.

G4.2.1 Single project

The impact of combining all three scheme into a single project, with costs and benefits merged.

	Overall				
	1	2	3	4	5
Damages (£)	29,375,370	19,245,251	8,587,412.85	7,542,700.16	6,814,449.42
Benefits (£)	-	10,130,119	20,787,957.02	21,832,669.71	22,560,920.45
Costs (£)	-	168,131	4,592,588.00	4,025,672.00	4,786,005.00
BCR		60.3	4.53	5.42	4.71
Costs eligible for GiA (£)			2,119,622.45	2,177,662.05	2,218,120.42
PF req'd (£)			2,472,965.55	1,848,009.95	2,567,884.58

G4.2.2 Combined scheme, reduced benefits and costs

This scenario shows what the situation would be with a combined scheme should further appraisal work identify 20% additional scheme benefits and also that a 20% optimism bias (rather than 40%) is likely to be sufficient. This is a best case scenario that would need to be verified using additional investigation.

Table 6	Overall (Benefits up 20%; Costs down 20%)				
	1	2	3	4	5
Damages (£)	29,375,370	19,245,251	8,587,412.85	7,542,700.16	6,814,449.42
Benefits (£) + 20%	-	12,156,143	24,945,548.42	26,199,203.65	27,073,104.53
Costs (£) - 20%	-	134,505	3,674,070.40	3,220,537.60	3,828,804.00
BCR		90.4	6.79	8.14	7.07
Costs eligible for GiA (£)			2,350,599.75	2,420,247.27	2,468,797.32
PF req'd (£)			1,323,470.65	800,290.33	1,360,006.68

G4.2.3 Malton and Norton combined

This scenario shows the situation should the works in Norton and Malton be combined, but the proposals in Old Malton, which are the least cost-beneficial, be removed from the combined scheme.

	Malton/Norton Only				
	1	2	3	4	5
Damages (£)	25,616,571	16,573,820	7,311,026.40	7,036,281.90	6,329,418.72
Benefits (£)	-	9,042,751	18,305,544.48	18,580,288.98	19,287,152.15
Costs (£)	-	84,066	3,588,718.00	3,279,920.00	3,635,541.00
BCR		107.6	5.10	5.66	5.31
Costs eligible for GiA (£)			1,731,306.34	1,746,569.93	1,785,840.10
PF req'd (£)			1,857,411.66	1,533,350.07	1,849,700.90

This scenario indicates that, depending on the option selected, combined scheme costs could feasibly be between £3.2m and £3.8m. Between £0.8m and £1.4m of these costs would need to be secured from sources other than FCERM GiA (ie from partnership funding).

G4.2.4 Malton and Norton, reduced benefits and costs

The scenario shows the situation should: Norton and Malton be combined (as above), and further appraisal work identify 20% additional scheme benefits and also that a 20% optimism (rather than 40%) bias is likely to be sufficient. This again is very much a best case scenario.

	Malton/Norton Only (Benefits up 20%; Costs down 20%)				
	1	2	3	4	5
Damages (£)	25,616,571	16,573,820	7,311,026.40	7,036,281.90	6,329,418.72
Benefits + 20% (£)	-	10,851,302	21,966,653.38	22,296,346.77	23,144,582.58
Costs - 20% (£)	-	67,253	2,870,974.40	2,623,936.00	2,908,432.80
BCR	-	161.35	7.65	8.50	7.96
Costs eligible for GiA (£)			1,934,701.28	1,953,017.58	2,000,141.79
PF req'd (£)			936,273.12	670,918.42	908,291.01

Under this alternative 'best case scenario' costs would lie in the range £2.6m-£2.9m; between £0.7m and £0.9m of which would need to be secured from partnership funding sources. Under this scenario though, the flooding problem in Old Malton would remain unaddressed.

G5 Recommendations

Based on the economic case identified above, further assessment of these options is merited. The following areas of work are recommended:

More detailed development of options.

There is potential with certain options (N4, N5, OM4, OM5) for value engineering to reduce the scale of works. Eg – greater hydraulic analysis to size drainage elements; the use of flexible pipes over the defence crest rather than fixed pipes through the defences (OM5).

More detailed costing

In depth costing of options carried forward may allow further reductions in uncertainty.

Identification of optimal pump sizes

In general, it is recognised that uncertainties in the estimation of inflows and groundwater flows are more significant than the choices between one standard of protection and another. Nonetheless, it is convention in economic appraisal to assess a range of standards of protection. Further data to support pump sizing may be difficult to obtain, but flow monitoring would be a significant help.

Threshold surveys

Some properties are known to have higher than average property thresholds. Certain key properties (LidL, Morrisons, Tate Smith) have potential to be a strong influence on benefits by virtue of their large size. Property threshold surveys will minimise the risks associated with this.

Additional benefits to be accrued

Rail and road disruption

The railway and road network are subject to significant and extended disruption during flood events, and may be a source of significant benefits.

Emergency Services

Emergency Services costs have been assessed on the basis of 5.6% of the direct damages, as per standard guidance from the MCM. However, there is a reasonable case to challenge this

Intangible health benefits

Intangible health benefits were not assessed in the above analysis, but can accrue to high values if the existing threshold of flooding is relatively low

Confirmation of the Standard of Protection of the River Derwent scheme

The stated standard of protection of the Derwent scheme has a 50 year return period. Water levels from the River Derwent models updates compared to the flood defence levels from the health and safety file suggest that the scheme has a high freeboard and it is plausible that the standard of protection may be higher. Since the proposed options can only accrue benefits up to the standard of protection of the Derwent scheme (after that point, the river is assumed to have overtopped flood defences), the standard of protection is a limit on the amount of benefit that can be accrued.

Moreover, Partnership funding scores are dependent on moving residential properties from flooding risk band to another. These risk bands are set by thresholds of flooding, of which the threshold between the significant and moderate flood risk band is the 75 year return period event. Therefore, if it could be proven that the standard of protection provided by the River Derwent scheme was in fact better than the 75 year return period, there would be a step change in the business case for the scheme.

Value to businesses

Identification of the potential flood disruption to individual businesses may demonstrate a strong case for partnership funding contributions from them.

Tables

1) Do Nothing Damages
2) Options Cost Estimates

	DO NOTHING DAMAGES									
	Return periods									
Present day return periods	**2**	**5**	**10**	**25**	**50**	**75**	**100**	**200**	**1000**	**Upper Bound**
2025 - 2039	2	4	7	17	33	50	66	128	739	Upper Bound
2040 - 2069	2	3	6	13	26	38	50	96	606	Upper Bound
2070 - 2115	1.8	2	4	8	16	23	30	56	429	Upper Bound

Flood Cell	Direct damages									
OldMalton	-	-	38,457	326,866	856,800	1,221,954	1,519,240	1,873,260	3,421,830	3,808,972
Malton 1	-	47,036	66,183	703,083	1,918,199	2,544,908	2,914,667	3,209,090	4,239,253	4,496,794
Malton 1.1	-	2,718	17,876	58,313	87,331	91,998	94,971	98,385	116,688	121,264
Malton 2	2,074	45,434	64,849	142,143	190,700	232,474	284,609	331,098	447,150	476,163
Malton 3	-	-	-	17,382	120,445	580,420	754,408	839,556	1,105,345	1,171,793
Malton 4	-	-	-	-	4,953	35,624	63,537	171,850	1,676,775	2,053,006
Norton 1	-	421,647	1,493,112	3,248,434	4,910,684	5,783,115	6,333,860	6,893,559	8,855,180	9,345,585
Norton 2	-	4,736	167,120	650,758	1,529,949	2,309,045	2,801,573	3,249,751	4,648,885	4,998,669

Flood Cell	Indirect damages									
OldMalton	-	-	-	41	547	1,033	1,346	1,683	2,726	2,987
Malton 1	-	-	-	13,858	44,950	61,308	71,611	79,327	106,862	113,746
Malton 1.1	-	-	-	-	-	-	-	-	-	-
Malton 2	-	0	24	165	239	279	309	349	499	536
Malton 3	-	-	-	-	-	-	-	-	-	-
Malton 4	-	-	-	-	30	135	271	380	3,345	4,086
Norton 1	-	265	1,562	6,008	13,002	17,044	20,077	22,868	32,343	34,711
Norton 2	-	140	4,858	18,538	42,658	63,861	76,630	88,178	126,180	135,680

Flood Cell	Vehicle damages									
OldMalton	-	-	-	28,768	107,880	136,648	154,628	179,800	287,680	287,680
Malton 1	-	3,596	3,596	21,576	50,344	53,940	53,940	57,536	57,536	57,536
Malton 1.1	-	-	3,596	7,192	7,192	7,192	7,192	7,192	7,192	7,192
Malton 2	-	3,596	3,596	3,596	3,596	7,192	14,384	17,980	17,980	17,980
Malton 3	-	-	-	-	10,788	82,708	82,708	89,900	100,688	100,688
Malton 4	-	-	-	-	-	-	-	28,768	28,768	28,768
Norton 1	-	11,452	60,532	158,010	210,287	231,594	234,588	242,679	253,518	256,228
Norton 2	-	-	-	-	-	-	-	-	-	-

Flood Cell	Emergency services & Utilities									
OldMalton	-	-	5,999	50,991	133,661	190,625	237,001	292,229	533,805	594,200
Malton 1	-	7,338	10,325	109,681	299,239	397,006	454,688	500,618	661,324	701,500
Malton 1.1	-	424	2,789	9,097	13,624	14,352	14,815	15,348	18,203	18,917
Malton 2	324	7,088	10,117	22,174	29,749	36,266	44,399	51,651	69,755	74,281
Malton 3	-	-	-	2,712	18,789	90,546	117,688	130,971	172,434	182,800
Malton 4	-	-	-	-	773	5,557	9,912	26,809	261,577	320,269
Norton 1	-	65,777	232,925	506,756	766,067	902,166	988,082	1,075,395	1,381,408	1,457,911
Norton 2	-	739	26,071	101,518	238,672	360,211	437,045	506,961	725,226	779,792

Flood Cell	**Total Do Nothing damages**									
OldMalton	-	-	44,457	406,666	1,098,888	1,550,259	1,912,216	2,346,972	4,246,041	4,693,839
Malton 1	-	57,969	80,104	848,198	2,312,732	3,057,162	3,494,906	3,846,570	5,064,975	5,369,576
Malton 1.1	-	3,142	24,261	74,602	108,147	113,541	116,978	120,925	142,084	147,373
Malton 2	2,397	56,118	78,586	168,079	224,284	276,210	343,701	401,079	535,385	568,961
Malton 3	-	-	-	20,094	150,023	753,673	954,804	1,060,427	1,378,467	1,455,280
Malton 4	-	-	-	-	5,755	41,317	73,720	227,807	1,970,464	2,406,128
Norton 1	-	499,141	1,788,131	3,919,207	5,900,039	6,933,919	7,576,608	8,234,502	10,522,448	11,094,435
Norton 2	-	5,615	198,049	770,815	1,811,279	2,733,117	3,315,248	3,844,891	5,500,292	5,914,142
TOTAL	2,397	621,984	2,213,588	6,207,661	11,611,148	15,459,199	17,788,180	20,083,173	29,360,155	31,649,734

	AAD				NPV	
Flood Cell	Present day	2025 - 2039	2040 - 2069	2070 - 2115	Uncapped	Capped
OldMalton	58,904	86,086	109,072	174,090	3,015,020	3,015,020
Malton 1	120,557	170,312	211,826	330,985	5,889,696	5,889,696
Malton 1.1	7,121	9,663	11,907	18,060	331,266	331,266
Malton 2	28,008	34,121	40,164	56,973	1,136,177	1,136,177
Malton 3	15,473.95	23,213.39	29,944	48,917	824,400	824,400
Malton 4	6,501	9,878	12,963.07	21,563	355,584	355,584
Norton 1	512,330	667,037	815,004	1,211,373	12,754,375	8,737,646
Norton 2	112,710	161,669	204,382	322,701	3,751,350	3,501,158

Flood Cell					
OldMalton	36	53	69	112	1,894
Malton 1	2,440	3,595	4,539	7,259	125,644
Malton 1.1	-	-	-	-	-
Malton 2	18	25	31	48	861
Malton 3	-	-	-	-	-
Malton 4	14	22	28	47	780
Norton 1	962	1,346	1,682	2,616	46,657
Norton 2	3,146	4,505	5,691	8,974	157,298

Flood Cell					
OldMalton	5,589	8,249	10,450	16,759	289,003
Malton 1	3,467	4,575	5,519	8,249	154,927
Malton 1.1	791	1,069	1,337	2,023	36,934
Malton 2	1,429	1,607	1,836	2,457	52,510
Malton 3	1,609	2,422	3,126	5,115	86,053
Malton 4	216	330	438	736	11,985
Norton 1	20,247	26,827	32,880	49,191	916,027
Norton 2	-	-	-	-	-

Flood Cell					
OldMalton	9,189	13,429	17,015	27,158	470,343
Malton 1	18,807	26,569	33,045	51,634	918,793
Malton 1.1	1,111	1,507	1,858	2,817	51,678
Malton 2	4,369	5,323	6,266	8,888	177,244
Malton 3	2,414	3,621	4,671	7,631	128,606
Malton 4	1,014	1,541	2,022	3,364	55,471
Norton 1	79,923	104,058	127,141	188,974	3,547,613
Norton 2	17,583	25,220	31,884	50,341	881,179

	AAD				NPV
Flood Cell	Present day	2025 - 2039	2040 - 2069	2070 - 2115	Capped
OldMalton	73,717	107,818	136,606	218,119	3,776,261
Malton 1	145,271	205,051	254,929	398,126	7,089,060
Malton 1.1	9,023	12,240	15,102	22,900	419,878
Malton 2	33,825	41,076	48,297	68,366	1,366,792
Malton 3	19,497	29,256	37,741	61,663	1,039,059
Malton 4	7,745	11,771	15,451	25,711	423,819
Norton 1	613,462	799,269	976,707	1,452,154	13,247,943
Norton 2	133,439	191,394	241,957	382,016	4,539,635
TOTAL	746,900	990,663	1,218,664	1,834,171	31,902,448

MALTON & NORTON FLOOD STUDY
HIGH LEVEL OPTION COSTS - MALTON
18th JUNE 2015

ARUP

OPTION	DESCRIPTION OF WORK	QUANT	UNIT	RATE	OPTION 3 £	OPTION 4 £	OPTION 5 £	NOTES / ASSUMPTIONS
1	Property level protection		item	10,000	510,000	290,000	80,000	Assumed rate of £10000 per property (with bulk purchasing
1	Improved telemetry				25,000	25,000	25,000	
1	Formalised sump chambers for temporary pumps inc excavation, concrete walls, base and cover slab	4	nr	10,000	40,000	40,000	40,000	Assume 3m diameter x 2.5m deep
1	Pump access requirements	4	nr	1,000	4,000	4,000	4,000	
2	Morrisons Car Park; allow for excavating and reinstating							
2	Linear drain Marhalls Max E or similar	36	m	200		7,200	7,200	Inc allowance for excavating road and reinstatement
2	100mm Gully pipes (2nr)	200	m	100		20,000	20,000	
2	French drain size 500 wide x 2m deep; granular fill	180	m	115		20,700	20,700	
2	500 diameter pipe in trench, granular b&s	10	m	500		5,000	5,000	
2	Connection 500 pipe to existing CSO pipe	1	nr	3,000		3,000	3,000	
2	500 diameter penstock	2	nr	4,000		8,000	8,000	
2	Chandlers Wharf					-	-	
2	Raised speed bump	20	m	250		5,000	5,000	
2	Castlegate					-	-	
2	French drain size 500 wide x 2m deep; granular fill	80	m	115		9,200	9,200	
2	Shallow kerb; exc, base and haunch, cut tarmac, reinstate highway	20	m	100		2,000	2,000	
2	300 diameter pipe in road inc exc tranch reinstatement; concrete b&s	40	m	400		16,000	16,000	
2	20m of guided augered pipe, 300mm diameter	20	m	600			12,000	
2	Mobilisation and de-mobilisation		item				5,000	
2	Allow for launch and reception pits	2	nr	4,000			8,000	
2	Sheepfoot					21,000	-	
2	Shallow kerb	100	m	50		5,000	5,000	
2	500 diameter penstock	2	nr	4,000		8,000	8,000	
2	500 diameter pipe in road inc exc tranch reinstatement; concrete b&s	10	m	600		6,000	6,000	
2	Connection 500 pipe to existing CSO pipe	1	nr	3,000		3,000	3,000	
	Permanent Pumping Station Capacity - For Malton 1							
3	100 L/s	1	nr	50,000			50,000	
3	Housing for pumping station	1	nr	12,000			12,000	
	Permanent Pumping Station Capacity - For Malton 1.1, 2 & 3							
3	50 L/s	1	nr	30,000			30,000	
3	Housing for pumping station	1	nr	8,000			8,000	
	Permanent Pumping Station Capacity - For Malton 4							
3	55l/s	1	nr	35,000			35,000	
3	Housing for pumping station	1	nr	25,000			25,000	
	SUB-TOTAL				579,000	498,100	452,100	
						-	-	
	ALLOWANCE FOR INDIRECT COSTS					-	-	
	Main Contractor's Preliminaries inc access	25	%		144,750	124,525	113,025	
	Traffic Management	item			10,000	25,000	30,000	
	Ground risk - Rock and contamination	5	%		28,950	24,905	22,605	
	Main Contractor's Construction Risk	10	%		57,900	49,810	45,210	
	Consultant's costs	10	%		57,900	49,810	45,210	
	Site investigation and survey	5	%		28,950	24,905	22,605	
	Compensation	5	%		28,950	24,905	22,605	
	Estimated Cost of Work at 3Q 2015				936,400	821,960	753,360	
	Emergency Response				-	-	-	Already accounted for in damages
	NPV O&M Costs	3000	£/yr	30			89,670	
	Optimism Bias							
	Allow for 40% uplift to cover optimism bias				374,560	328,784	337,212	
	MALTON WORKS TOTAL CONSTRUCTION COST ESTIMATE with 40% OB			£	**1,310,960**	**1,150,744**	**1,090,572**	

MALTON & NORTON FLOOD STUDY
HIGH LEVEL OPTION COSTS - NORTON
18th JUNE 2015

ARUP

OPTION	DESCRIPTION OF WORK	QUANT	UNIT	RATE	OPTION 3 £	OPTION 4 £	OPTION 5 £	NOTES / QUESTIONS
1	Network Rail pump arrangement				100,000	100,000	100,000	
1	Property level protection			10,000	870,000	450,000	-	Assumed rate of £10000 per property (with bulkpurchasing advantage)
1	Improved telemetry				25,000	25,000	25,000	
1	Formalised sump chambers for temporary pumps inc excavation, concrete walls, base and cover slab	2	nr	10,000	20,000	20,000	20,000	Assume 3m diameter x 2.5m deep
1	Pump access requirements	2	nr	1,000	2,000	2,000	2,000	
2	**Bark Knots pumping station upgrade**					-	-	
2	Replace existing pump with 300 l/s pump	2	nr	150,000		300,000	300,000	Based on £500k per cumec
2	50% Risk associated with increasing chamber siz	2	nr	15,000		30,000	30,000	Review size on sketch
2	Auxillary overflow and SPS defence					-	-	
2	New "V" shaped ditch 3mwide x 1m deep	200	m	80		16,000	16,000	Excavated material spread and levelled
2	Forming embankment / bund 1m high with 2m crest	120	m	150		18,000	18,000	5m3 per metre + seeding; assumed imported material
	Mill Beck pumping station upgrade					-	-	
3	Existing pumps replaced with total capacity of 1200 l	1	nr	720,000			720,000	
3	Money back from reuse of existing pumps	2	nr	- 75,000			- 150,000	Assumed 50% of value of existing pumps is recoverable
3	50% Risk associated with increasing chamber siz	1	nr	22,500			22,500	Size of pump station assume circa 30m2
3	50% Risk on Additional chamber on existing system inc excavation, concrete walls, base and cover slab	1	nr	15,000			15,000	
	SUB-TOTAL				1,017,000	961,000	1,118,500	
						21,000	-	
	ALLOWANCE FOR INDIRECT COSTS					-	-	
	Main Contractor's Preliminaries inc access	25	%		254,250	240,250	279,625	
	Traffic Management	item			15,000	20,000	30,000	
	Ground risk - Rock and contamination	5	%		50,850	48,050	55,925	
	Main Contractor's Construction Risk	10	%		101,700	96,100	111,850	
	Consultant's costs	10	%		101,700	96,100	111,850	
	Site investigation and survey	Item			10,000	15,000	20,000	
	Compensation	5	%		50,850	48,050	55,925	
	Estimated Cost of Work at 3Q 2015				1,601,350	1,545,550	1,783,675	
	Emergency Response				-	-	-	Already accounted for in damages
	NPV O&M Costs		£		89,670	104,615	119,560	Change in O&M costs assumed low, because there are already pumps in place
	Optimism Bias							
	Allow for 40% uplift to cover optimism bias				676,408	660,066	761,294	
	NORTON WORKS TOTAL CONSTRUCTION COST ESTIMATE with 40%			£	**2,277,758**	**2,205,616**	**2,544,969**	

MALTON & NORTON FLOOD STUDY
HIGH LEVEL OPTION COSTS - OLD MALTON with diversion
18th JUNE 2015

ARUP

OPTION	DESCRIPTION OF WORK	QUANT	UNIT	RATE	OPTION 3 £	OPTION 4 £	OPTION 5 £	NOTES / ASSUMPTIONS
1	Property level protection - already costed			10,000	430,000	10,000	-	Assumed rate of £10000 per property (with bulk purchasing advantage)
1	Formalised sump chambers for temporary pumps inc excavation, concrete walls, base and cover slab	1	nr	20,000	20,000	20,000	20,000	Assume 3m diameter x 2.5m deep
1	Pump access requirements	1	nr	1,000	1,000	1,000	1,000	
2	Diversion							
2	Forming embankment / bund 1m high with 2m (	75	m	150		11,250	11,250	
2	Culvert through embankment 1m x 2m	8	m	3,500		28,000	28,000	Assume precast concrete standard sections
2	Scour protection Reno mattress	16	m2	500		8,000	8,000	
2	Penstock 1m x 2m wide	1	nr	6,000		6,000	6,000	
2	1000 diameter pipe jack or guided auger culvert	16	m	1,750		28,000	28,000	Rates as discussed with HB Tunnelling
2	Launch and reception pits	4	nr	5,000		20,000	20,000	
	Mobilisation and de-mobilisation	4	nr	5,000		20,000	20,000	
2	Inlet and outlet structures	4	nr	7,000		28,000	28,000	
2	New "V" shaped ditch 3m wide x 2m deep	100	m	160		16,000	16,000	
2	Upsize existing ditch	370	m	150		55,500	55,500	
2	Re-grading existing field		item	5,000		5,000	5,000	
2	1000 diameter open cut culvert	16	m	2,000		32,000	32,000	
						-	-	
3	Permanent Pumping Station Capacity with diversion							
3	0.15 cumec	1	nr	75,000			75,000	
	Housing for pumping station	0	nr	20,000			-	(pumping station accounted for by sump, above)
3	70m of gullies ; allow for Marshalls Max E or similar	70	m	300		21,000	21,000	Enhanced rate for existing carriageway
3	Draw-off ducts to connect Cat Well and culvert to su	40	m	1,000			40,000	Assumed 600mm diameter duct
3	Penstocks	2	nr	6,000			12,000	To suit 600 pipe
							-	
3	Concealed pump lines, 500 daimeter pipe in trench	80	m	600			48,000	
3	Breaking through embankment to form culvert for 500 pipe and subsequent reinstatement		item	5,000		-	5,000	
							-	
							-	
	SUB-TOTAL				451,000	309,750	479,750	
						-	-	
	ALLOWANCE FOR INDIRECT COSTS					-	-	
	Main Contractor's Preliminaries inc access	25	%		112,750	77,438	119,938	
	Traffic Management	item			10,000	20,000	20,000	
	Ground risk - Rock and contamination	5	%		22,550	15,488	23,988	
	Main Contractor's Construction Risk	10	%		45,100	30,975	47,975	
	Consultant's costs	10	%		45,100	30,975	47,975	
	Site investigation and survey	5			8,000	15,488	23,987.50	
	Compensation	5	%		22,550	15,488	23,988	
	Estimated Cost of Work at 3Q 2015				717,050	515,600	787,600	
	Emergency Response				-	-	-	Already accounted for in damages
	NPV O&M Costs		£			59,780	119,560	
	Optimism Bias							
	Allow for 40% uplift to cover optimism bias				286,820	230,152	362,864	
	OLD MALTON WORKS TOTAL CONSTRUCTION COST ESTIMATE with 4			**£**	**1,003,870**	**745,752**	**1,150,464**	

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Appendix H

Environmental

File Note

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Project title	Malton and Norton Environmental Desk Study	Job number	239474-00
cc		File reference	
Prepared by	Lee Wallace	Date	19 May 2015
Subject	Appendix H – Environmental Desk Study.		

1 Introduction

The purpose of the following report is to provide information relating to the environmental, cultural and heritage features within the Malton, Norton and Old Malton areas. The information provided is to aid decision making processes in relation to developing outline solutions to residual flood risk in the Malton Norton and Old Malton areas. The report shall highlight any potential local constraints or features that could be of concern as well as highlighting any options that may provide environmental enhancement.

2 Air Quality

Malton is a designated Air Quality Management Area (AQMA) due to the annual mean nitrogen dioxide (NO2) which has been observed in the local area[1]. The AQMA encompasses the centre of Malton including the properties along the B1248 (Castlegate and Yorkersgate, between Sheepfoot Hill and Market Street), and the B1257 (Wheelgate and Old Maltongate, between Finkle Street and 20m east of the junction with East Mount). The area also includes part of Church Hill.

During the construction phase the increase in works vehicles in the local area, will have a temporary negative effect on local air quality.

3 Archaeology and Cultural Heritage

Across Malton, Old Malton and Norton there are approximately over 250 listed buildings. The majority of the listed buildings are situated in Malton Town Centre, however there are still significant numbers in Old Malton and Norton. Malton Castle and the adjacent Roman Fort are both designated Scheduled Ancient Monuments. The Fort itself is split into two sites (next to the Castle SE791716) and the other at SE792718. Old Malton Priory Church is also a scheduled monument

[1] DEFRA. 2015. AQMA Interactive Map.

and is located near Old Malton at SE799725, which is proximal to one of the proposed flood alleviation strategy options.

4 Ecology

4.1 Introduction

This section gives an overview of the local ecological characteristics that could be impacted as a result of the works. Potentially sensitive habitats have been considered such as the presence of designated sites or Biodiversity Action Plan (BAP) habitats alongside any records of known protected species in the local area.

4.2 Statutory designations

The Derwent is a Special Area of Conservation (SAC) and Site of Special Scientific Interest (SSSI), which acts as a boundary which separates the towns of Malton and Norton. It should be noted that there is a section of the River Derwent within the main urbanised area between Malton and Norton which is not a designated SAC and SSSI, which is approximately 1km in length. Malton town centre is approximately 1.6km to the east of the Howardian Hills Area of Outstanding Natural Beauty (AONB). Malton and Old Malton are also within a designated Nitrate Vulnerable Zone (NVZ) for groundwater. South of Norton there is also a designated NVZ for groundwater but it is unlikely to be of concern as it is not located close to any of the flood alleviation strategy options.

4.3 Non-statutory designations

Non statutory designations such as Site of Importance for Nature Conservation (SINC) and Local Nature Reserves are not always freely available for public access. Subsequently it is not currently known if there are any non-statutory designations in the local area. A formal ecological/biological records search, obtained from the local biological records centre, would be required to ascertain the presence of locally designated sites.

4.4 Habitats

Accordingly to freely available data provided on Magic[2] and the National Biodiversity Network[3] locally designated habitats under Biodiversity Action Plan/Sec 41 of NERC Act 2006 which may be of concern locally as follows but not limited to:

- Traditional Orchard
- Deciduous Woodlands
- Two areas of Lowland Fens
- Floodplain grazing marsh

The proposed flood alleviation works are not currently anticipated to impact upon the locations of these habitats.

Species

[2] Magic.gov.uk. 2015. Interactive maps. www.magic.gov.uk
[3] National Biodiversity Network. 2015. Data resources. www.nbn.org.uk

Accordingly to freely available data provided on Magic and the National Biodiversity Network. It should be noted that information on species is limited in that it only utilises freely available data sources. Species of concern are, but not limited to, include the following;

- Corn bunting
- Curlew
- Grey Partridge
- Lapwing
- Tree Sparrow
- Yellow wagtail
- Bats
- Water Voles

These high level results are not fully conclusive, consequently is recommended that a data request is to be made to the local biological records centre in order to obtain a more complete inventory of protected species present/likely absent from the target area. Additionally, it is recommended that a Phase 1 Habitat survey is undertaken to definitively quantify protected species and habitats.

5 Ground Condition

5.1 Introduction

The following section details the anticipated local geology as attained from Magic as well as potential contamination issues. Contamination issues were assessed through utilising historical maps, on the National Library for Scotland[4], in order to attain previous local land uses. These were subsequently cross referenced to Department of Environment Industry Profiles to ascertain the likely contaminants for that particular land use in question.

5.2 Geological conditions

The bedrock geology of the regions varies. On the northern bank of the Derwent the bedrock is predominantly limestone. However on the southern bank it is predominantly mudstone. There is a band of sandstone between the two described areas. Either side of the river banks of the Derwent there are abundant alluvium deposits, which is the main superficial deposit of concern.

There are no characteristics locally indicative of mining activity within the towns which could have altered geological conditions, given that no mine entries, coal outcrops and abandoned mine catalogues are within the area[5]. Additionally no past surface hazards or shallow surface mines have been present locally.

5.3 Potential contamination

Local historical land use across Malton, Norton and Old Malton since the 1880's have been detailed in Table D1. The industries named are potential sources of contamination to the local River Derwent and immediate area thus potentially impacting other receptors other than the watercourse. It should be noted that made ground which could contain a variety of contaminants may be of

[4] National Library for Scotland. 2015. Interactive Map Viewer.
[5] Coal Authority. 2015. Interactive Maps. www.gov.uk/government/organisations/the-coal-authority

concern, due to the semi urban nature of the local area and the previous land uses which have been discussed in Table D1.

Table D1: Potential primary contaminants of concern for the wider local Malton and Norton area based on historical land uses. (Department of Environment Industry Profiles[6]).

Land use	**Year and location**	**Primary contaminants of potential concern.**
Gas works	Apparent on the maps from 1913-1952 the intervening years to present day are not freely available, although it does not appear present in modern day. Site was located on the northern bank of the River Derwent to the east of Malton Bridge on Sheepfoot Hill. (SE 79260 71579)	• Constituents of coal tar (i.e. hydrocarbons, organo-sulphur compounds, nitrogen compounds and heterocyclic nitrogen compounds) • Petroleum's • Heavy metals • Sulphuric and hydrochloric acid • Sodium hydroxide/carbonate
Railways (both working and non-working)	From 1840's to present day. Southern bank of the River Derwent and largely follows the shape of the river through Norton town.	• Heavy metals • Asbestos • Ash fill • Sulphates • Hydrocarbons (PCB's, PAH) • Solvents
Brewery	Does not appear on historical maps but is current land use in central Malton on Yorkergate. Additionally given it appears to be a recent land use the brewery is likely to be regulated and adheres to their environmental permit requirements. The distance away from the potential alleviation sites is also significant as such the likely modern day regulation and distance to the proposed works locations, the contaminants are most likely not of concern	Brewery functioning is characterised by wastewater discharges which are typically: • High BOD • High TSS • High pH • High nitrogen and phosphorus concentrations. During the brewing processes solid waste is also produced that may contain: • Phosphorous • Nitrogen • Potassium • High organic matter
Manure works	Shown on maps from 1909 to 1952. Manure works were approximately 300m south west of the train station. Unlikely to be of concern due to the distance to the potential sites.	• Pathogens and disease • High organic waste • High nutrient content (N and P) • Direct input of manure into watercourses

There are also several disused landfill sites around both Malton and Norton, which may be of concern. The contaminants may potentially leach out into local groundwater, local sub surface or even the river. Whilst the landfill sites are not directly adjacent the River Derwent they may still be a source of contamination concern. The location of the sites are:

[6] Department of Environment. 2014. Land contamination: Department of Environment (DOE) industry profiles. www.gov.uk/government/publications/department-of-environment-industry-profiles.

- Park engineering landfill site (Park Road, Norton, last operated 1980).
- Disused railway cuttings at Rear of Wykeham Villa, Peasey Hill Road, Malton, North Yorkshire and Rear of Peasey Hill Depot, Malton (Malton, last operated 1993).
- Highfield quarry (Highfield Road, Malton last operated 1994)
- Highfield road landfill (Malton, last operated 1980).

The information in Table D1 indicates potential contaminated land issues across the wider local area and as such could potentially be of concern given the commonly associated contaminants with the historical land use that has been noted locally. Should the scheme be developed further a desk based geotechnical desk study is highly recommended. Depending upon the findings of the desk study a full ground investigation may be required for a full analysis of the ground conditions and soils, in order to fully quantify the local geology any potential contaminants of concern.

6 Transport and Access

6.1 Road

Malton is bound to the north by the A64 which is the primary access route to the town. Subsidiary roads in the form of B1257 (from the North West), B1248 (from the West), A 169 and B1257 (both from the North) all provide additional access routes to Malton. The B1248 and B1257 intersect one another in the centre of the Malton Town, with the B1257 continuing east linking Malton to Old Malton.

The B1248 which intersected Malton from the West, turns south and acts as a river crossing between Malton and Norton. The road continues south providing access to Norton and indirectly Malton. Thus from the southern side of the River Derwent, Malton can be accessed indirectly via Norton, the neighbouring town.

The A64, that sweeps the northern edge of Malton, crosses the River Derwent after Old Malton and continues east. Norton can be accessed also by the A64 from the east through the exit onto B1248 which not only links to the south, but also branches to the east to meet the major A64 road on the eastern outskirts of Norton.

The road network and access to Malton and Norton is varied with several access routes available. The majority of the smaller access and transport routes bottleneck in both Malton and Norton town centres.

6.2 Rail

Malton Railway station is situated on Norton Road, YO17 9RD (Grid reference SE787713) and is operated by First TransPennine Express. The site is located in an area that may be susceptible to flooding. Should any works be required around the immediate vicinity of the station, consultation with both the management (Network Rail) and operator firm (First TransPennine Express) will be required.

6.3 Public Rights of Way

According to Magic there are no national trails, national cycle networks or other notable designated access routes under public rights of way within either Malton or Norton town centres.

It is not anticipated that the proposed flood alleviation works will cause significant transport disruption. There are numerous options for diversions in the local area; however if the works are of a large enough scale a transport assessment may be required in order to ensure that there is minimal disruption.

7 Water Resources and Flood Risk

The River Derwent flows through the centre of Malton and Norton and acts as the border between the two towns. The river flows from south west to the north east. According to the Environment Agency significant portions of the local area are allocated within Flood Zone 3 and Flood Zone 2.

The River Derwent has the potential to be affected as a result of the construction of the new flood alleviation scheme as could local ground water. Due care and attention alongside adhering to best practice measures and utilising the best available technologies will reduce the potential impacts of the construction phase upon water resources.

Given that the scheme is to enhance local mitigation in order to offset local flooding, any potential effects on water resources will be temporary. The benefits of the scheme are expected to be positive for the local area.

8 Initial Options Environmental Impact Assessment

8.1 Introduction

A review was undertaken of the shortlisted options to assess what the key environmental issues associated with the proposals are likely to be. Consideration of site specific ground and contamination risks is beyond the scope of this initial assessment. Should the scheme be developed further a desk based geotechnical desk study is highly recommended. Depending upon the findings of the desk study a ground investigation may be required for an analysis of the ground conditions and soils and potential contaminants of concern.

8.2 Malton Option M3

Improving the flood warning measuring through the use of an existing borehole would not impact the local environment. Likewise the local property level protection does not involve significant construction efforts or disruption to the local community or environment. The construction of chambers for the deployment of temporary pumps may cause minor traffic and noise disruption during the construction phase. The effects of Option 1 are most likely to be temporary and generally related to noise and traffic disruption during the construction phase of the chambers to allow use of temporary pumps.

The Option itself may not lead to discharge into an area of the River Derwent that is designated However approximately 1km downstream the River Derwent is designated a SSSI and SAC consequently a Habitat Regulation Assessment Screening may be required under the European Directive (92/43/EEC) on the Conservation of Natural Habitats and Wild Flora and Fauna (the Habitats Directive), and transposed in to UK law as the Conservation (Natural Habitats etc) Regulations 2010 (as amended), which protects habitats and species of European nature conservation importance. This relates to the potential risk to the SAC from upstream discharge and surface run off and or associated cumulative impacts. In addition it is probable that consultation with Natural England may also be required in relation to impacts on the SSSI.

8.3 Malton Option M4

During the installation of the drainage measures proposed, traffic on the B1248 is likely to be disrupted. The B1248 is heavily used to access Norton but also hosts a supermarket which will most likely make use of HGV for deliveries and logistics. Disruption will therefore need to be kept to a minimum and the design will need to be compatible with ongoing use of these roads for these purposes following construction.

The use of, full road-width speed bumps to redirect runoff could be a viable option. Whilst the integrity of the road strength would be assured, traffic and the associated noise and air pollution could become a wider issue, as the speed bumps would significantly inhibit local vehicles. Whilst this may lead to ‘traffic jams’ the use of speed bumps would indirectly slow down road users which would make them safer for the local community.

As with the previous option, potential impacts on the downstream SSSI/SAC will need to be considered and NE consulted.

8.4 Malton Option M5

The construction of chambers for the deployment of permanent pumps could cause minor traffic and noise disruption during the construction phase. Likewise if there is a connecting pipe constructed there will be further localised disruption which will be temporary in nature in relation to traffic and transport. The additional effects of Option M5 are most likely to be temporary and generally related to noise and traffic disruption during the construction phase only of the chambers to allow use of temporary pumps. The increased road traffic could also lead to a temporary impact upon local air quality during the construction phase due to increased road traffic emissions.

As with the previous option, potential impacts on the downstream SSSI/SAC will need to be considered and NE consulted.

8.5 Norton Option N3

The proposed Network Rail under-pumping arrangement has the potential to affect ground conditions in the local area. By utilising ducts to pass under the railway the structural integrity of the existing railway banks could be compromised. Appropriate design and investigation into the technology required to ensure sound ground conditions, during both the construction and operation phases, would ascertain if the option was practical and safe.

As with the previous option, potential impacts on the downstream SSSI/SAC will need to be considered and NE consulted.

8.6 Norton Option N4

Overflow diversion to Bark Knot stream could provide a viable option with minimal environmental disruption. The primary limitations may be landownership and access issues in terms of creating the new drainage ditches along the edge of Bark Knots Farm which would be the primary access point in order to implement the option.

The capacity of Bark Nott Stream and the culvert which links the stream to the River Derwent may unable to manage the increased flows which potentially arise from the option. An assessment of the stream and culvert will be required in order to quantify the stream’s capacity.

As with the previous option, potential impacts on the downstream SSSI/SAC will need to be considered and NE consulted.

8.7 Norton Option N5

The permanent new pump station at Church Street to mitigate local 'ponding' is unlikely to have any significant impact on the environment. The area is already urbanised, the works involved would be in keeping with the local surroundings and would not be of a significant size, whereby it would detract from the cultural and historical amenity of Norton town.

There is likely to be temporary traffic and noise disruptions during the installation process due to the works that would be required however they would not be permanent and the operational benefits of removing local surface flooding would outweigh any potential temporary transport negatives.

A Habitats Regulation Assessment Screening may be required due to the proximity of an SAC. This would be to quantify the potential cumulative risk to local habitats due to the potential for upstream discharge and surface run off, which for example may temporarily have increased contaminants due to the increase traffic flows during the construction phase.

8.8 Old Malton Option OM3

The potential environmental and social limitations of Old Malton Option OM3 reflect that of Malton Option 1. Improving the flood warning measuring through the use of an existing borehole would not impact the local environment. Likewise the local property level protection does not involve significant construction efforts or disruption to the local community or environment. Maintenance of urban drainage would create traffic disruption during the clearance of gullies and pipes blockages, but the effects would be minimal and temporary. The construction of chambers for the deployment of temporary pumps could cause minor traffic and noise disruption during the construction phase. The effects of Option OM3 are most likely to be temporary and generally related to noise and traffic disruption during the construction phase only of the chambers to allow use of temporary pumps. The increased road traffic could also lead to a temporary impact upon local air quality during the construction phase due to increased road traffic emissions.

As with the previous options, potential impacts on the downstream SSSI/SAC will need to be considered and NE consulted.

8.9 Old Malton Option OM4

The option to divert the Riggs Road Drain has both limitations and opportunities. By diverting flood flows the Riggs Drain itself will be less likely to exceed capacity and flood the local area. During the construction phase transport and noise disruption is likely to impact local residents, but these effects are only temporary. The option could incorporate existing agricultural drainage systems which have been demarcated on OS maps which would reduce the amount of construction works required to create new drainage systems.

The option would require permission from the landowner, who would need to be compensated for any loss of productivity. There is the opportunity to landscape the proposed flood area into a wetland habitat. Lascelles Lane is located nearby meaning any created features could be accessed by the public for recreational purposes which would provide additional benefits beyond the environmental benefits of flood water storage and habitat creation.

A limiting factor of the option is that the proposed flood area is immediately adjacent the River Derwent SSSI and SAC with an area immediately to the west also being designated as part of the designation. However this could also yield opportunities in that the area could be incorporated as part of the wetland or SUD scheme to buffer the SSSI, SAC and create local ecological corridors.

8.10 Old Malton Option OM5

The permanent new pump station would ensure that flows from the Riggs Road Drain and surface water collecting behind defences have a permanent, pre-installed discharge mechanism. The River Derwent SSSI and SAC exists nearby yet the works are not anticipated to large scale and the access route is not via or adjacent the receptors and in turn they should not be affected. Old Malton Priory Church is a scheduled monument in the local vicinity but is not located immediately adjacent the works so is unlikely to be impacted, there are numerous listed buildings around the location of the proposed works. The heritage assets may be temporarily impacted in relation to the construction works detracted from the local visual and amenity appeal. However the impacts would only be temporary as during the operational phase the pumping stations are not expected to be visually intrusive and would also protect the heritage assets by through the removal of local surface water.

There is likely to be temporary traffic disruptions during the installation process due to the works that would be required however they would not be permanent and the operational benefits of removing local surface flooding would outweigh any potential temporary transport negatives. The increased road traffic could also lead to a temporary impact upon local air quality during the construction phase due to increased road traffic emissions.

As with the previous options, potential impacts on the downstream SSSI/SAC will need to be considered and NE consulted.

DOCUMENT CHECKING (not mandatory for File Note)

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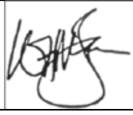
Signature			

Appendix I

Shortlisting Process

Contents

I1 Introduction

The Arup project team held an internal workshop to review the initial long-list of measures and select a shortlist of technically feasible and economically viable measures for reducing flood risk in Malton, Norton and Old Malton. The short-listed options have then been taken forward for initial appraisal.

Engineering judgement and experience, coarse economic baseline assessment and an understanding of the catchment and flood mechanisms from data and models have been used to assess each of the long-listed measures with regard to four criteria. Relevant measures were independently assessed for each of the three main locations where flooding is a problem.

A scoring threshold of 8 has been used to ensure a manageable number of options is shortlisted for detailed appraisal. For each area, engineering judgement has been used to combine appropriate measures into three option scenarios beyond the Do Nothing and Do Minimum options.

I2 Scoring assessment

The long list of options was assessed against the following criteria:

- **Environmental/social**: impact on all, or any combination of, the natural, built and human environments
  - 3 = major positive impact
  - 2 = minor positive impact
  - 1 = minor negative impact
  - 0 = major negative or unmanageable impact
- **Economic**: impact of the construction and operational costs of the option on the business case
  - 3 = major positive impact
  - 2 = minor positive impact
  - 1 = minor negative impact
  - 0 = major negative unacceptable impact
- **Technical viability/efficiency**: technical feasibility of option and widespread benefit to properties throughout Malton, Norton and Old Malton
  - 3 = major positive feasibility, resolves much flood risk
  - 2 = minor positive feasibility, resolves some flood risk
  - 1 = minor technical challenges, some localised protection
  - 0 = major technical challenges, minimal protection
- **Resilience index**: this measures the extent to which each option satisfies the following criteria, which are considered desirable form a long-term resilience perspective:
  - **Passive** – low reliance on energy and operator intervention

- **Self-sufficient** – not reliant on performance of other systems
- **Fail-soft / Fail-safe** – won't fail catastrophically nor worsen situation if design standard exceeded / system failure occurs
- **Flexible and adaptive** – can be adapted to take account of evolving changes in circumstance / climate
- **No regrets** – won't close off potentially attractive alternatives
- **Self-reinforcing** – work with, rather than against, natural processes, supporting ecosystem integrity
- **Diverse and distributed** – not reliant on a single technology / technique in one location.

This index was scored as follows:

- 3 = 6 or 7 resilience criteria met
- 2 = 4 or 5 resilience criteria met
- 1 = 2 or 3 resilience criteria met
- 0 = 0 or 1 resilience criteria met

Total scores are a sum of the four criteria scores above with no weighting.

I3 Short-listing scores

The results of the short-listing workshop are presented in the following sections. Options IDs are cross-referenced to the Long List within the main report.

I3.1 Malton

Category	Option	Option name	Timeframe	Environmental / social	Economic	Technical	Resilience	Total Score	Comments
Maintenance	1.1	Flood defence maintenance	Short term and Long term	1	3	3	2	9	No regrets measure
Pumping	2.1	Temporary pumping arrangements	Short term	1	2	2	2	7	No regrets measure
	2.3	Formalised/improved pump chambers (sumps)	Short term	1	2	2	3	8	Sumps in each of 4 flood cells
	2.7	Permanent land drainage pumps	Medium term	2	3	3	2	10	Reliant on ensuring all areas can drain to it. Less flexible and adaptive than temporary pumps
Modify urban drainage network	3.1	Separation of foul and surface water in flooded area only	Long term	3	1	1	2	7	Costly and disruptive, unlikely to resolve problem, but may reduce contamination
	3.2	Separation of foul and surface water in wider catchment	Long term	3	0	1	2	6	Costly and disruptive, unlikely to resolve problem, but may reduce contamination
	3.3	Sewer rehabilitation to reduce infiltration-inflow	Medium term	2	1	2	2	7	Unlikely to significantly reduce the flood flows as springs believed to be deliberately piped in
	3.5	Add capacity at existing Sewer Pumping Stations	Long term	2	2	2	1	7	Reduces contamination of floodwater, and minor reduction in flood volumes
Control of flowpaths	5.1	Malton – surface water	Medium term	2	2	2	3	9	Traffic calming benefit. Likely to be a supportive measure for others
	5.2	Malton – ground water	Medium term	2	2	2	3	9	Supportive measure, not full solution on own
Property level protection	6.1	Resistance and resilience	Short term	2	2	2	3	9	If property maintenance company for social housing units could be brought on board.
Flood warning	7.1	Broughton groundwater and/or local telemetry	Short term	2	3	2	2	9	No regrets measure to use existing telemetry as part of warning. Could be locally improved
Flood storage	8.3	Flood storage in Malton	Long term	1	1	1	3	6	Unlikely to be sufficient capacity for long events
Development control	9.1	Development control	Long term	3	3	2	3	11	No regrets measure
Derwent modifications	10.1	Kirkham Sluices	Short term	1	1	1	3	6	Potential increase flood downstream, potential modification of heritage structure, archaeological sensitivity

I3.2 Norton

Category	Option	Option name	Timeframe	Environmental / social	Economic	Technical	Resilience	Total Score	Comments
Maintenance	1.1	Flood defence maintenance	Short term and Long term	1	3	3	2	9	No regrets measure
Pumping	2.1	Temporary pumping arrangements	Short term	1	2	2	2	7	No regrets measure
	2.3	Formalised/improved pump chambers (sumps)	Short term	1	2	2	3	8	South of Church Street, connecting into rail crossing point
	2.4	Network Rail pumping agreement	Short term	1	0	2	2	5	Deals with already flooded situation. Agree to stop trains to allow pumps installed
	2.5	Network Rail underpumping arrangement	Medium term	2	2	2	2	8	Need to ensure duct adequate size. Need to address rail safety issues
	2.6	Modify use of CSO	Medium term	1	2	0	1	4	H&S implications of maintaining outfall
	2.7	Permanent land drainage pumps	Medium term	2	3	3	2	10	Upgrading Mill Beck pump capacity / or new permanent PS at Church Street. Reliant on ensuring all areas can drain to it. Less flexible and adaptive than temporary pumps
	2.8	Optimise Mill Beck Pumping Station on/off levels	Short term	3	3	2	2	10	To prevent surcharging at CSO. Subject to detailed understanding of arrangements
Modify urban drainage network	3.1	Separation of foul and surface water in flooded area only	Long term	3	1	1	2	7	Costly and disruptive, unlikely to resolve problem, but may reduce contamination
	3.2	Separation of foul and surface water in wider catchment	Long term	3	0	2	2	7	Costly and disruptive, unlikely to resolve problem but perhaps more so than above, and may reduce contamination
	3.5	Add capacity at existing Sewer Pumping Stations	Long term	2	2	2	2	8	Reduces contamination of floodwater, and minor reduction in flood volumes
Diversion	4.1	Norton	Medium term	1	2	2	3	8	Only deals with larger floods
	4.2	Norton – Priorpot Beck	Long term	1	1	0	2	4	Groundwater and limited sewer catchment
Property level protection	6.1	Resistance and resilience	Short term	1	1	2	3	7	Many more properties here, much higher cost. Does not address road flooding or foul flooding (foul likely to be more important mechanism than in other areas)
Flood warning	7.2	Local telemetry groundwater or wet well pump alarms	Short term	2	3	2	2	9	No regrets measure to use existing telemetry as part of warning. Could be locally improved
Flood storage	8.1	Flood storage on Mill Beck	Long term	1	1	1	3	6	Limited flooding from Mill Beck itself - main mechanism flood-locking and sewer system
Development control	9.1	Development control	Long term	3	3	2	3	11	No regrets measure
Derwent modifications	10.1	Kirkham Sluices	Short term	1	1	1	3	6	Potential increase flood downstream, potential modification of heritage structure, archaeological sensitivity, negligible impact at Malton and Norton
Flood walls	11.1	Formalisation of defences at sewer pumping station in Norton.	Medium term	2	2	2	3	9	Replace sandbags with formal defence

I3.3 Old Malton

Category	Option	Option name	Timeframe	Environmental / social	Economic	Technical	Resilience	Total Score	Comments
Maintenance	1.1	Flood defence maintenance	Short term and Long term	1	3	3	2	9	No regrets measure
	1.2	Land drain maintenance	Short term and Long term	2	1	0	2	5	Positive for agricultural land, but likely to increase floodwater downstream to Old Malton
	1.3	Urban drainage system maintenance	Short term and Long term	2	2	2	2	8	Subject to connectivity verification for gullies connecting to Cut, Cat Well, RRD, or sewer
Pumping	2.1	Temporary pumping arrangements	Short term	1	2	2	2	7	Very dependent on pump availability
	2.3	Formalised/improved pump chambers (sumps)	Short term	1	2	2	3	8	In Cat Well, RRD culvert, Town Street or other manhole points
	2.7	Permanent land drainage pumps	Medium term	1	2	3	2	8	Permanent installed PS in Cat Well and/or RRD, subject to confirmation of local connectivity
Modify urban drainage network	3.1	Separation of foul and surface water in flooded area only	Long term	3	1	1	2	7	Costly and disruptive, unlikely to resolve problem, but may reduce contamination
	3.2	Separation of foul and surface water in wider catchment	Long term	3	0	1	2	6	Costly and disruptive, unlikely to resolve problem, but may reduce contamination
	3.4	Reconfigure CSOs	Short term	2	1	0	2	5	Removing CSO connection to RRD maintains status quo but separates the surface water and sewer flood problems. Could work in combination with YW pump upgrade or reconfiguration
	3.5	Add capacity at existing Sewer Pumping Stations	Long term	2	2	2	1	7	Reduces contamination of floodwater, and minor reduction in flood volumes
Diversion	4.3	Divert RRD downstream of A64	Medium term	2	2	3	2	9	Diversion south of A64 to east fields at Abbey Ings. Baseflow maintained in RRD but flood flows could be diverted to large amenity wetland type feature.
	4.4	Divert RRD upstream of A64	Medium term	2	2	2	2	8	Diversion RRD upstream of A64 will capture less of the urban and rural contributing catchments.
Control of flowpaths	5.4	Old Malton reinstate the Cut	Medium term	2	1	0	3	6	Subject to detailed verification survey of current connectivity
	5.5	Old Malton soffit connection between Cat Well and RRD	Medium term	1	2	1	3	7	Potential to contribute to optimise / aid other measures, e.g. optimisation of pump locations
	5.6	Old Malton road runoff	Short term	1	1	2	3	7	Subject to connectivity of road gullies, divert flow down to Town Street towards fields or Cat Well.
Property level protection	6.1	Resistance and resilience	Short term	2	2	2	3	9	Based on £10k / property
Flood warning	7.2	Local telemetry groundwater or wet well pump alarms	Short term	2	3	2	2	9	EA policy of “1 in 1 out” on telemetry stations
Flood storage	8.2	Flood storage on Riggs Road Drain	Long term	2	1	0	0	3	Unlikely to be sufficient capacity for long duration events
Development control	9.1	Development control	Long term	3	3	2	3	11	No regrets measure

I4 Descriptions and illustrations of shortlisted improvement options

For each of the three locations (Malton, Norton and Old Malton), the key short-listed ‘improvement’ options have been annotated in GIS and described in more detail to facilitate coarse costing. Most options (with the exception of Old Malton’s diversion) are built around three measures: sump points, drainage to those sump points, and pumping stations (for submersible pumps). All options include continuation of existing FRM activities where appropriate.

I4.1 Malton

I4.1.1 Option M3

- Property Level Protection
- Improved telemetry
- 4 x formalised sump chambers for temporary pumps
    - 2 m deep concrete chamber with access manhole
    - Access details for pump (step irons, winch point, harness point etc)

I4.1.2 Option M4

As per Option 1, plus management of flow paths into sump chambers, as follows:

- Carpark flowpaths:
    - 2 x linear drain across road, similar to Marshalls Max-E – each 18m long.
    - 2no 100m gully pipes
    - 180m French Drain
    - 2no 5m length 0.5m dia connection into existing CSO pipe
    - 2no 0.5dia penstock
- Chandlers Wharf flowpaths:
    - 1 x raised speed bump across road, 20m long.
- Castlegate flowpaths
    - 80m French Drain
    - 20m shallow kerbing
    - 40m 0.3m dia pipe under road
- Sheepfoot flowpaths

- 100m shallow kerbing
- 2no 0.5dia penstock
- 2no 5m length 0.5m dia connection into existing CSO pipe

I4.1.3 Option M5

- 4 x permanent pumping stations (in locations of sump points proposed above)
- Pump capacities (indicative price for each):

  40 l/s; 50 l/s; 100 l/s; 150 l/s; 200l/s.

Alternative options for indicative cost comparison:

- 4 x formalised sumps with permanent pumps with no connecting pipe beneath Castlegate B1248 to connect west and east yards, OR
- 3 x formalised sumps with permanent pumps with 20m thrust bored pipe under Castlegate B1248 to connect west and east yards.

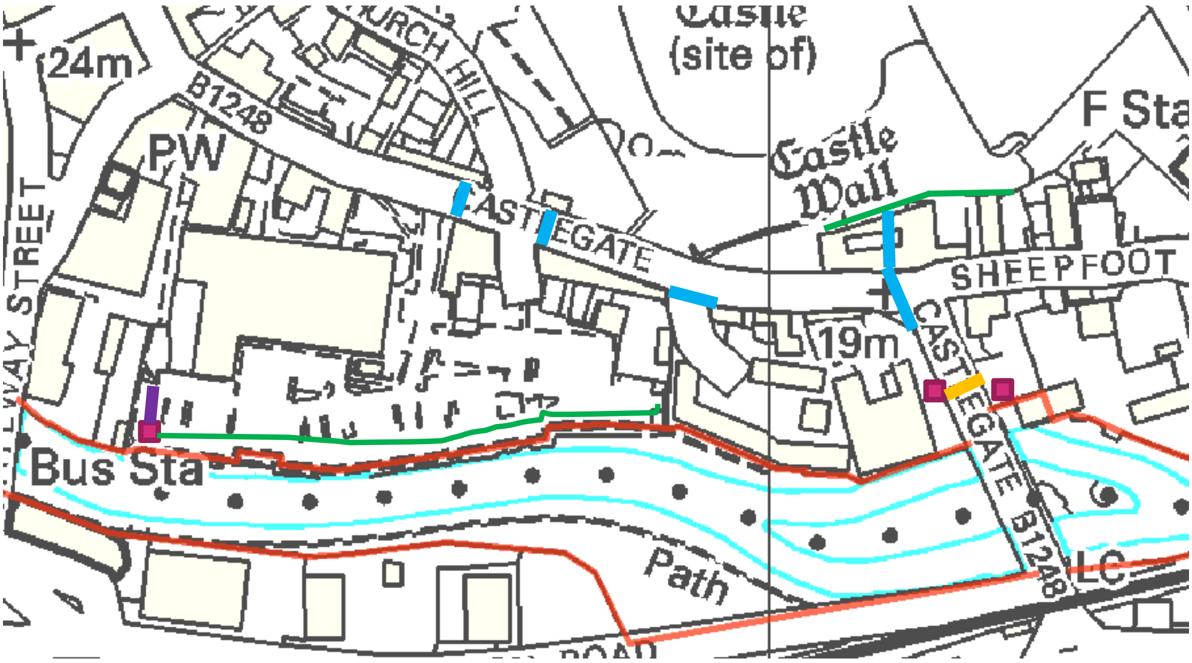


Figure 1 Malton intervention sketch.

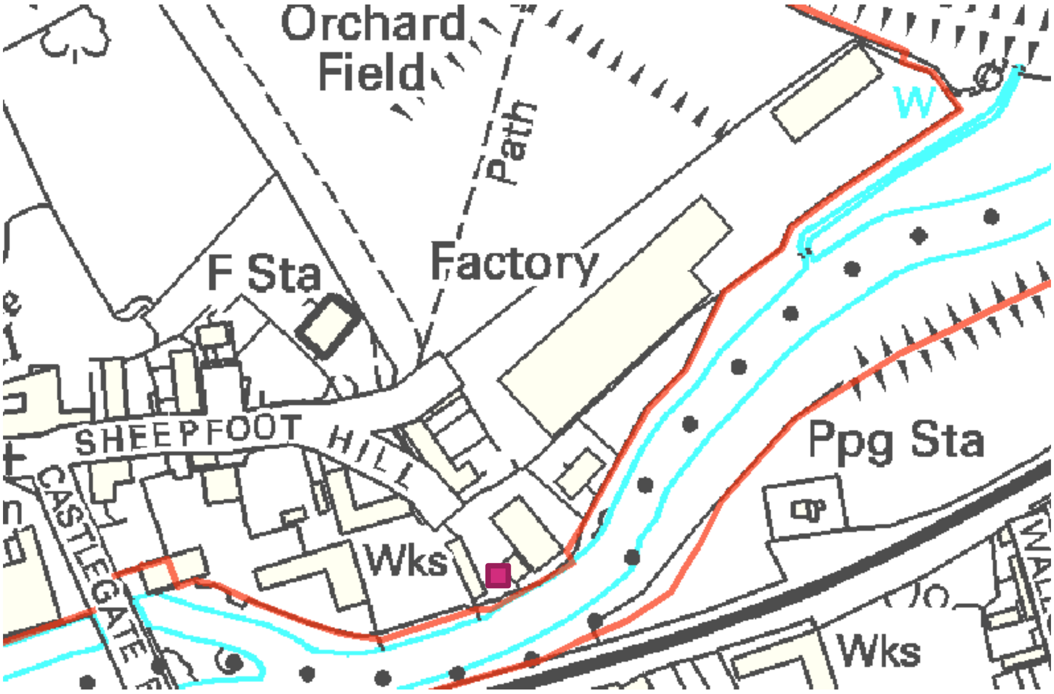


Figure 2 Malton Sheepfoot Hill area intervention sketch.

I4.2 Norton

I4.2.1 Option N3

- Network Rail pump arrangements
- Property Level Protection
- Improved telemetry.
- 2 x formalised sump chambers for temporary pumps
    - 2 m deep concrete chamber with access manhole
    - Access measures for pump

I4.2.2 Option N4

- Mill Beck PS upgrade
    - Replace existing pumps with 2no new 500 l/s capacity pumps.
    - RISK ITEM – possible chamber size upgrade needed.
- Auxilliary overflow and SPS defence
    - 200m new ditch
        - V-shape, 3m wide at top, 1m deep in centre.
    - 120m embankment/bund, 1m high, 1 in 3 slopes, 2m wide crest.

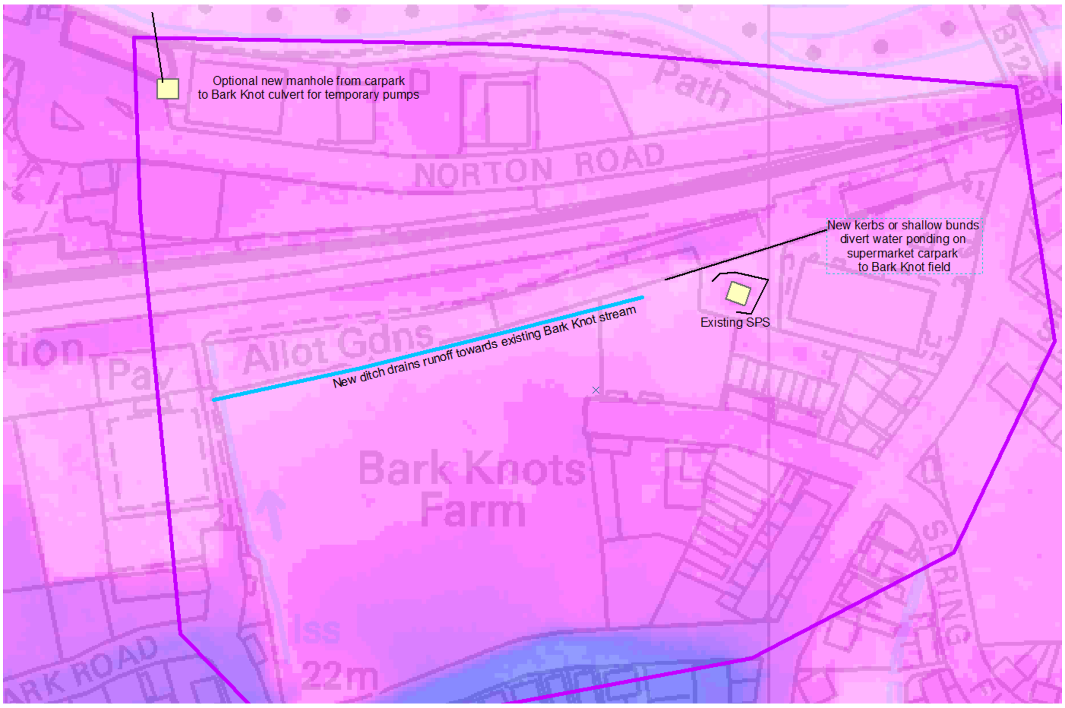


Figure 3 Norton intervention sketch - Option 2.

I4.3 Option N5

- New permanent PS in a chamber as installed above
  - 50 l/s pump capacity
  - Additional chamber to connect to existing drainage system
  - Ducts under road and railway already installed as per earlier options

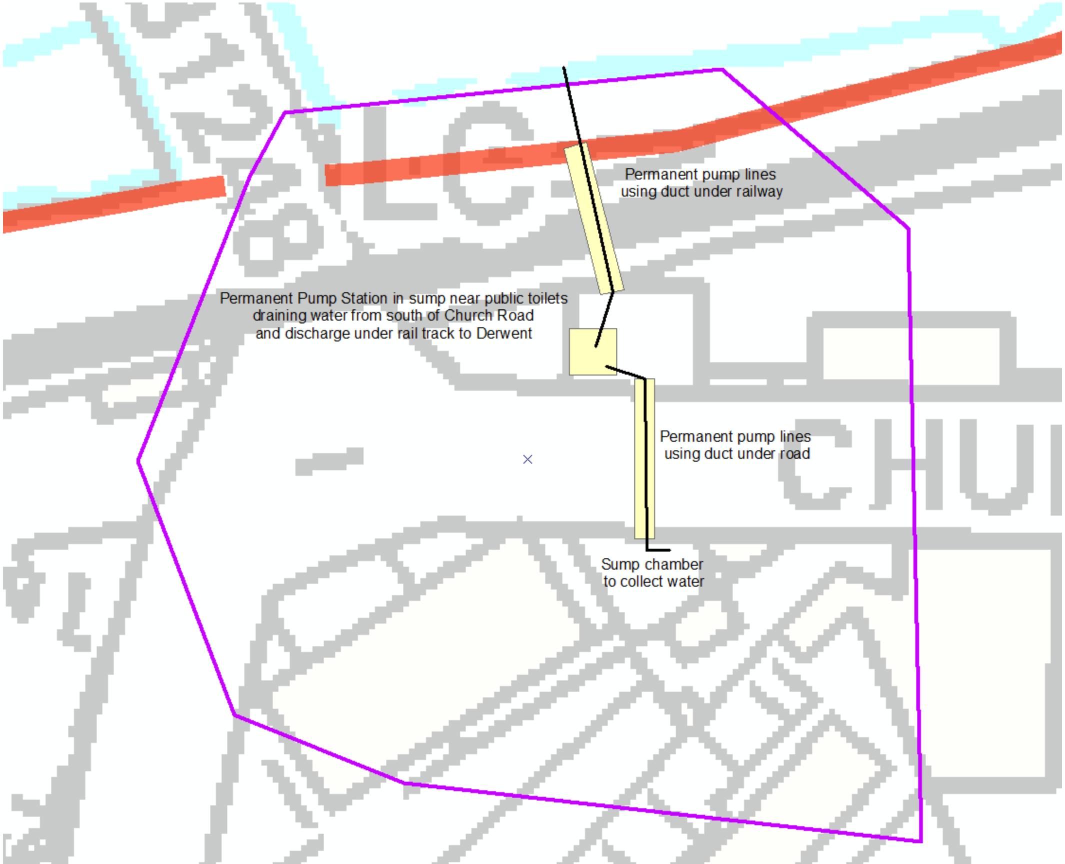


Figure 4 Norton intervention sketch - Option 3.

I4.4 Old Malton

I4.4.1 Option M3

- Road gully clearance.
- Property Level Protection.
- 1 x formalised sump chamber for temporary pumps
    - 2 m deep concrete chamber with access manhole
    - Access point for pump

I4.4.2 Option M4

- Diversion
    - 75m long embankment, 2m high, 1 in 3 side slopes, 2m wide crest.
    - 1 x 1m*2m culvert through embankment (8m long)
    - Scour protection works – 8m^2 reno mattress
    - 1 x penstock (1m x 2m wide, manually operated)
    - 2no 1m diameter thrust bored culverts under road, with inlet and outlet structures

- 100m new ditch
  - Trapezoidal, 3m wide base, 2m deep, bank slopes 1:1.
- 370m upsize existing ditch
  - Trapezoidal, 3m wide base, 2m deep, bank slopes 1:1. (existing ditch 1m deep x 2m wide V shaped)
- 2no 1m diameter open cut culvert 8m long under track, with inlet and outlet structures.

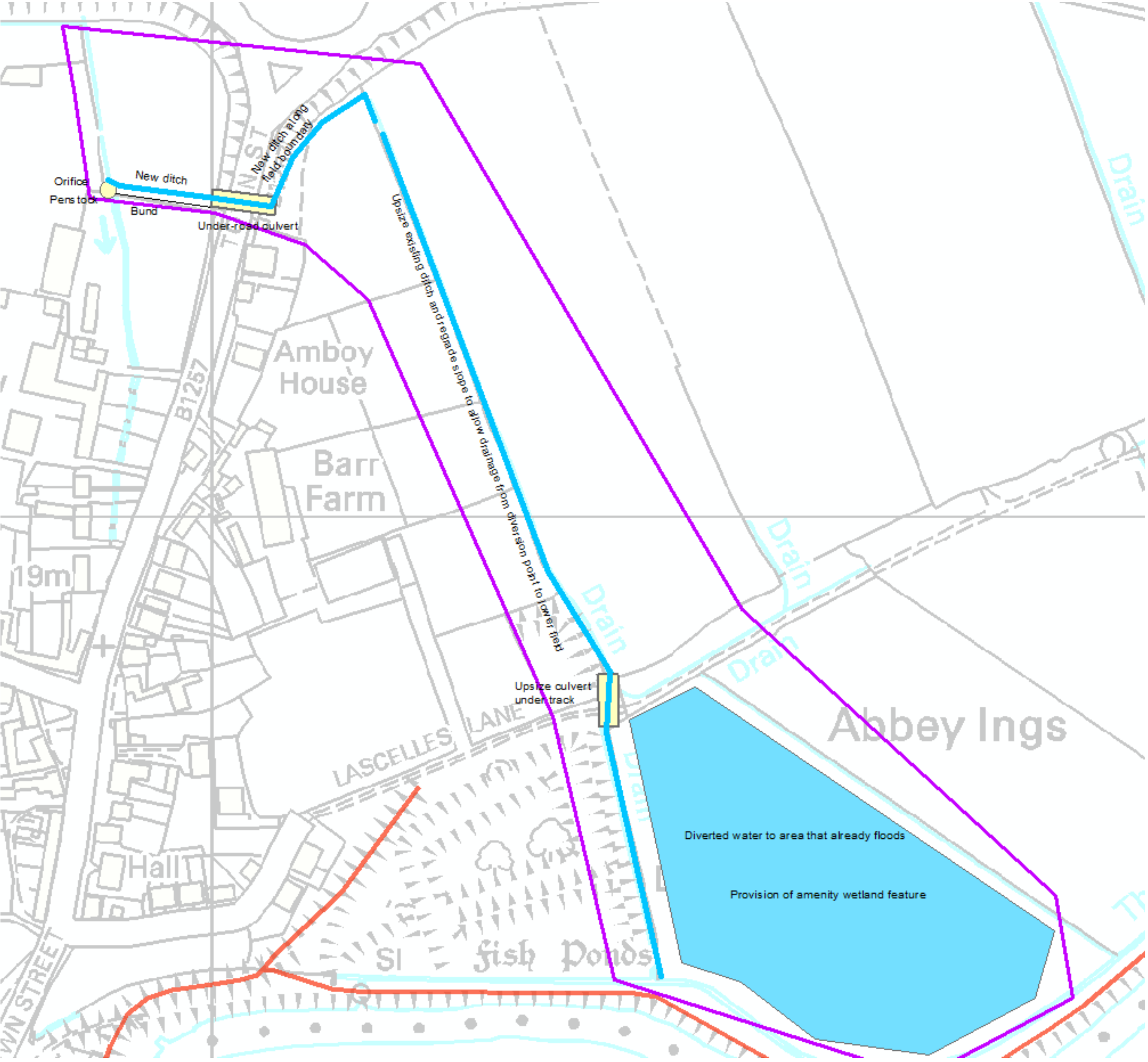


Figure 5 Old Malton intervention sketch - Option 2.

I4.4.3 Option M5

- New permanent PS
  - pump station capacities:

        - 0.05, 0.1, 0.15 (m3/s)
        - 1.0, 1.5, 2.0 (m3/s) (assumed provided by 1 duty, 1 assist pump, each of half the noted capacity)
    - 70m gullies to connect runoff from road
    - 2 x draw-off ducts to connect Cat Well and culvert to sump chamber, each 20m long, 1m dia.
    - 60m concealed pump line over flood embankment to river (assume 1m dia)
    - 2 x penstocks

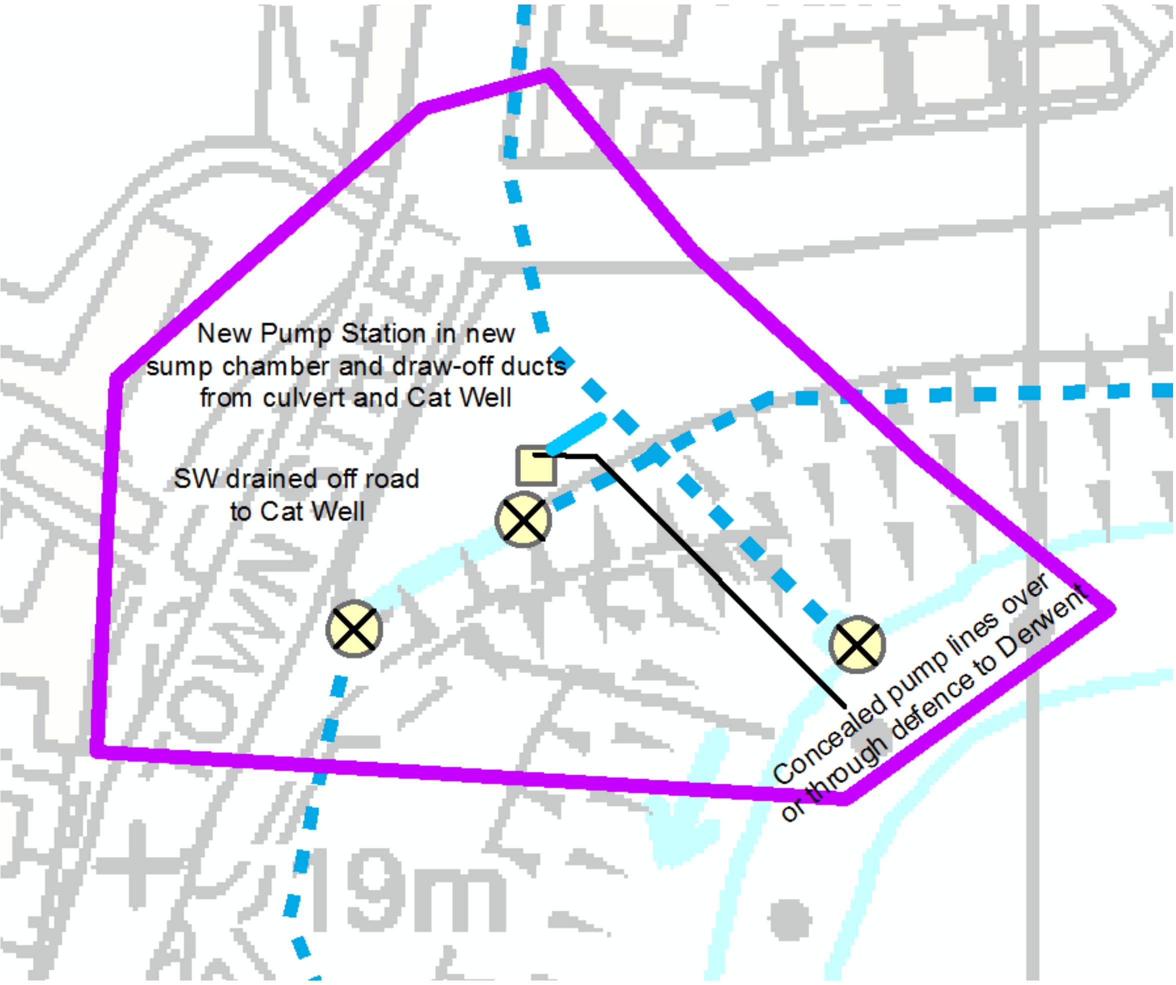
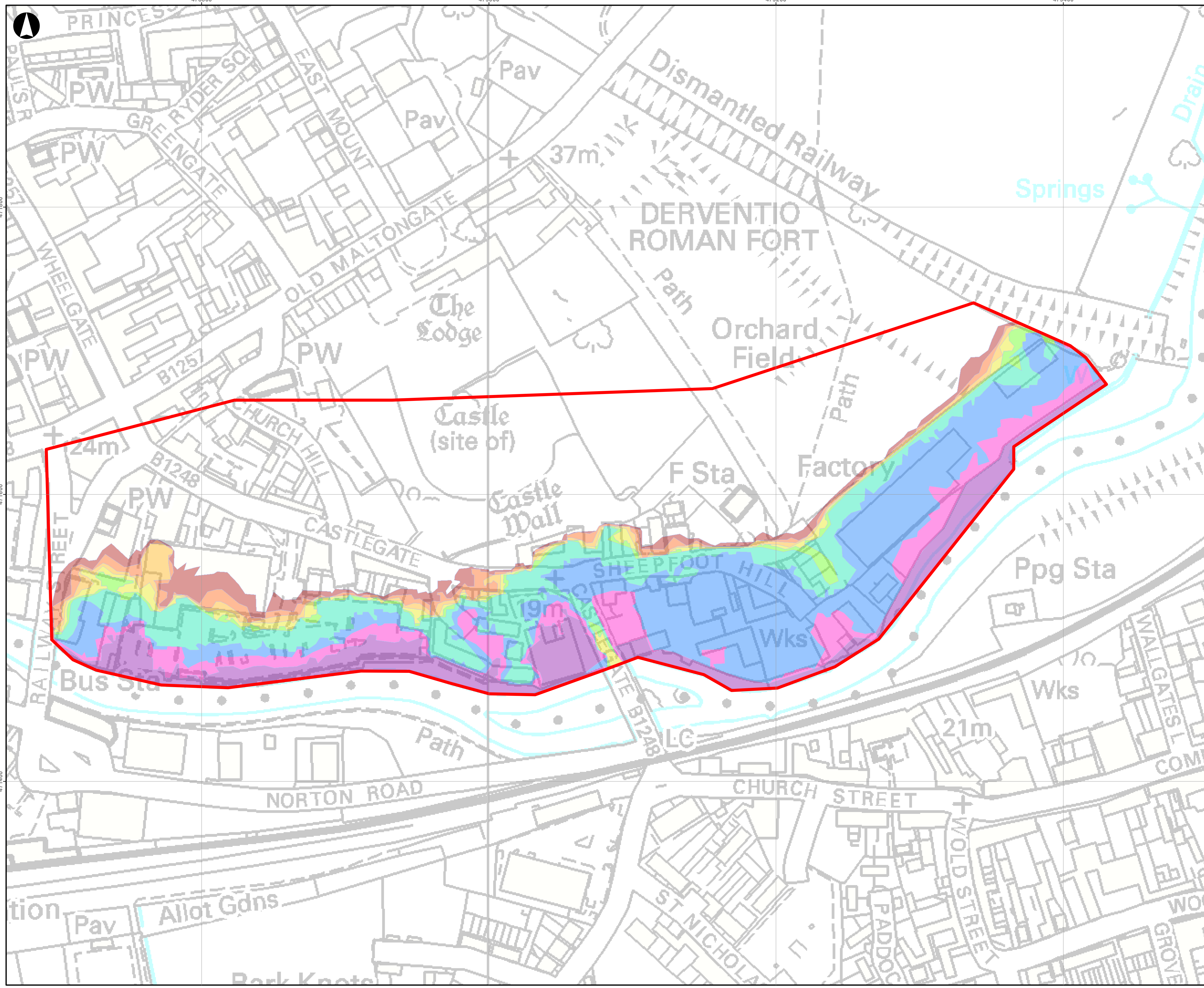


Figure 6 Old Malton intervention sketch - Option 3.

Appendix J

Flood Maps

A3



Legend

- Limit of Flood Mapping
- 1:5 year
- 1:10 year
- 1:20 year
- 1:50 year
- 1:75 year
- 1:100 year
- 1:200 year
- 1:100 + climate change
- 1:1000 year

Note: where flood extents overlap, the most frequent one is shown.

Issue	Date	By	Chkd	Appd
P0	2015-06-24	AB	LB	WM

Metres
0 30 60 120

ARUP

Rose Wharf 78 East Street
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Client

North Yorkshire County Council

Job Title

Malton and Norton Flooding Study

Do Nothing Flood Extents - Malton

Scale at A3
1:2,500

Job No	Drawing Status
239474-00	**Preliminary**

Drawing No	Issue
101	**P0**

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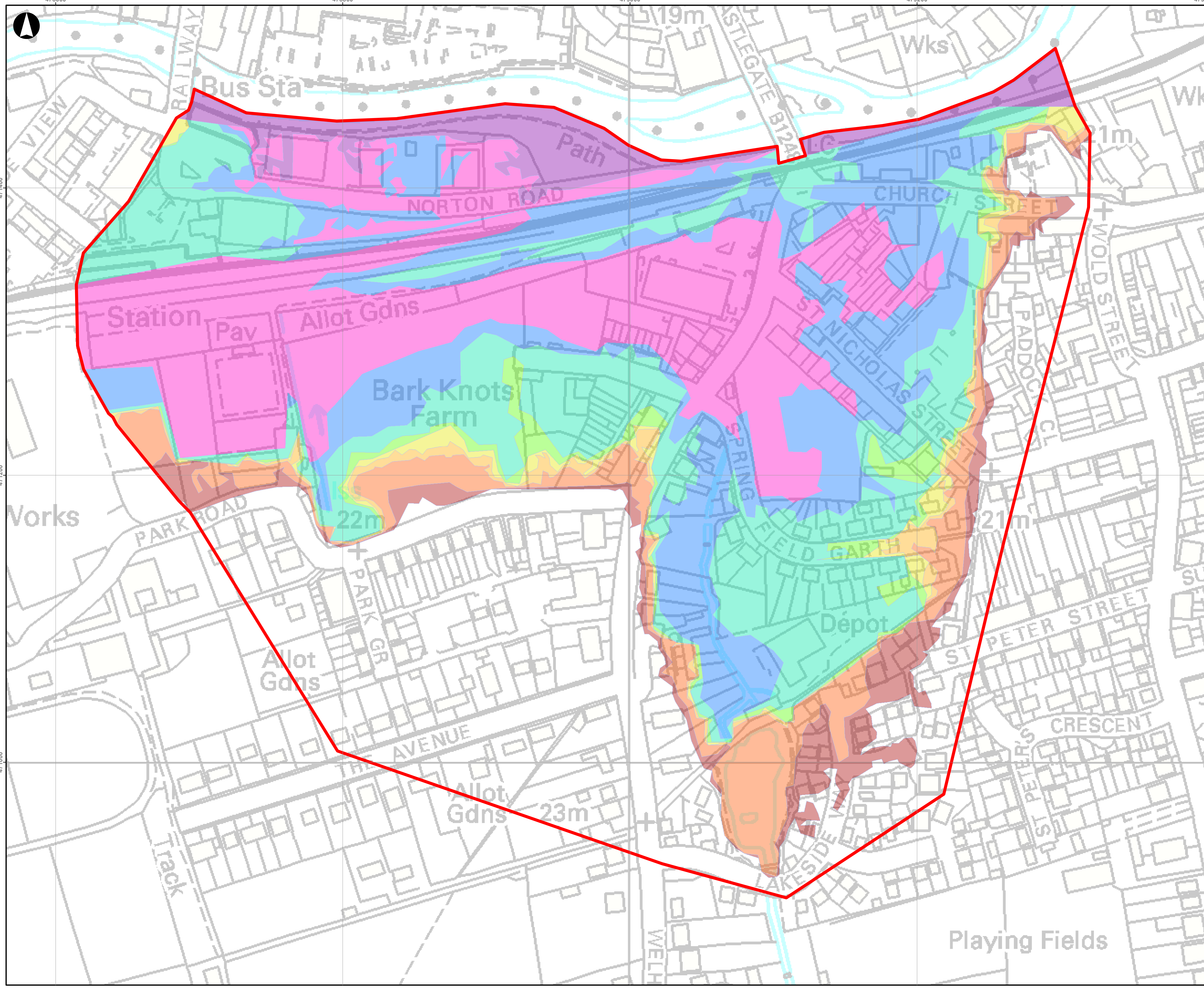
MXD Location

A3



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Legend

- Limit of Flood Mapping
- 1:5 year
- 1:10 year
- 1:20 year
- 1:50 year
- 1:75 year
- 1:100 year
- 1:200 year
- 1:100 + climate change
- 1:1000 year

Note: where flood extents overlap, the most frequent one is shown.

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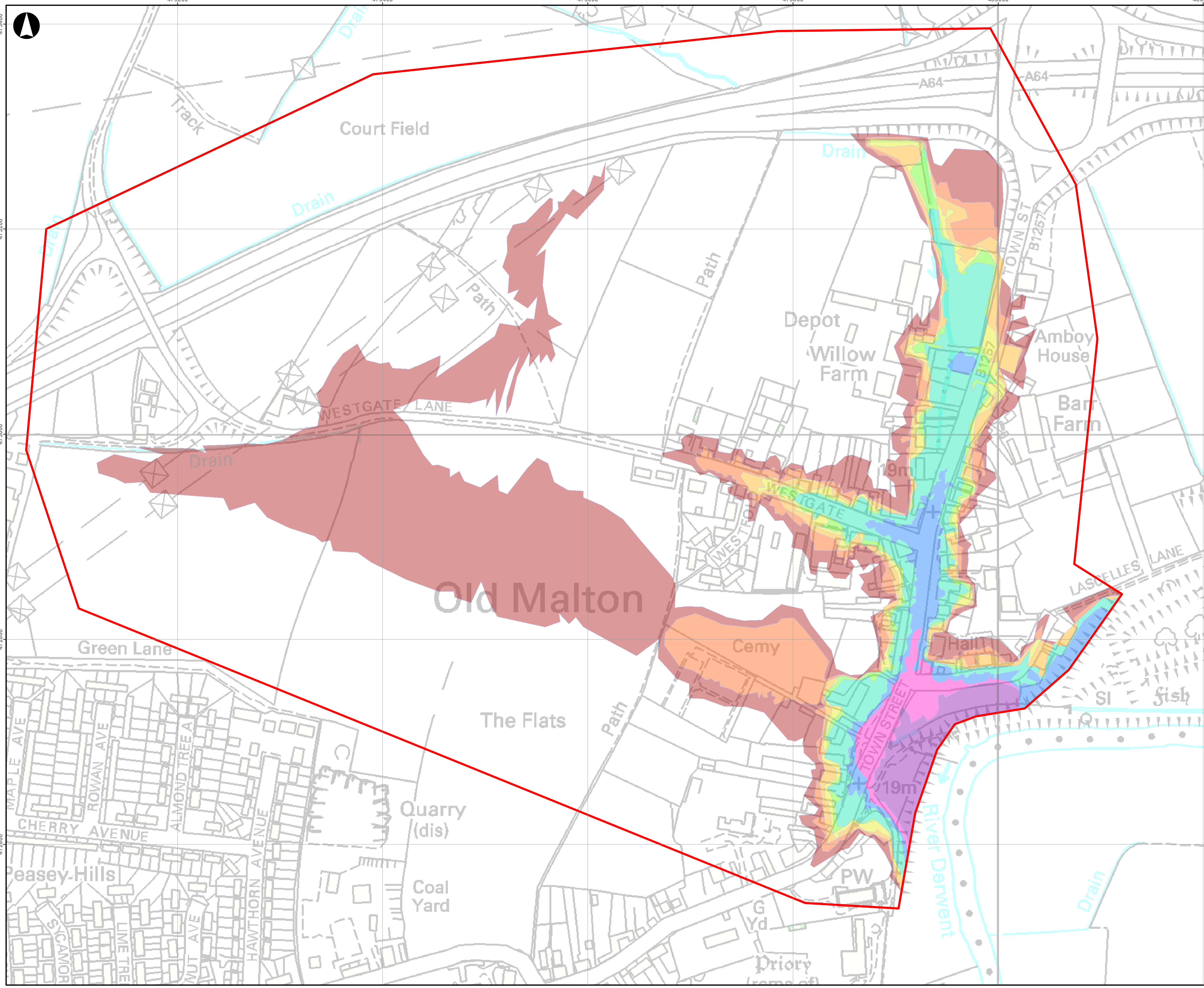
Job No	Drawing Status
239474-00	**Preliminary**

Drawing No	Issue
102	**P0**

MXD Location

A3



24/06/2015 14:35:59

Legend

- Limit of Flood Mapping
- 1:5 year
- 1:10 year
- 1:20 year
- 1:50 year
- 1:75 year
- 1:100 year
- 1:200 year
- 1:100 + climate change
- 1:1000 year

Note: where flood extents overlap, the most frequent one is shown.

Issue	Date	By	Chkd	Appd
P0	2015-06-24	AB	LB	WM

Metres
0 45 90 180

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Client

North Yorkshire County Council

Job Title

Malton and Norton Flooding Study

Do Nothing Flood Extents - Old Malton

Scale at A3

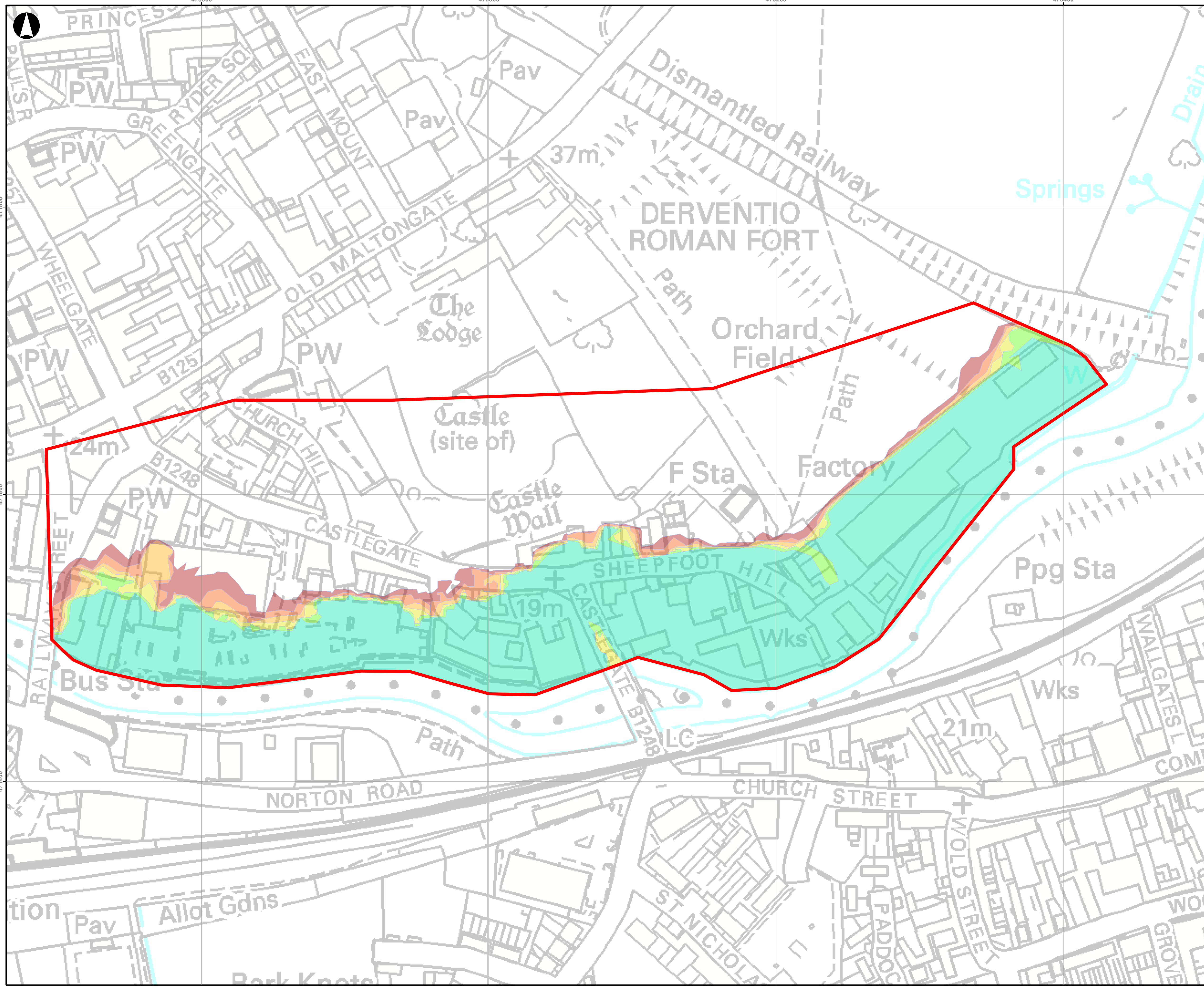
1:3,500

Job No	Drawing Status
239474-00	**Preliminary**

Drawing No	Issue
103	**P0**

MXD Location

A3



Legend

- Limit of Flood Mapping
- 1:5 year
- 1:10 year
- 1:20 year
- 1:50 year
- 1:75 year
- 1:100 year
- 1:200 year
- 1:100 + climate change
- 1:1000 year

Note: where flood extents overlap, the most frequent one is shown.

Issue	Date	By	Chkd	Appd
P0	2015-07-02	AB	LB	WM

Metres
0 30 60 120

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Client
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Job Title
Malton and Norton Flooding Study

**Flood Extent -
Malton Option M5**

Scale at A3
1:2,500

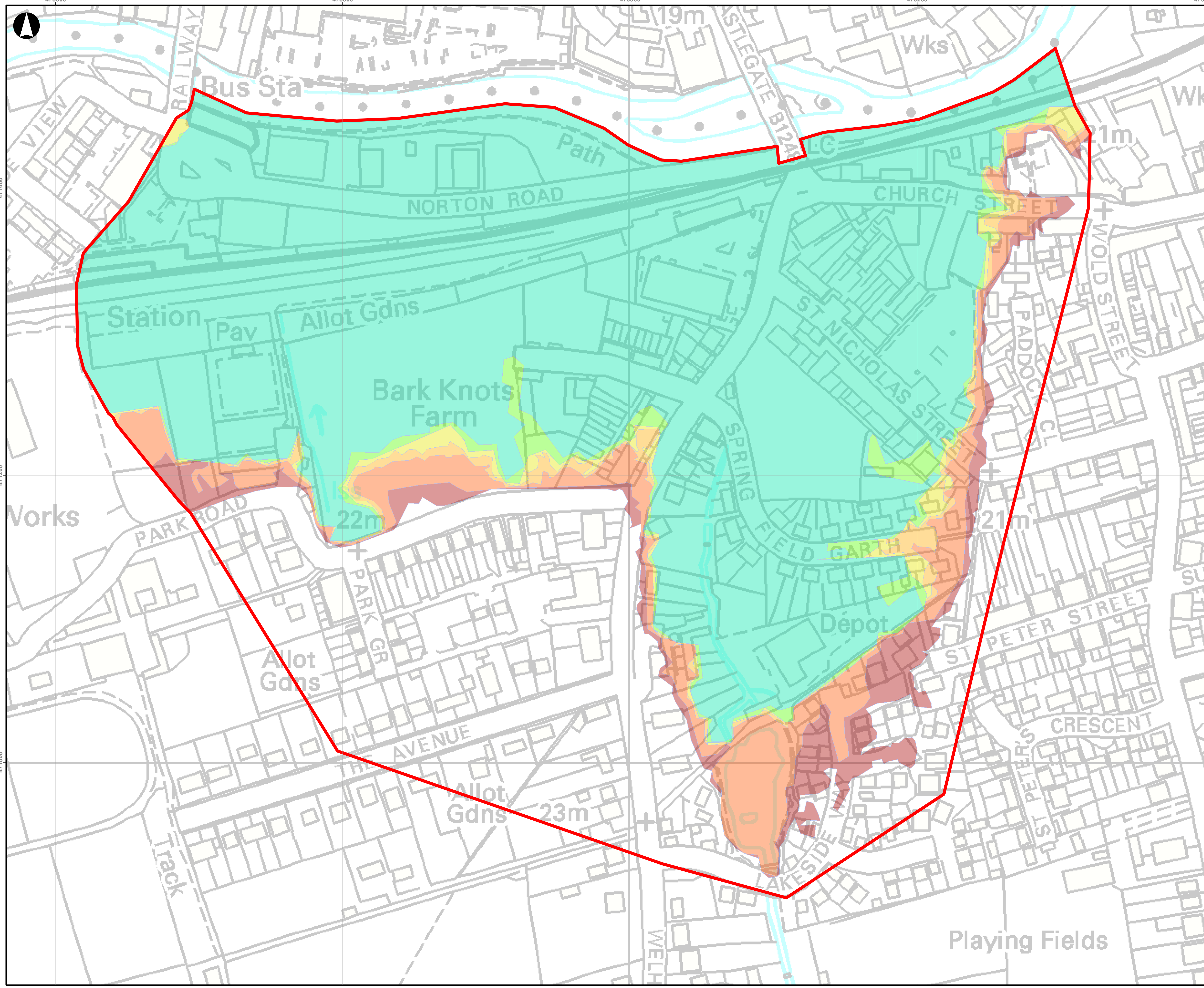
Job No	Drawing Status
239474-00	**Preliminary**

Drawing No	Issue
201	**P0**

02/07/2015 10:22:41

MXD Location

A3



Legend

- Limit of Flood Mapping
- 1:5 year
- 1:10 year
- 1:20 year
- 1:50 year
- 1:75 year
- 1:100 year
- 1:200 year
- 1:100 + climate change
- 1:1000 year

Note: where flood extents overlap, the most frequent one is shown.

Issue	Date	By	Chkd	Appd
P0	2015-07-02	AB	LB	WM

Metres
0 30 60 120

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Job Title
Malton and Norton Flooding Study

Flood Extents - Norton Option N4

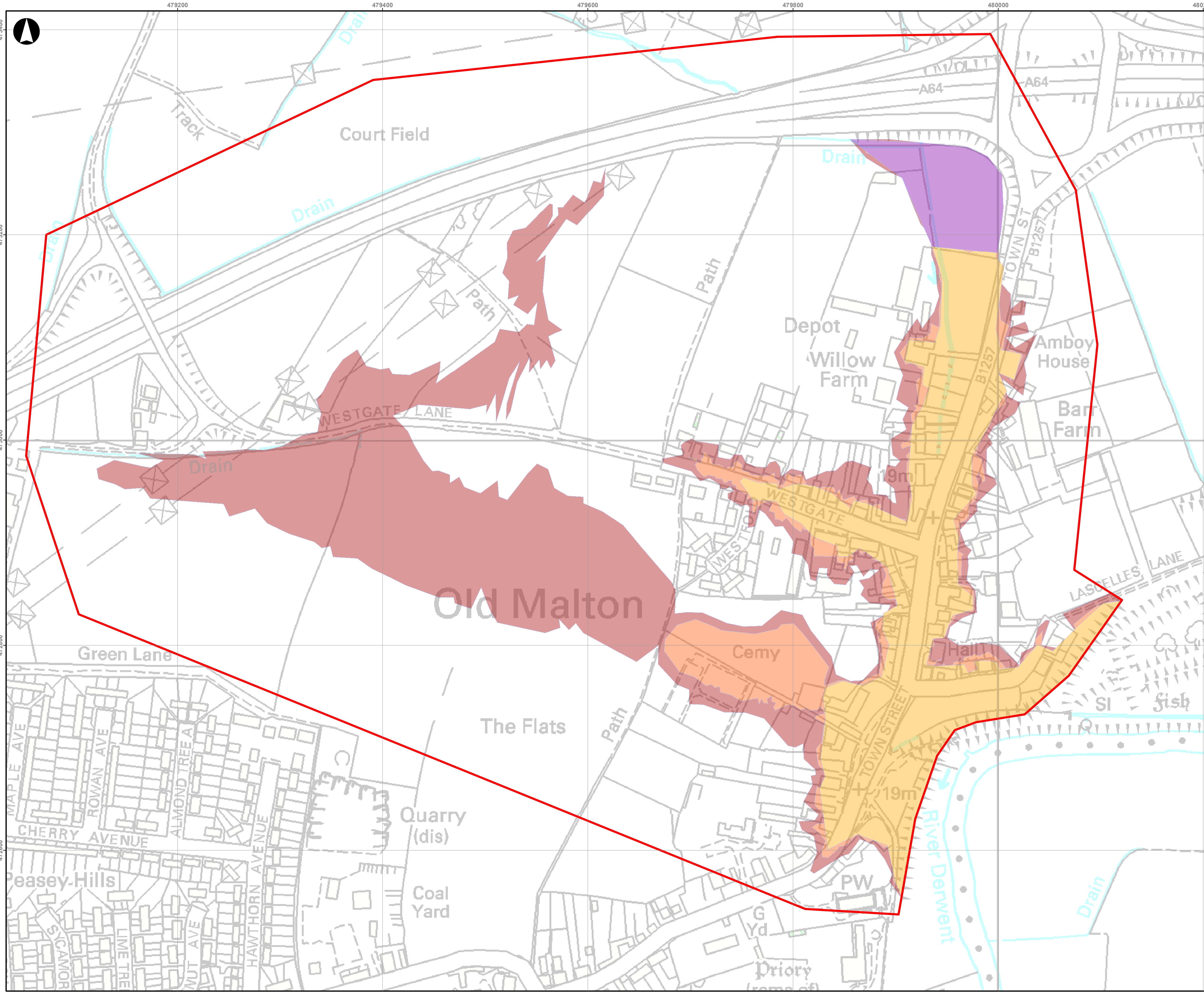
Scale at A3
1:2,500

Job No **239474-00**
Drawing Status **Preliminary**
Drawing No **202**
Issue **P0**

02/07/2015 10:22:35

MXD Location

A3



02/07/2015 10:22:29

Legend

- Limit of Flood Mapping
- 1:5 year
- 1:10 year
- 1:20 year
- 1:50 year
- 1:75 year
- 1:100 year
- 1:200 year
- 1:100 + climate change
- 1:1000 year

Note: where flood extents overlap, the most frequent one is shown.

Issue	Date	By	Chkd	Appd
P0	2015-07-02	AB	LB	WM

Metres
0 45 90 180

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Client
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Job Title
Malton and Norton Flooding Study

Flood Extents -
Old Malton Option OM4

Scale at A3
1:3,500

Job No **239474-00**
Drawing Status **Preliminary**
Drawing No **203**
Issue **P0**

MXD Location