APPENDIX I

Modelling methodology used for NFM assessment

Appendix I. Modelling Methodology

I.1 Modelling Approach

I.1.1 Generic Approach

Given the technical nature of the modelling and the relatively specialised nature of the work, details on the process adopted are included here in order to keep the main report as concise as possible.

Following the screening stage, option assessment sought to provide a basis for the prioritisation of options. The overall approach to quantification of all options is described within the methodology section, with specific detail on the hydraulic modelling processes that have been used.

The overall approach used individual 1D-2D hydraulic models, linked by a routing model where appropriate. Options were grouped based upon their spatial proximity, resulting in an initial 5 models, subsequently reduced to 4 (the Thornhill model was initially split into 3 models until the importance of interactions between the tributaries and the mains stem of the Nith was understood).

I.1.2 1D-2D Hydraulic Modelling

Hydraulic modelling of the River Nith and its tributaries was undertaken using a linked 1D - 2D, ISIS – TUFLOW, hydrodynamic flood model. TUFLOW is a two dimensional modelling software package, and this was used for modelling the floodplain elements. ISIS is a one dimensional modelling package, which was used for modelling in-channel flow, including representation of structures in the watercourses where adequate survey information was provided. The two elements of the model are dynamically linked and therefore water can flow between both domains, as per reality, which results in an accurate representation of the impact of floodplain storage on flood flows, which is not possible using a purely 1D model.

I.1.3 Why Use Flow Routing?

Flow routing was conceived as a way of providing an indication of the effect of a measure at the catchment scale, enabling the temporal distribution of events to be taken into account throughout the catchment. The numerical methods used for flow routing are computationally less intensive than 1D-2D hydrodynamic modelling and so provide a quick basis for routing flows downstream.

While hydrodynamic modelling can provide a more accurate estimate of the change in velocity, flood level and inundated area for a particular reach, it can be very demanding at a catchment scale with respect to computational processing and data requirements. We developed separate hydrodynamic models for specific reaches of the river network, linked by routing models. In our opinion this provided the best balance between efficiency given the project programme and data constraints and the project objectives.

The flow routing employed is a variable parameter Muskingum-Cunge method, which can be considered more generally as one of a number of linear transfer function models (Shaw, 2011). This is a simplification of the solutions typically used in 1D-2D models and as such is based upon assumptions that may not always be valid (routing methods such as Muskingum Cunge consider the channel as a store of water with variable inflows). As such, it is assumed that the contribution from friction is considered insigificant in this type of routing approach.

I.1.4 Alternative Options

As part of the methodology development, consideration was given to the use of alternative options such as simplified catchment based flow routing methods, pure 1D models and pure 2D models.

Flow routing methods are typically simplified approaches, which in their most advanced form use 'typical' cross sections of the channel (as described above). Because of this, they are not particularly well suited to catchment scale assessment of relatively subtle changes as the channel form is not well represented. There is limited ability to capture the proposed change in channel and floodplain geometry. To do this adequately may require extensive cross-sections (in both number and extent) to represent the floodplain. The assumption of negligible contribution from frictional forces may not be valid in lower catchment areas, where friction may provide a significant control on water levels, with less contribution from gravitational forces due to the low gradients typically experienced in these areas.

1D models provide an improvement on the routing model style of approach. They typically need more cross sections to ensure model stability and hence a more accurate representation of the channel geometry is captured. Frictional forces are applied at each cross section, varying across their chainage if appropriate, hence removing some of the uncertainty associated with routing models. 1D models can represent floodplain storage, but to do so can require extensive manipulation of cross-section geometry which is time consuming if carried out over extensive reach lengths. In addition, standard floodplain storage cells in 1D models usually do not account for the time of travel of water across the floodplain. 1D model storage cells fill vertically according to their dimensions and the rate of inflow from adjacent channel units or other storage cells; the model does not account for the rate of flow across the floodplain within these storage areas. Given the concern expressed in previous studies regarding the risk of increasing downstream channel flows by removing channel embankments, this limitation of 1D models is thought to be particularly pertinent for this specific catchment.

The resulting 1D solution clearly solves in one dimension only which can provide an under or overestimation in floodplain spreading. A key finding of the work carried out on the River Nith indicates the extent to which the 1D approach would neglect storage in embanked tributaries of the main watercourses (of which there are a significant number in areas such as the New Cumnock reach).

Pure 2D methods have the advantage that they do not require time consuming work to link the 1D and 2D elements of the model. However, inclusion of a 1D element to model the channel often allows for a more accurate representation of the channel geometry.

2D representations would require complex interpolation between surveyed channel sections prior to modelling or the use of the more simplistic representation of the channel from a remote sensed 2D surface such as LiDAR. LiDAR does not penetrate the water surface and therefore the channel capacity can be underestimated if limited channel survey data is available. This problem is exacerbated if only Nextmap DTM data is available due to its coarser resolution and hence poor representation of river channels. The use of standard mesh sized 2D models provides a secondary problem in terms of the balance to be struck between the accuracy of the representation of the topography and the computational run-time, which increases with decreasing mesh size.

I.2 Reach Model Structure and Model Build

I.2.1 Model Domains

Model domains were based upon the aggregated geographical area of the options taken forward for assessment.

Table I.1: Model Domains

Model	Domain Description	Comments
New Cumnock	Confluence of Afton Water downstream to Nith Bridge.	1D-2D ISIS-TUFLOW hydrodynamic model.
The upstream boundary of the model was moved to the Nith bridge to prevent flow u/s along the floodplains which was resulting in model instabilities.		
This included the need to represent the Afton Water tributary in the model.		
Thornhill	Nith – From Thornhill running 9.5km downstream.	
Scar Water – From Scaur Bridge at Penpont to confluence with the River Nith, 4km downstream.		
Cample Water – From Cample to confluence with the River Nith, 3.8km downstream.	1D-2D ISIS-TUFLOW hydrodynamic model Originally conceived as separate models for Scar and Cample water, subsequently combined into one model to consider the effects of water elevations in the main channel on tributary behaviour and to capture all floodplain flow interaction at the watercourse confluences.	
Upper Cairn	From Stewarton to Dalgonar Bridge, 7km downstream.	1D-2D ISIS-TUFLOW hydrodynamic model.
Originally extended to Moniaive but due to the lack of channel survey data and the fact that the DTM in the upper reaches only Nextmap, the model domain was reduced and the upstream boundary		

Model	Domain Description	Comments
moved further downstream.		
Lower Cairn	From Drumpark Bridge running 5.4km downstream.	1D-2D ISIS-TUFLOW hydrodynamic model
Halls Bridge to Drumlanrig	From Halls Bridge gauging Station to Drumlanrig gauging station, approximately 27km downstream	ISIS routing model

I.2.2 Modelled Build Summary

A simple and consistent model build procedure was followed to ensure efficiency during the model build and also to ensure that outputs from the model were derived from a consistent approach.

Steps in the standard model build procedure are stated below. All deviations from the standard model procedure for each of the model domains stated in Table I.1 above are also reported.

I.2.2.1 1D Domain

Baseline

1. Collation and checking of topographical survey data to ensure no erroneous data was used in the model build.
2. Transfer of cross sectional survey data into ISIS (v3.6) including distance between sections; channel roughness (standardised as a Manning's 'n' value of 0.038 for the channel) and details of any in channel structures included in the survey data.
3. Analysis of gauged data to generate the inflow hydrograph to be included in the upstream boundary condition.
4. Generation of supporting files housing upstream and downstream boundary conditions and linkage to TUFLOW model files. Normal depth boundary conditions have been used at the downstream extent of the model, including a gradient calculated from surveyed data.
5. Generation of initial model conditions (water depths at the model inception time) was undertaken through running the model firstly in steady state and then in unsteady state to ensure model stability.
6. Embankment Removal Scenario
7. Alteration of cross sections to remove any representation of embankments within the 1D domain. Where embankments were located in the Baseline scenario, the ground level was reduced to that of the surrounding area.
8. Extension of cross section width. To remove the embankments from the 2D domain the 1D domain area was extended (see the following explanation) to remove the need for extensive alterations to the DTM. This results in extending the cross sections. Therefore, the cross sections in the ISIS (v3.6) model were extended by the same length to preserve the flow capacity in the 1D environment.

I.2.2.2 2D Domain

Baseline

1. Outline of the 1D and 2D modelling domains using GIS. TUFLOW uses a layered approach to build the model where different GIS layers equate to different functioning parts of the model by using GIS attribute tables to amend the DTM for example.
2. Connection of the 1D domain to the 2D domain to allow out of bank flow to spill onto the floodplain, which is modelled in TUFLOW.
3. Enforcement of bank crest levels and embankment heights using data from the DTM to ensure model stability.
4. Inclusion of a layer to enforce Manning's 'n' roughness coefficients across the floodplain area. These vary depending on the land cover class as defined in the LCM2007 data set provided by SEPA.
5. Inclusion of downstream boundary conditions on the floodplain areas to allow flow from the floodplain to leave the model. Normal depth boundary conditions have been used at the downstream extent of the model, including a gradient calculated from DTM data to replicate the gradient of the floodplain.
6. Inclusion of layers to record flow in pertinent locations such as at the outflow boundary.
7. Selection of an appropriate cell size to allow accurate representation of the topography of the area, reasonable model runtime and to reduce the risk of instabilities within the model.
8. Setup of TUFLOW modelling files to reference the correct GIS layers and link to the ISIS model of the 1D domain.

Embankment Removal Scenario

1. Removal of river embankments. As noted previously the 1D domain area is moved beyond the embankment location, away from the channel, for the embankment removal scenario. This ensures that the embankment area is now removed from the model and is now covered by the 1D domain. The ISIS cross sections are extended in length to be consistent with the extended 1D domain.
2. Removal of floodplain embankments. Any embankments present on the floodplain are removed through altering the DTM so the ground level either side of the embankment is maintained laterally across it.
3. Update of TUFLOW modelling files to reference the correct GIS layers and link to the ISIS model of the 1D domain.

I.2.2.3 Modelling Outputs

Topographic Data

Defining channel and floodplain geometry accurately is extremely important, even for a crude modelling approach. Even limited topographic ground survey can give confidence in the use of remotely sensed products.

The ISIS TUFLOW models produce a variety of different results including flood depth, flood level and velocity, both in the channel (ISIS) and on the floodplain (TUFLOW). Figure I.2 and Figure I.3 show an example of flood depths from the New Cumnock model for the baseline and embankment removal scenarios. The temporal variation in the results can also be outputted from the model and viewed as an animation using specific software, so the development of the flood can be viewed through the event.

I.2.2.4 Deviation from Standard Methodology

On several occasions in the model development process, it was necessary to define the channel geometry using DTM data rather than surveyed cross sections. Only limited cross sectional data was collected to inform the modelling process and therefore the DTM data was used to supplement the models of the Cairn Water. This was only undertaken where LiDAR DTM was available as it is detailed enough to give a clear estimate of the channel and the embankment geometry. In areas where only Nextmap DTM was available, the model domain was curtailed (the upper section of the Upper Cairn model was removed due to only Nextmap DTM being available). The resolution of Nextmap data fails to give a detailed estimate of the channel shape and therefore cannot give a reasonable estimate of the channel capacity; in many cases for this specific reach of the Upper Cairn, the channel embankments were not evident at all from the Nextmap data, and therefore inclusion of this reach in the model would have had a significant detrimental effect on the quality of the model results.

Where LiDAR data was used for modelling an assumption was made to account for the fact that the equipment used to define the topography in the LiDAR cannot penetrate water surfaces. This means that using LiDAR to define the channel geometry results in an underestimate of channel capacity. A comparison of surveyed cross sections with LiDAR data was undertaken across the catchment where it was found that the water depth on the day of flight when the LiDAR data was collected was approximately 0.5m. In cases where LiDAR was used to define the channel cross section, the bed level was lowered by 0.5m to account for this.

The limited scope of the topographical survey meant that a number of structures present on the Cairn Water, Cample Water and Scar Water have not been surveyed and therefore have not been included in the model. This will have the results of increasing the flow of water downstream as no bridges are present to form a barrier to flood flows, and the flood extent at these locations may be underestimated.

I.3 Hydrology for Options Quantification

I.3.1 Design Event or Observed Event?

Recommendation

Testing the effectiveness of measures under several observed scenarios is recommended in order to gain a full understanding of the potential range of change to flood risk.

The initial hydrology work undertaken for characterisation provided the basis for model hydrological inputs. Traditional flood studies often use the concept of a design event, typically due to the requirement for measures to meet a particular design standard. In the case of NFM, it is more difficult to design measures to a particular standard, partly because of the uncertainty in prediction, but also because the physical implementation of measures does not always lend itself to different levels of protection.

As a result of this, early development of the methodology identified the use of observed data as being essential to understanding catchment behaviour. While it is reasonably straightforward to generate inflows at any single location within the catchment, it becomes more difficult to generate a number of inflows in different locations within the catchment due to a need to maintain the spatial relationships in return periods of flood flows. For example, the 10 year return period flow observed at Friars Carse may be generated by significantly different combinations of flows from all contributing sub-catchments. It is too simplistic to assume the 10 year return period flow is the correct inflow to use for all contributing sub catchments, as the analysis undertaken shows this would give rise to an event well in excess of the 10 year event at the downstream point of assessment.

This aspect is considered extremely important to the methodology; where modelling is used to attach a quantitative estimate of benefit to an NFM measure, the benefit is subjective depending upon the magnitude of the event being used to assess benefit. Using an unrealistic inflow event may still give rise to a predicted benefit, but it may never be realisable if the measure is ever implemented. It is for this reason that observed hydrometric analysis is recommended to inform the inflow hydrology for modelling, as it can be justified as event which can plausibly be generated in that catchment.

I.3.2 Practicalities of Generating Model Inflows

While the benefit of using observed data is clear, the practicalities of using it in a distributed routing model or hydraulic model are more difficult. Observed data are only available at discrete points in a catchment, which are unlikely to coincide with the inflow locations of model domains. Moreover, the Nith benefits from a relatively good gauged network and hence future studies in alternative catchments may not have access to gauged data. As such, it was considered important that the approach to inflow hydrology generation recognised this constraint and that a framework was established which could be usefully and easily applied to future work.

I.3.3 Generation of Inflow Scenarios

The approach taken to inflow generation was a two stage process.

For the event(s) being used to test NFM measures, a return period estimate of the flow at all gauged locations within the catchment was generated using the FEH WINFAP analysis procedure.

Key Finding

While the use of observed data has clear benefits for testing measure effectiveness in reducing flood risk, the FEH rainfall-runoff method provides a useful compromise between method efficiency and hydrological representation.

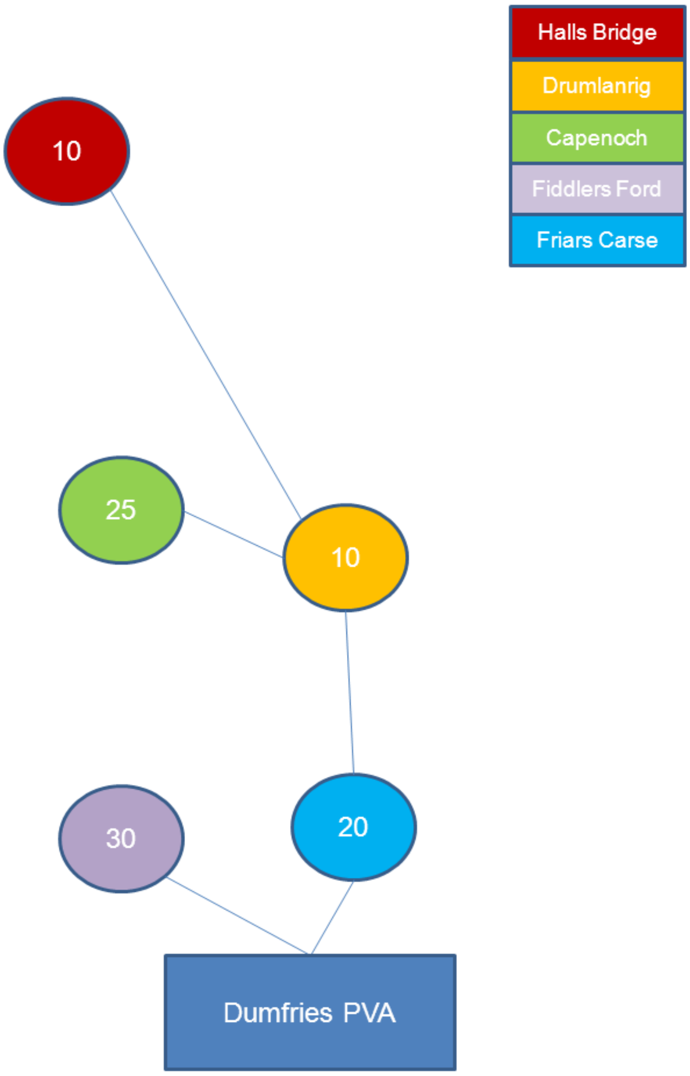
Secondly, the inflows are generated using a FEH rainfall-runoff module within ISIS. The return period of the rainfall-runoff event was determined from the closest corresponding gauged estimate. In some cases, it was more appropriate to take the closest similar catchment RP estimate rather than just the nearest gauged location (similar to a donor approach).

While observed data would be preferable, it is considered that using the FEH rainfall-runoff inflows is a suitable compromise between complexity and consistency. Clearly gauged inflows are only available at discrete locations within catchments and while flows could be scaled and transferred to other locations, this is a complex procedure to undertake if robust results are required. The FEH approach maintains the spatial relationship in return period for the observed event and provides an efficient means for modellers to generate inflows to their models.

This approach is easily transferrable to other catchments, where various methods can be used to estimate the spatial relationship in flow return periods from sub-catchments. This then allows the application of the FEH rainfall-runoff based approach.

For the River Nith catchment, a single event has been chosen to assess measures at the catchment scale. It was agreed that a realistic assessment of the effectiveness of NFM measures should use a relatively low return period event, as the available literature suggests that the effect of NFM measures significantly diminishes at higher return periods . The event chosen occurred on the 19th December 1982. It had an estimated return period of 20 years at Friars Carse. The spatial relationship in return periods for this event is shown in Schematic I.1.

Schematic I.1: Schematic showing estimated return period relationship of flows for the 19th December 1982 event at Friars Carse



I.4 Flow Routing

I.4.1 Routing Model Build

Flow routing for the pilot project was carried out within ISIS v3.6. This is an industry standard piece of commercially available software. The routing model was built using cross-sections from LiDAR. While ground surveyed sections would be preferable, surveying would be required over a significant distance to generate the representative sections. This was not practical given the scope of the project and the added uncertainty in results that may arise from using LiDAR was not considered significant when considered in the context of the uncertainty in routing approaches themselves.

Routing was carried out using a variable parameter Muskingum-Cunge method with representative cross sections extracted from LiDAR as noted above. Routing models do not typically require cross-sections as for a 1D model, and therefore a representative section was used approximately every 4km.

I.4.2 Routing Hydrology

As with model boundary inflows, several tributary inflows needed to be represented in the routing model. These inflows were generated using FEH rainfall-runoff methods as described in I.3.3.

The return periods for the inflow tributaries were determined from the nearest similar gauged catchment.

I.5 Appraisal/Review of Approach and Future Development

I.5.1 Hydraulic Assessment/Routing

Hydrodynamic modelling of the 5 reaches of the River Nith catchment has successfully provided an assessment of the impact removing embankments on flows, flood depths, velocities and inundated areas. It is recognised that the chosen methodology has advantages and disadvantages which should be considered for similar projects to be undertaken in the future.

Advantages to the Adopted Approach

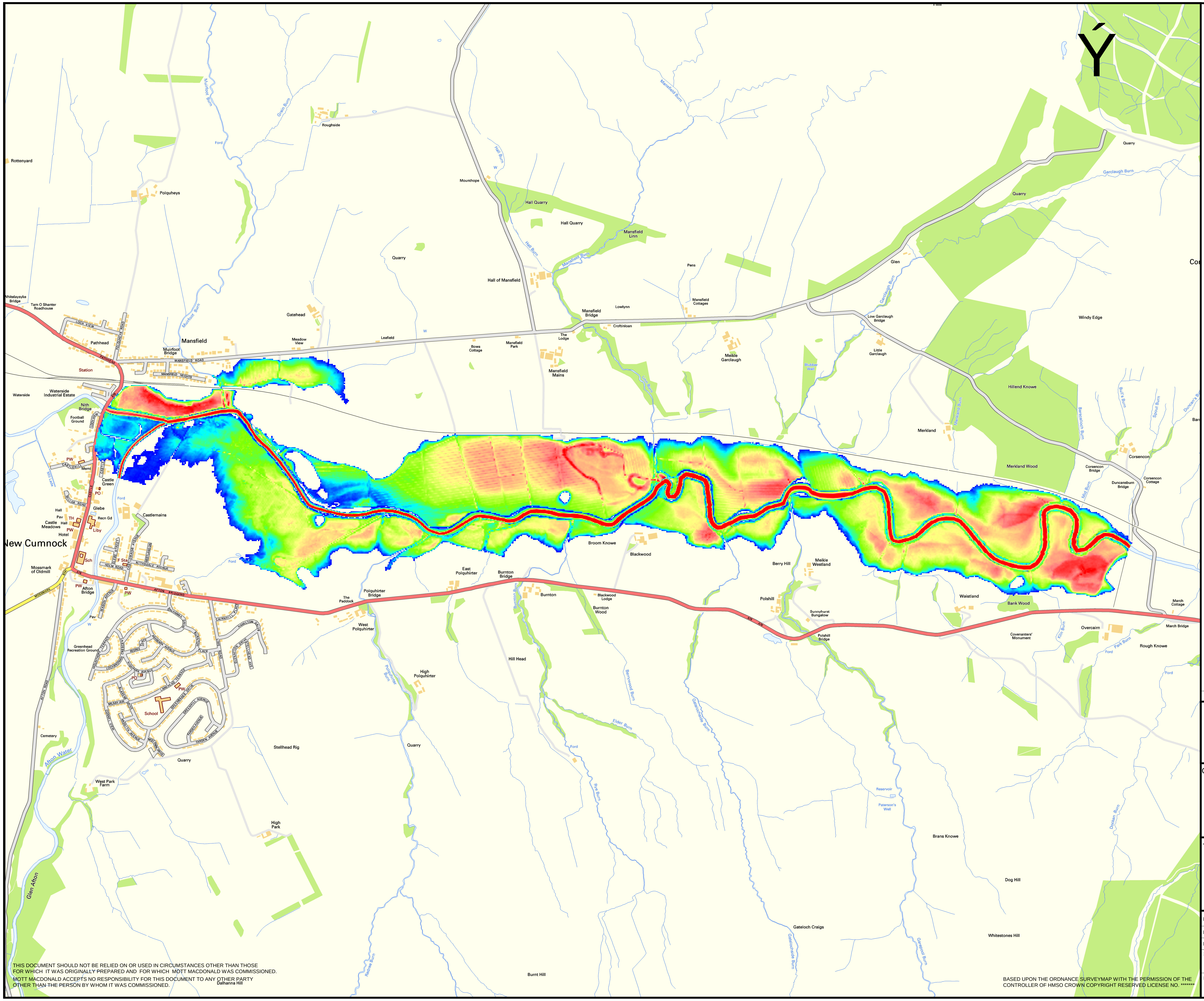
1. A combined 1D-2D modelling methodology produces an accurate representation of inundated areas, flood depths and velocities on the floodplain. This is not possible using a purely 1D modelling approach.
2. Inclusion of a 1D element in the modelling methodology allows detailed modelling of channel geometry and detailed representation of in channel structures, where they have been surveyed and where they will have a significant impact on flood water depths and flow paths.
3. Inclusion of detailed floodplain modelling, the 2D element of our models, allows targeted implementation of softer floodplain NFM measures such as tree planting, which could not be undertaken if a purely 1D approach is used.
4. Land owner boundaries can be superimposed on the modelled results to target areas which are owned by landowners who are sympathetic to implementing NFM measures, therefore resulting in a targeted approach.

Disadvantages to the Adopted Approach

1. It is not possible to build a catchment scale 1D 2D hydraulic model of a large catchment such as the catchment area for the River Nith. The run time of a 1D 2D model is dependent on the cell size, model timestep and inundated area during modelling. The cell size and model timestep are restricted to an extent due to the need to set these values to reduce the risk of model instabilities. The model size is can be curtailed by splitting up a catchment to focus on specific areas as per the modelling approach adopted for this study. If this is not done, a catchment scale model would take a significant amount of time to set up and run.
2. Representation of the embankment removal option is time consuming when using a 1D 2D model. This is because the topography needs to be altered in both the 1D domain (ISIS) and the 2D domain (TUFLOW).
3. Hydraulic or hydrodynamic modelling using 1D, 1D/2D or fully 2D models cannot replicate the results of a rainfall runoff model. The interaction of rainfall across the catchment with vegetation and percolation processes cannot be simulated in a hydraulic model and therefore investigation into the benefits of reforesting an area of a catchment for example, cannot be explored quantitively.

Figure I.1: New Cumnock Baseline Run
Figure included on the following page.

Figure I.2: New Cumnock Embankment Removal Option
Figure included on the following page.



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00	04/09/2013	AL	First Issue	JL	TJ

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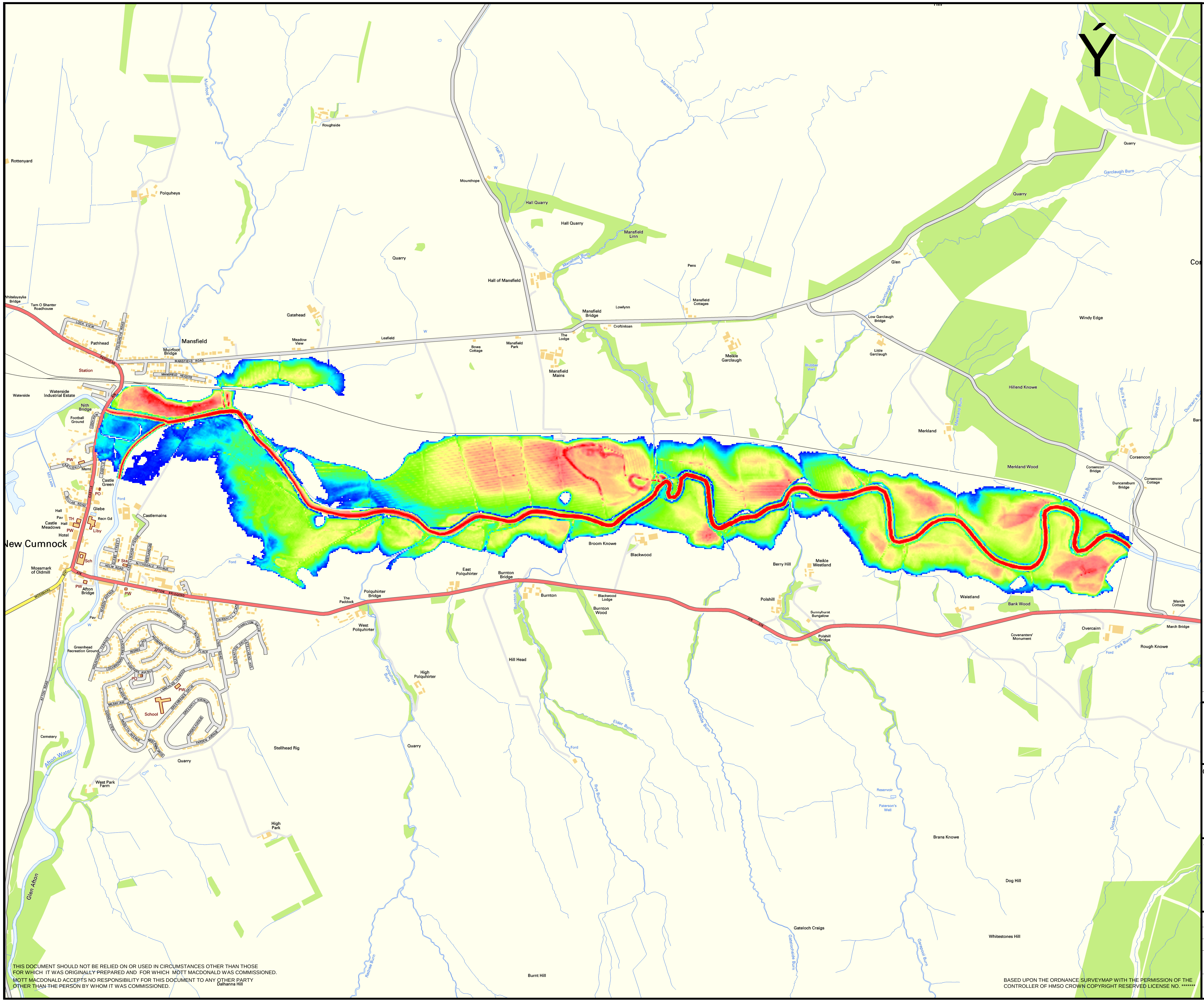
Title

New Cumnock
Baseline Run
Maximum Depths

Designed	AL	Eng. Chk.	N/A
Drawn	AL	Coordination	N/A
Drg. Chk.	JL	Approved	TJ

Scale at A3 1:17,500	Project 318688 Mapinfo file New_Cumnock.WOR	Status PRE
Drawing Number 318688/XXX		Rev 00



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New Cumnock
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Maximum Depths

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Drawn	AL		Coordination	N/A	
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