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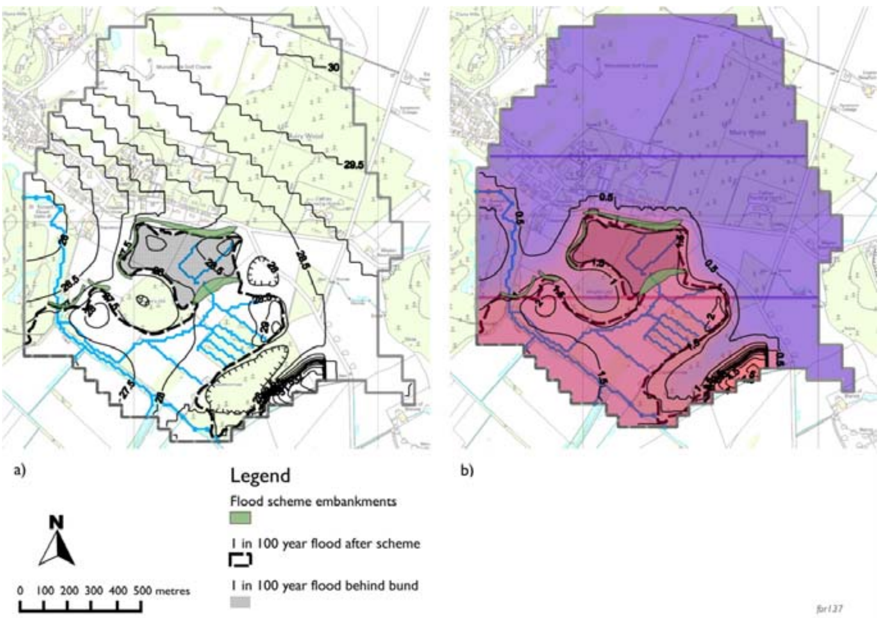
Groundwater modelling of the impact of the Burn of Mosset FAS on the Chapletonmoss Spring

Groundwater Programme

Commissioned Report CR/11/130

15th November 2011



BRITISH GEOLOGICAL SURVEY

GROUNDWATER PROGRAMME

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Groundwater modelling of the impact of the Burn of Mosset FAS on the Chapletonmoss Spring

Hulme P.J., Hughes A.G. and MacDonald A.M.

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Front cover

Model results showing head after 1:100 year run (6 days with FAS).

Bibliographical reference

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1 Introduction

1.1 BACKGROUND TO PROJECT

BGS were first involved in the Burn of Mosset Flood Alleviation Scheme (FAS) in 2005 when they were commissioned by Moray Flood Alleviation (MFA) to investigate the source and chemistry of water for the Benromach distillery which was poorly understood by all parties at this time. This work was carried out collaboratively with Gordon & MacPhail and together the series of pipes and ditches which made up the spring supply were identified (Ó Dochartaigh 2005).

A detailed investigation programme was undertaken in 2006 to collect new geological, hydrogeological and chemistry data for the area, investigate the spring supply and use these data to model the impact of the FAS on groundwater and the existing network of springs and drains (MacDonald et al. 2006).

During 2005 and 2006, BGS also oversaw the drilling and testing of a potential standby borehole supply for the Benromach distillery, and concluded after testing that it was not a reliable alternative (Ó Dochartaigh and MacDonald 2005; Ó Dochartaigh et al 2006).

BGS were involved with the Public Local Inquiry in 2006 and provided advice to improve the general standard of the spring supply and to estimate the impact of flooding on the spring network. Agreement was reached with Gordon & MacPhail to modify the scheme to give protection to a portion of the Chapelton Spring for an event of return period up to 1 in 66 years. This part of the spring network is now known as Spring 1.

In 2011, BGS were commissioned by MFA to develop a groundwater model to specifically represent flows in the Benromach Spring 1 in response to an overtopping event (i.e. an event of magnitude greater than 1 in 66 years). This was in response to the hydrological claims by AMEC, based on an interpretation of the initial BGS data and general 2006 model and used by Gordon & MacPhail in their claims for compensation (Salmon 2011).

1.2 STRUCTURE OF REPORT

This report describes the groundwater modelling undertaken to support the findings presented in MacDonald (2011). This work is presented as a separate report to avoid disrupting the flow of MacDonald (2011) and to provide further information. For completeness, some of the information contained in MacDonald (2011) is repeated here.

The report consists of four further sections: a brief description of the conceptual understanding of groundwater to the spring, a description of the model development and the presentation of the prediction runs. Finally, a summary and conclusions section is included.

2 Conceptual understanding

2.1 GROUNDWATER FLOW TO THE SPRING SYSTEM

The understanding of the hydrogeology of the area draws on investigations carried out by BGS in 2005 and 2006. There is general agreement between AMEC (Salmon 2011) and BGS regarding these data and conceptual model. The setting of the Chapelton area is shown in Figure 1 and a simplified cross section of groundwater flow in Figure 2.

There are two main aquifers below Chapeltonmoss: the deeper Devonian sandstone aquifer overlain by a shallow unconsolidated sand and gravel aquifer. The underlying Devonian bedrock comprises a medium-grained sandstone and forms an important regional aquifer in the area. Across Chapeltonmoss, the overlying superficial deposits generally comprise permeable sands and gravels. These deposits can be up to 20 m thick, but are more commonly 10 m thick in the lower lying areas. The sands and gravels are permeable with a transmissivity of 150 m^2/d measured around Wright's Hill. Peat deposits up to 1.5 m thick have developed in the low-lying areas (Figures 1 & 2).

Modelling of rainfall data has indicated that effective rainfall (rainfall minus evapotranspiration) is likely to be approximately 250 mm $year^{-1}$ (MacDonald et al. 2006) and is likely to have been higher in the past 2 years when rainfall has been 30 – 40% higher than the 1961-1990 mean. Since most of the catchment is underlain by highly permeable soils, much of the effective rainfall is likely to recharge the aquifer. This is supported by the lack of natural streams and rivers in the area.

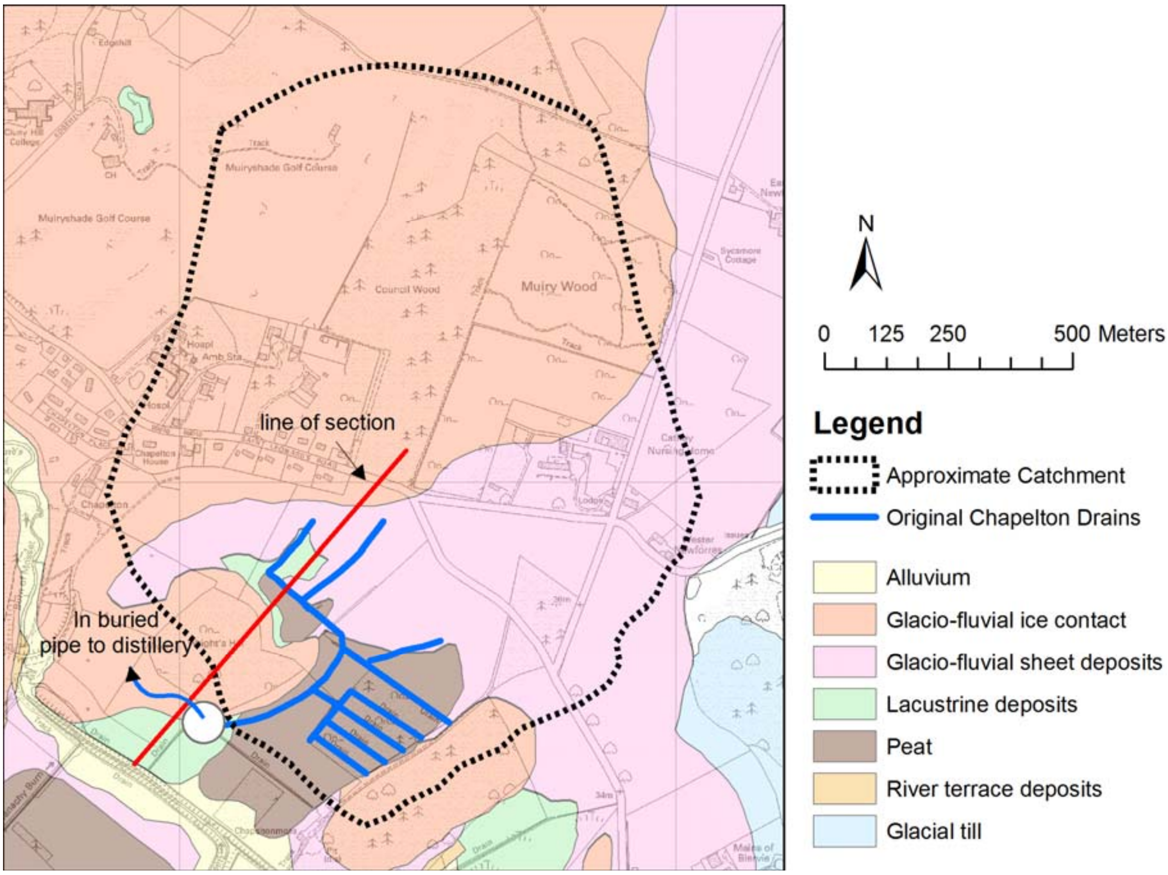

Figure 1. A map showing the setting of the original Chapelton Spring, with the superficial geology, the original drains and approximate catchment area for the Chapelton Spring system. The map also indicates the location of the cross section shown in Figure 2.

Groundwater flow in the superficial deposits in Chapeltonmoss is dominated by discharges to drains and ditches. Groundwater gradients are almost flat across the area, due to the high permeability of the sands and gravels; therefore groundwater gradients will not always reflect the same gradient as the topography, but rather will be dominated by the elevation and locations of drains and ditches Residence time indicators show that groundwater is young in the superficial deposits – less than 15 years old (MacDonald et al. 2006).

On the basis of observed distinctive chemistry, there appears to be little exchange of groundwater between the bedrock and superficial aquifer. Groundwater in the bedrock is weakly mineralised, dominated by calcium and bicarbonate ions and has pH of around 7.5. Groundwater in the superficial deposits has pH of around 6.5, is generally dominated by sodium and chloride and has greater mineralisation than the bedrock groundwater, expressed as a higher electrical conductivity.

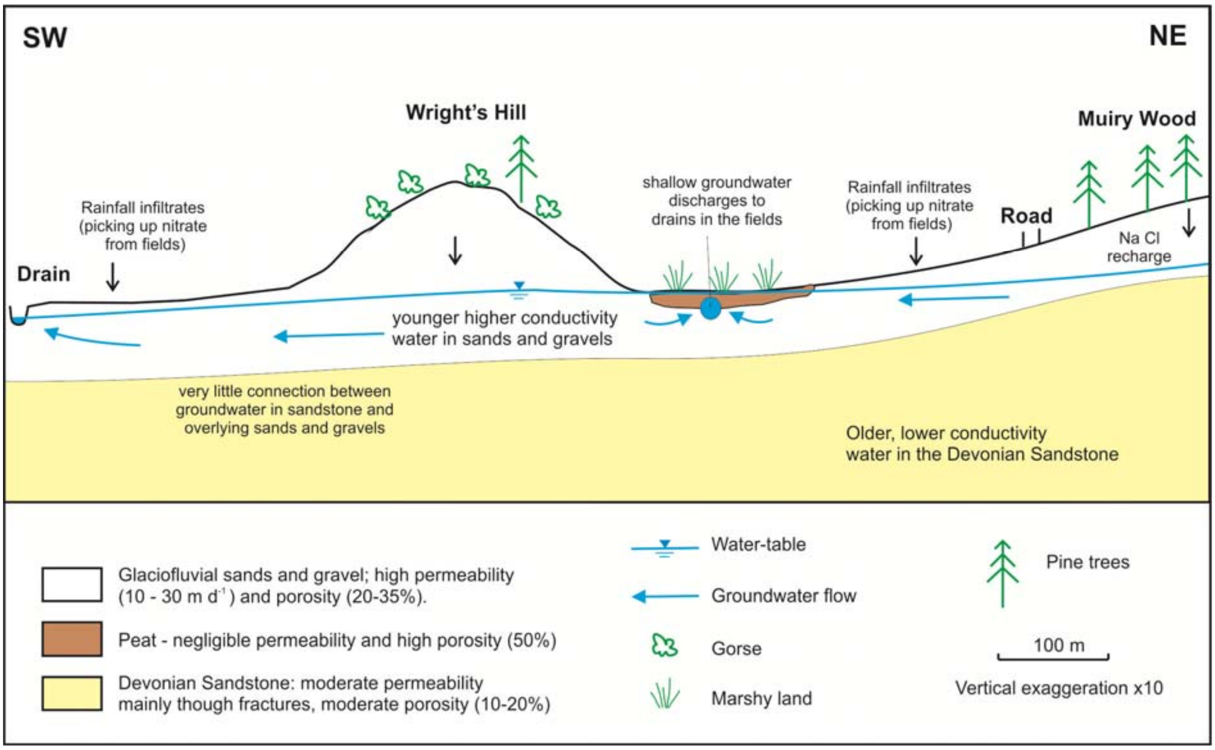

Figure 2. A schematic cross section of the hydrogeology of the Chapelton Spring area.

2.2 WHAT HAPPENS DURING A FLOOD

The likely sequence of events for a 1 in 100 year flooding event before the construction of the FAS (see MacDonald et al. 2011) are as follows:

1. Heavy rain leads to increased infiltration in the Chapeltonmoss area.
2. Heavy rain in the upper catchment where soils are less permeable leads to an increase in stage in the Burn of Mosset, overbanking of the burn and inundation of the floodplain (see Figure 3).
3. The floodplain is flooded to a depth of approximately 2 m for several days.
4. The water table rises as a result of the combined effect of river stage and increased recharge.

5. Water from the inundated area saturates the soil and a "wetting front" moves downwards to meet the rising water table.
6. The river stage falls and water flows from the floodplain back to the river.
7. Groundwater within the Chapelton area flows to the rivers, drains and ditches driven by the now higher heads.

The likely sequence of events for a 1 in 100 year flooding event after the construction of the FAS are as follows:

1. Heavy rain leads to increased infiltration in the Chapeltonmoss area.
2. Heavy rain in the upper catchment, where soils are less permeable, leads to an increase in stage in the Burn of Mosset, overbanking of the burn and inundation of the floodplain (see Figure 4).
3. The floodplain is flooded for approximately 2 days before overtopping the embankment protecting Spring 1.
4. The area around Spring 1 is flooded for approximately 6 – 7 days to a maximum depth of 4 m.
5. The water table rises as a result of the increased recharge from local rainfall and from inundation of the floodwater into the aquifer.
6. Water from the inundated area saturates the soil and a "wetting front" moves downwards to meet the rising water table.
7. The river stage falls and water flows from the floodplain back to the river.
8. Groundwater within the Chapelton area flows to the rivers, drains and ditches driven by the now higher heads.

The prediction runs described below are designed to represent this process in the best way possible given the limitations of groundwater models.

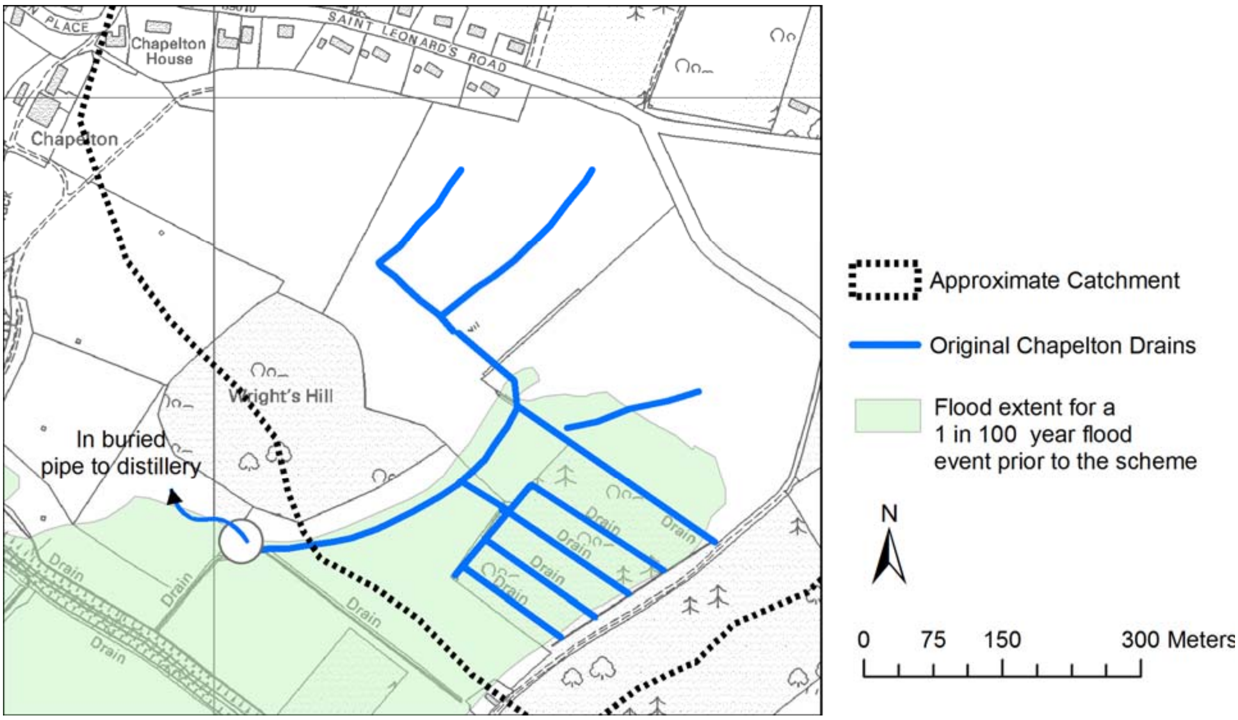

Figure 3. Flood extent for a 1 in 100 year flood event prior to the construction of the FAS.

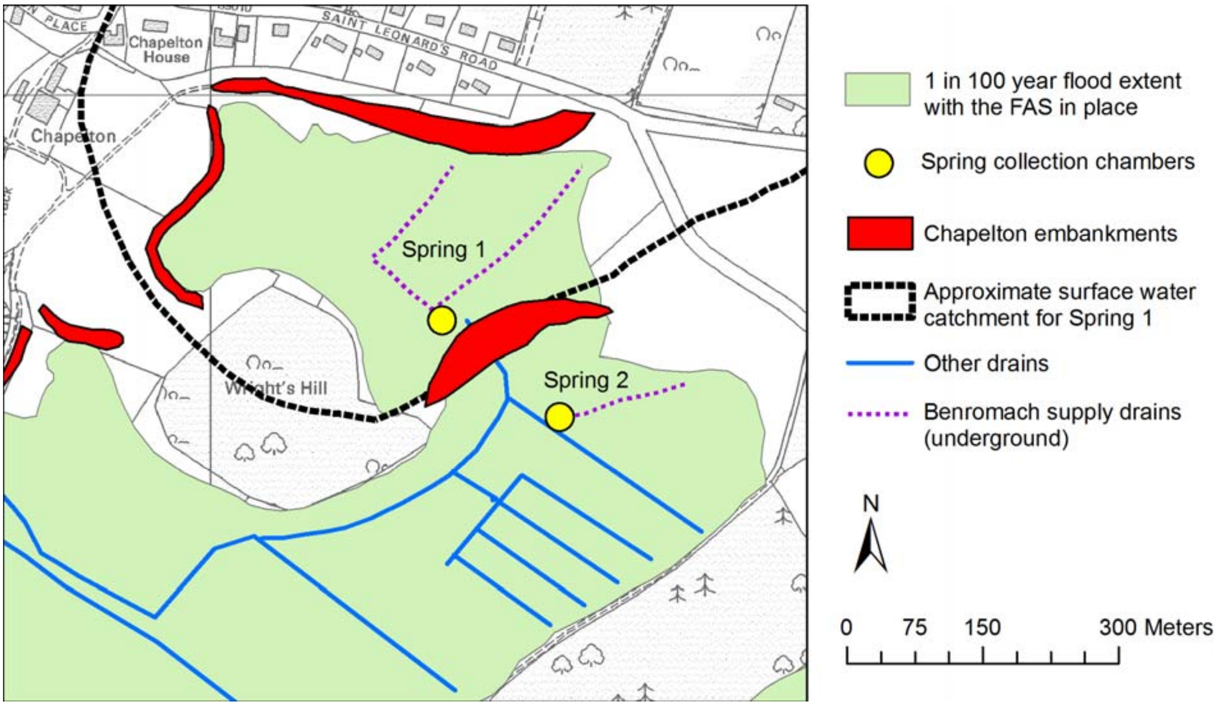

Figure 4. Maximum flood extent for a 1 in 100 year flood event for the Burn of Mosset after the construction of the FAS.

3 Model development

3.1 MODEL CONSTRUCTION

The model used to carry out the simulations is ZOOM. ZOOM is a collection of object oriented groundwater models. The object-oriented approach has been adopted to facilitate local grid refinement (LGR) which allows groundwater flow to be modelled at different scales using any number of grids placed within each other. The current suite of models includes a groundwater flow model, ZOOMQ3D (Jackson and Spink 2004), an advective particle tracking model, ZOOPT (Jackson 2004) and a distributed recharge model, ZOODRM (Mansour and Hughes 2004).

The following sections describe how the model was built, leading from model boundaries geometry (layering and boundaries), inflows and outflows and the distribution of parameters.

3.1.1 Model boundaries and geometry

The extent of the model is presented in Figure 5. The boundaries are defined to be larger than the potential groundwater catchment of the spring system, but not so large that too many other features need to be taken into account. The boundaries of the model are set to be no-flow.

A three layer model of the system has been developed. The upper two layers represent the superficial deposits, whilst layer 3 corresponds to the sandstone bedrock. For simplicity and to avoid complications with detailed understanding the layers are "flat" with the top and bottom being set to the same value for each layer (see Table 1).

The model basegrid has a spacing of 50 m in the X and Y direction (Figure 6). To allow more accurate representation of processes around the spring system, a single refined grid with a mesh interval of 12.5 m in both directions was added to the model (Figure 6).

Table 1. Geometry of groundwater flow model

Layer	Top (m aOD)	Bottom (m aOD)
1 – Upper Superficial Deposits	20	10
2 – Lower Superficial Deposits	10	0
3 - Sandstone	0	-100

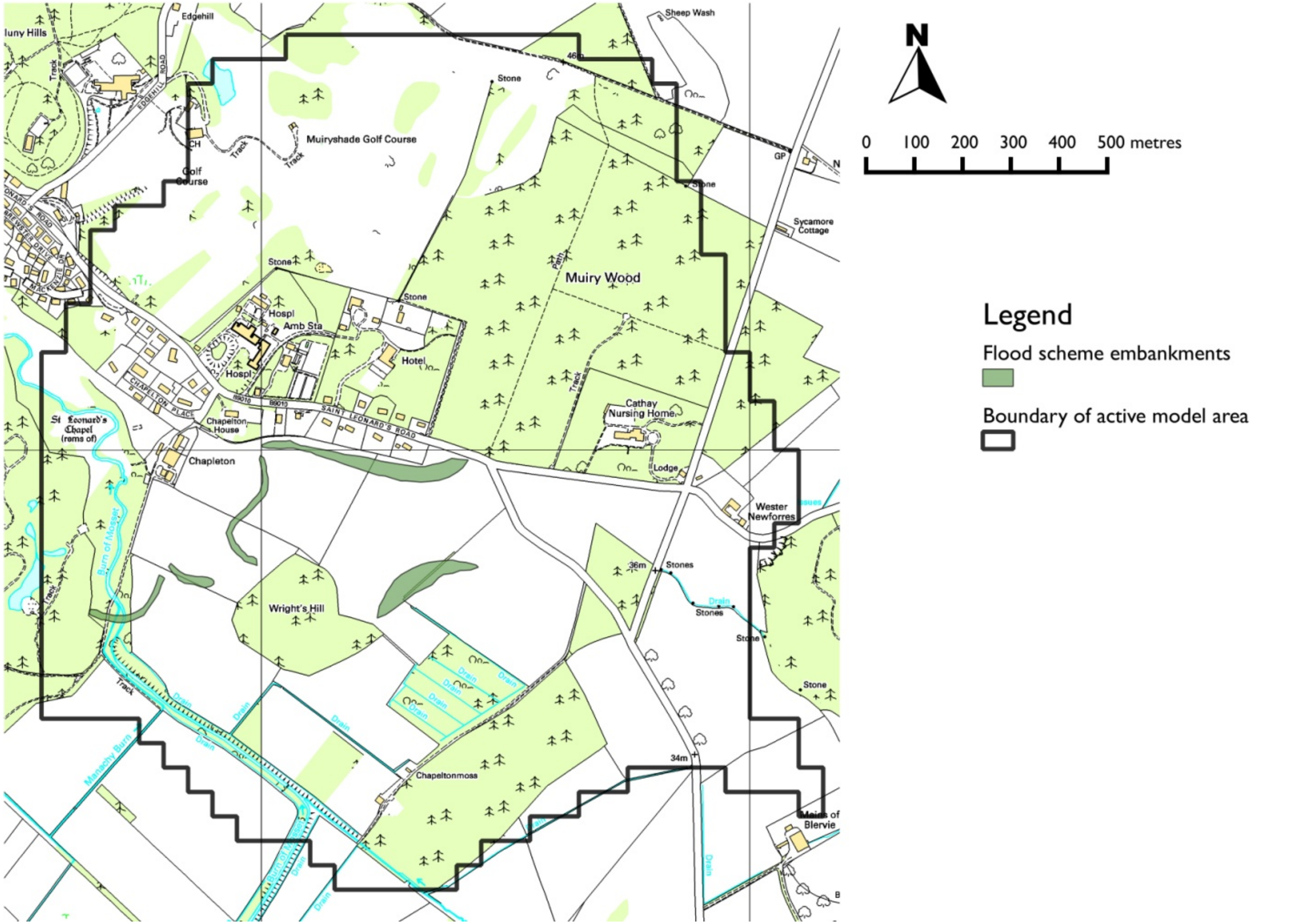

Figure 5. Extent of groundwater model boundaries

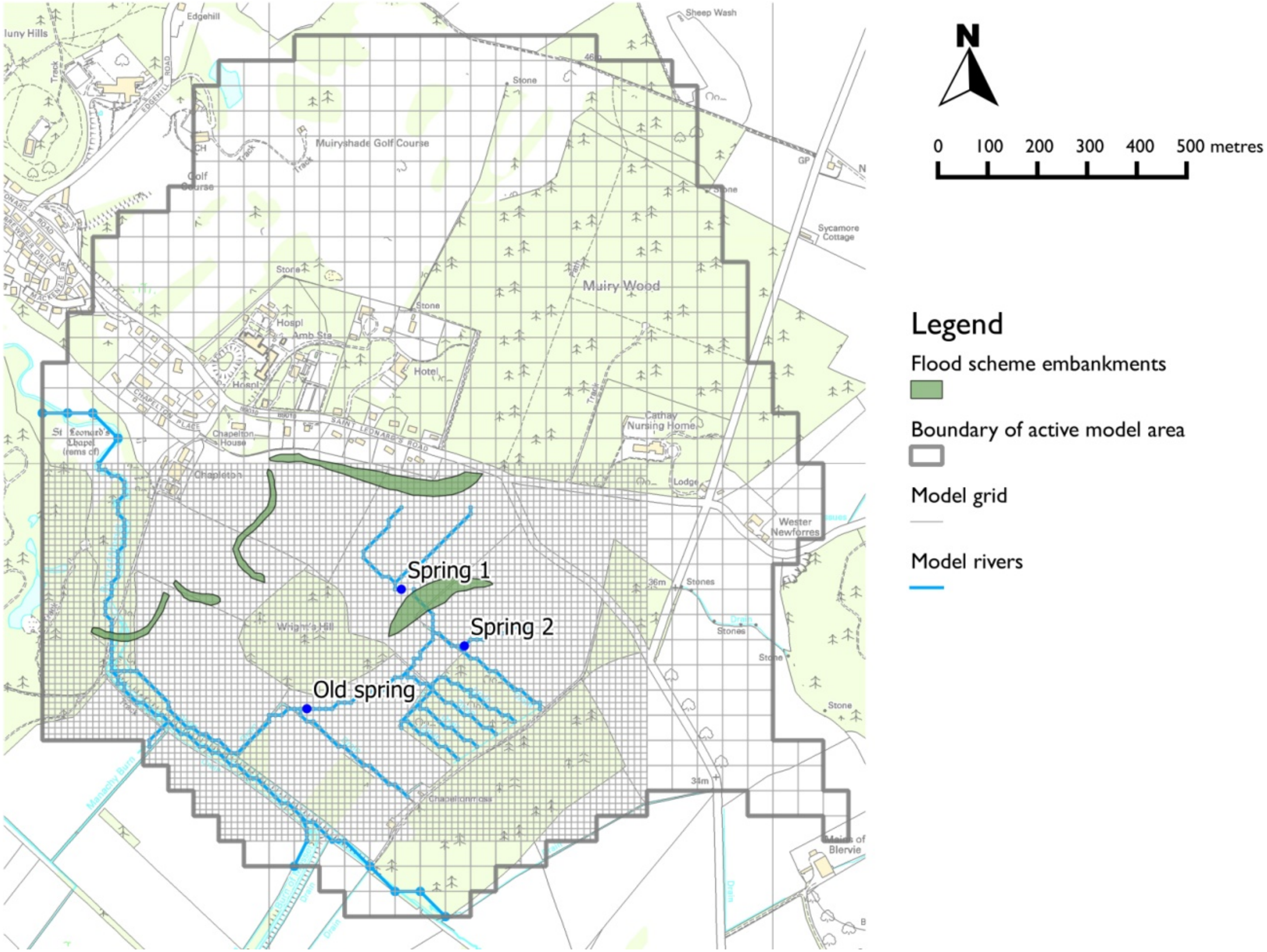

Figure 6. Model grid and rivers

3.1.2 Inflows and outflows

The model is relatively simple with the inflow provided by rainfall recharge and the outflow provided by the river system, springs and drains feeding into the rivers. The recharge is provided from the recharge model developed for previous work (MacDonald et al., 2008). The only modification is that the revised grid for this model is used to ensure that recharge is provided in the correct format.

The main river is the Burn of Mosset (Figure 6) which runs along the southern and western boundaries of the model. This is fed by a series of drains which include the spring system which supplies the Benromach Distillery. The stage of the river was read from LIDAR for the area. An inflow of 10,000 m^3/d is added to each of the three upstream river nodes where the river enters the model domain to ensure that sufficient flow is in the river system so that the river can always supply the aquifer.

The drain system was more complex to construct. The drain system, where open, was assumed to have 30 cm of standing water. The elevations used in the model for Spring 1 and Spring 2 were taken from information supplied from Moray Council. These consisted of elevations surveyed by their consultants and are presented in Figure 7. The location are from drawings MCSL-MFA-BOM-002, CAP08002_1561, and the OS 1 :10, 000 maps.

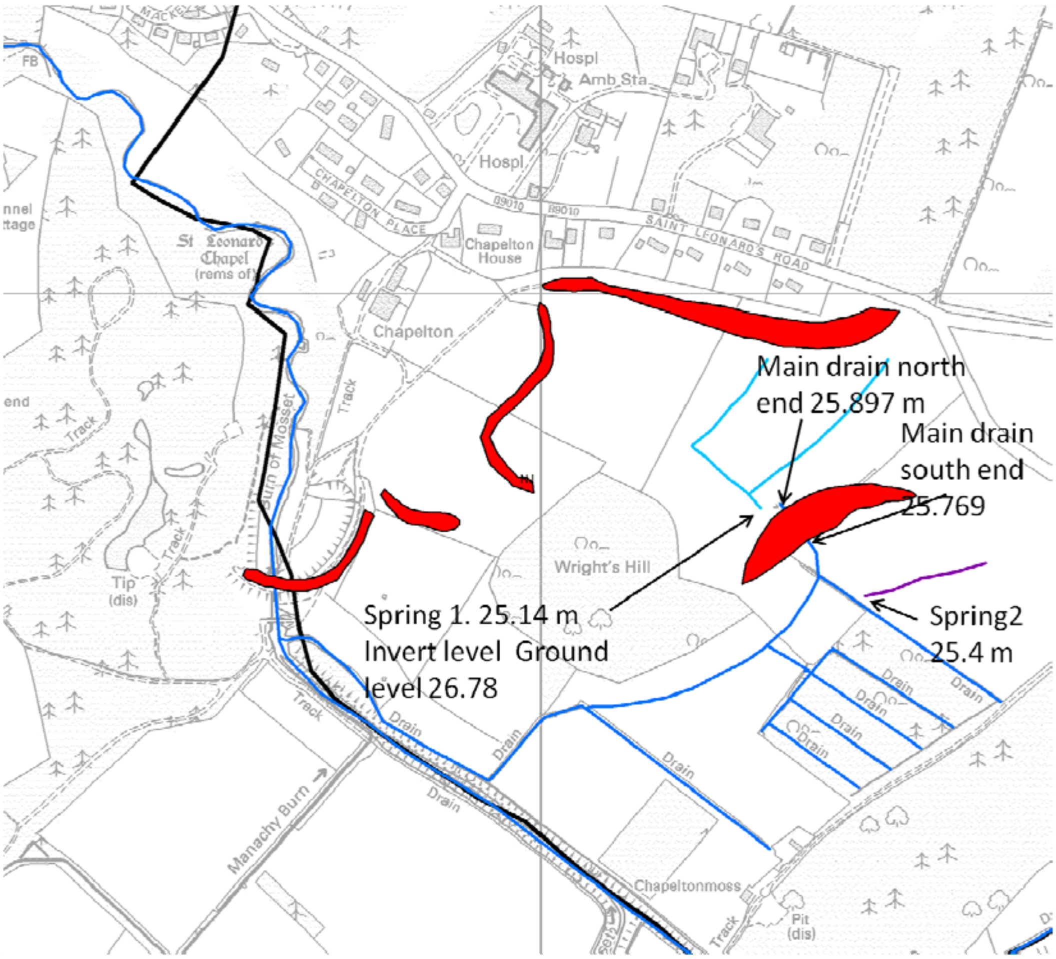

Figure 7. Levels used to create elevations for Spring 1 and Spring 2.

3.1.3 Distribution of parameters

Transmissivity (T) of the superficial deposits was derived from the distribution used in the previous work (MacDonald et al., 2006). The distribution of T is illustrated in Figure 8. The T distribution is based on a combination of hydraulic conductivity and saturated thickness. Higher T zones, therefore, reflect both higher hydraulic conductivity and thicker saturated thickness, i.e. around the spring. Lower T values (5-20 m^2/d) reflect deposits where the water table is lower and a reduced saturated thickness exists.

The T for the model layer representing the sandstone (Layer 3) is constant and set at 50 m^2/d. The storage coefficient used for the prediction runs is 0.25.

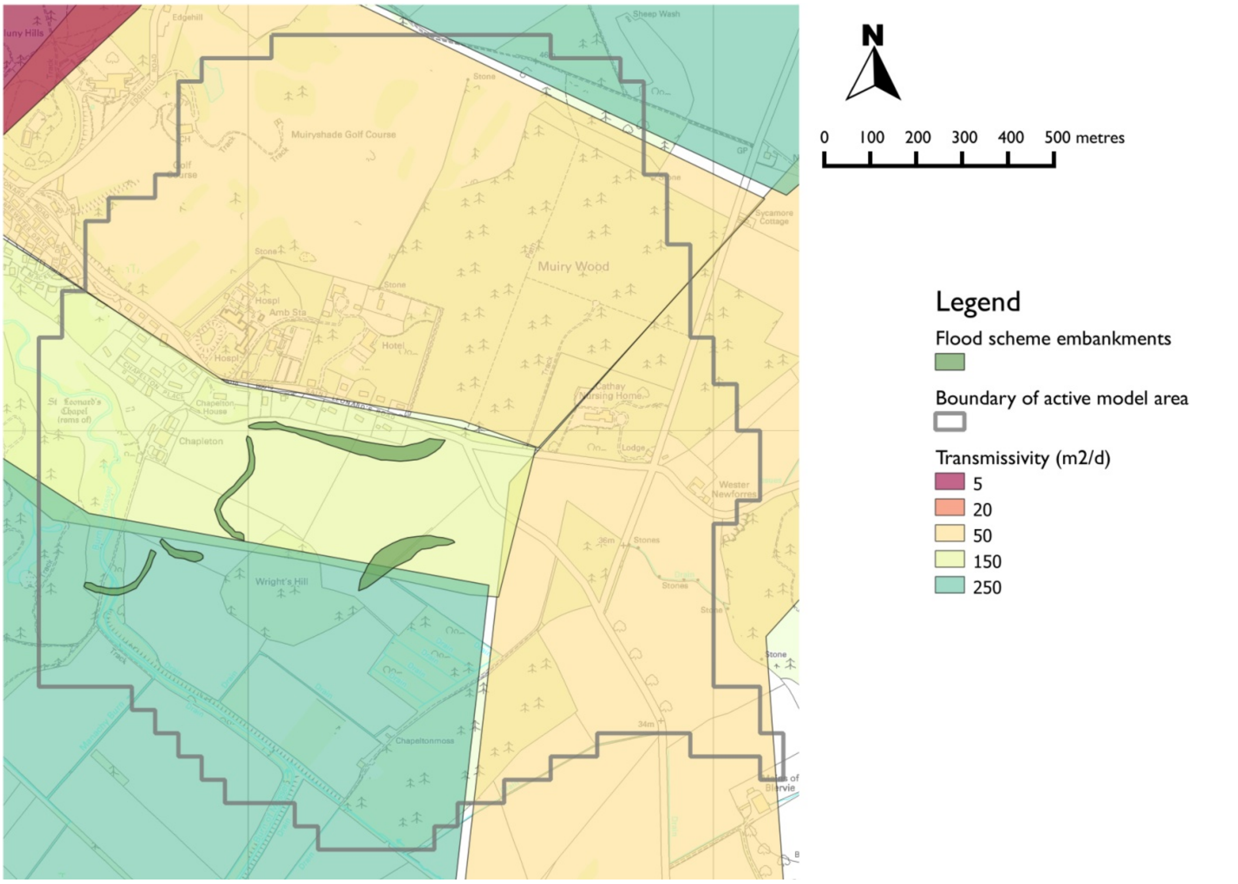

Figure 8. Distribution of transmissivity for the superficial deposits (Layer 1 and 2) in the model

3.2 MODEL REFINEMENT

3.2.1 Introduction

Typically a groundwater model is refined until the conceptual understanding encapsulated in the model means that the modelled outputs matches observations. For the Chapleton area, few measured groundwater heads are available. Despite this, given the amount of work undertaken, a good conceptual understanding of groundwater flow exists and was used to inform the model development process. Data are available for both flow and hydrochemistry at the springs, so the refinement of the model concentrated on reproducing the springflow at Spring 1, the main focus of the study.

The main features of the model that have changed since the last phase of work (MacDonald et al., 2006) are:

- Boundaries – the overall size of the model has been reduced so that the model area is closer to the assumed groundwater catchment of the spring system.
- Recharge – this has been spatially distributed using the recharge model developed in previous work (MacDonald et al., 2008) and adapted for this study. The run-off coefficient in the area of the groundwater flow model was decreased to 0.01. This was justified by considering the high permeability of the superficial deposits and the lack of surface water drainage in the northern part of the model area. The rainfall was increased by 20% to reflect the increase in rainfall over the period of measured springflows. This was justified by examining the rainfall records for Nairn, which showed that rainfall in the period from June 2009 to May 2011 was 20% above the 1961-1990 average.
- Drains – a significant amount of work was undertaken to ensure that the drains included in the model reflected those encountered in the field.

No changes were made to the T distribution for the superficial deposits as there was no further available data. The final steady-state model was checked by BGS staff not directly involved with the project.

3.2.2 Best model

The modelled groundwater heads for the best model described above are shown in Figure 9. As would be expected the head gradient is towards the rivers where groundwater discharges. The modelled heads are consistent with the range of observed groundwater levels at the three boreholes around Wright's Hill (Figure 9) and the one at Muiry Wood.

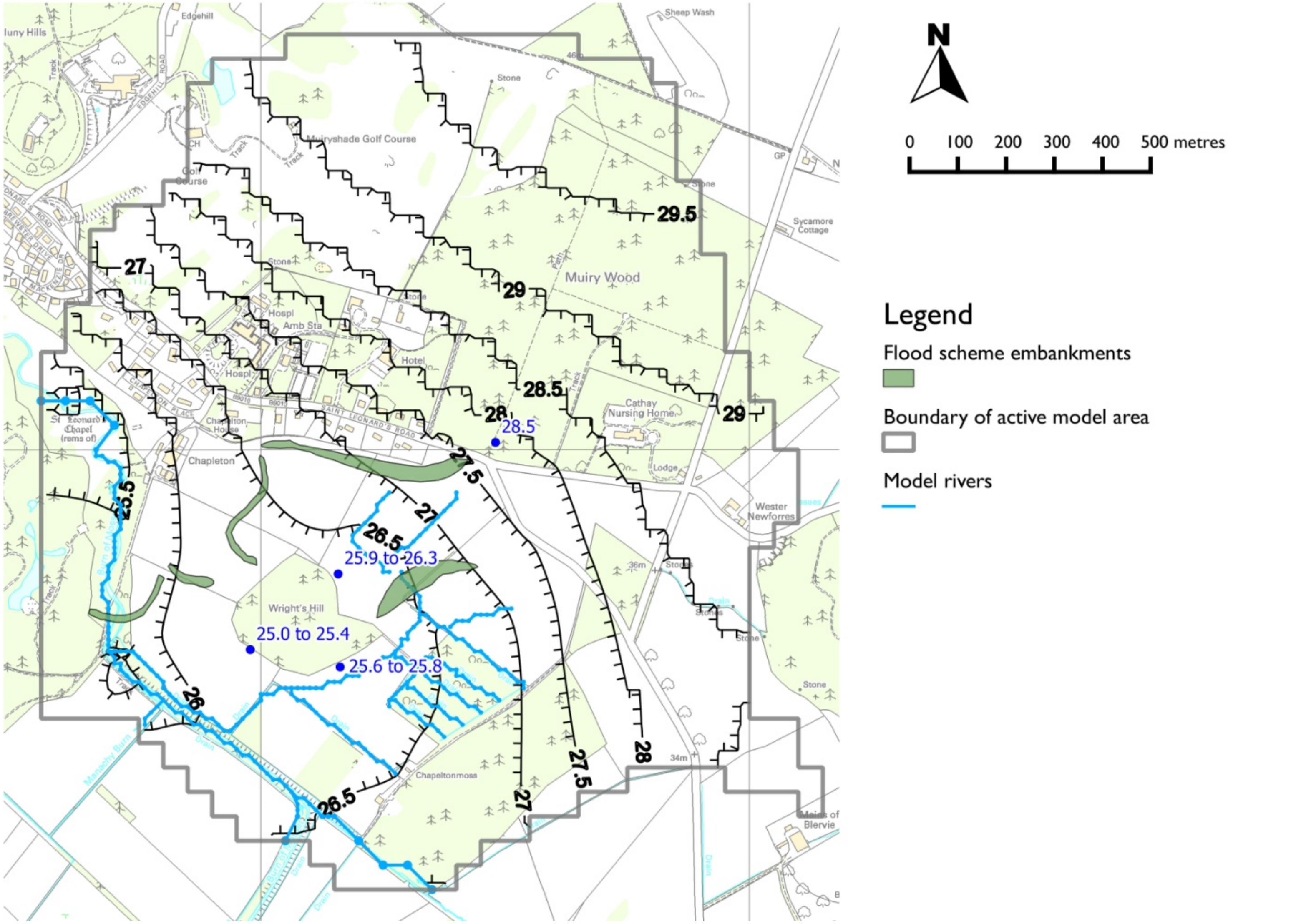

Figure 9. Steady state head contours (m aOD), hatches pointing down gradient. Three observed groundwater levels around Wright's Hill and in Muiry Wood are shown in blue (m aOD).

The components of the model water balance at steady state are shown in Table 2. The imbalance over the whole model is 0.016% which is acceptable. The recharge applied in this run is 1,727 m^3/d (about 0.8 mm/d over the active model area of 2,115,000 m^2). Table 2 shows that at steady state about 80% of the recharge discharges to the Burn of Mosset and its tributaries, including the drains through Chapelton Moss, 16% discharges to Spring 1 and 4% to Spring 2.

The modelled flow from Spring 1 is 268 m^3/d (3.1 L/s), which is 25% lower than the observed long-term average flow of 4.1 L/s over the period 19 Jun 2009 to 6 May 2011.

Table 2. Water balance for steady-state model

	Flow (m^3/d)
IN	
Recharge	1,727
Flow in Burn of Mosset as it enters the model domain	30,000
Total in	**31,727**
OUT	
Discharge to Burn of Mosset & its tributaries	31,379
Discharge to Spring 1	268
Discharge to Spring 2	75
Total out	**31,722**
Imbalance	**5 (0.016%)**

3.3 SENSITIVITY ANALYSIS

Given the uncertainty associated with the parameters in the model, it is import to address how this uncertainty affects the predicted response at the spring. A balance has to be struck between the understanding of uncertainty gained and the resources required to do so. Therefore, a limited series of sensitivity runs were undertaken to investigate the impact of varying model parameters on the model output. The main uncertainties identified during the model development are: transmissivity, river geometry & bed conductance, and recharge. The uncertainty in these parameters have been examined in different ways. A formalised sensitivity analysis on transmissivity and the length of the main spring system (Spring 1) has been undertaken. The transmissivity was increased everywhere by 50 % (multiplied by 1.5). The results from the steady-state runs showed that the spring outflow decreased slightly (to 2.7 l/s). A prediction run was undertaken to determine the impact on the time taken for the springflows to return to normal (see Section 4.3.7). For Spring 1 the length of the spring system was reduced by removing the north-south tributaries. The results of this run showed that the springflow was markedly reduced (to 1.7 L/s). This result puts the model outside of the plausible range of springflows. The model was deemed not suitable and therefore prediction runs were not undertaken.

Sensitivity analysis of springflows to river conductance was not undertaken. Recharge was also not assessed as a formal sensitivity, but was evaluated during the model refinement process. The runs undertaken showed the importance of both the amount of recharge and also cast light on run-off in the catchment. The amount of springflow was directly proportional to the average value of recharge, with higher springflow produced by greater recharge.

4 Prediction runs

4.1 INTRODUCTION

The following prediction runs were undertaken to produce the scenarios described in the main report:

- Heavy rainfall, assuming either 50% run-off or zero run-off
- Flood inundation prior to the scheme
- Flood inundation after the scheme
- Recession with recharge at long-term average rates

Table 3 provides a summary of these runs and they are described more fully in the next section.

Table 3. Summary of the key model prediction runs

Run ID	Description	Recharge (mm/d)	Duration	Comment
A	Heavy rainfall, 50% run-off	43.5	1 day	Recharge is uniform
B	Heavy rainfall, zero run-off	87	1 day	Recharge is uniform
C	Flood inundation before scheme	150	1 day	150 mm/d is the spatial average of the recharge distribution No groundwater discharge to streams
D	Flood inundation after scheme	76	6 days	76 mm/d is the spatial average of the recharge distribution No groundwater discharge to streams
E	Recession	0.8	5 years	0.8 mm/d is the spatial average of the recharge distribution

4.2 METHODOLOGY

4.2.1 Heavy rainfall

Two runs were used to represent the infiltration of rainwater into the superficial deposits below ground during a heavy rainfall storm event of 87 mm over 24 hours. In the first run it is assumed that 50% of the rainfall (43.5 mm) infiltrates as recharge into the superficial deposits and 50% forms run-off and discharges to the streams over a few days whereas in the second run it is assumed that all 87 mm infiltrates as recharge and there is no run-off. The total 87 mm rainfall is used since this is the lowest volume of rainfall to produce a 1 in 100 year flood event. As comparison, the 1997 flood event has a rainfall of more than 130 mm, and the 2009 flood event (categorised as 1 in 20 year event) had rainfall of 93 mm.

In both runs the model was started using the steady state heads from the base run described in Section 3.2.2, all model parameters except recharge were the same as the base run and the model was run for one day. In the first, recharge was 43.5 mm/d and in the second it was 87 mm/d over the whole active area of the model (Figure 5).

4.2.2 Flood inundation

Two runs were used to represent recharge of the superficial deposits due to the infiltration of ponded flood water following the inundation of the Chapelton area with flood water when the Burn of Mosset breaks its banks. The first run represents the infiltration of flood water for 24 hours over the area covered by a 1 in 100 year flood prior to the flood alleviation scheme (magenta dashed line, Figure 10). The second represents a similar process but for six days and over the area covered by the 1 in 100 year flood after construction of the scheme (black dashed line, Figure 10). The flood extents for the 1 in 100 year flood prepared by Royal Haskoning for Moray Council have been used (Haskoning 2009)

To make sure that the unsaturated zone could accept the volume of water being applied, the recharge at each node was factored by the unsaturated zone thickness at that node and the porosity (25%). The depth to groundwater was estimated from the CEH digital terrain model (Morris and Flavin, 1990) and the steady state heads of the base run. During the flood inundation runs it was assumed that there would be no groundwater discharges to any of the streams and so river-aquifer interaction was made inactive by setting the river leakage coefficients to zero.

4.2.3 Recession

The recession runs apply recharge at the same rate as the base run, and are run for 5 years following either a heavy rainfall or a flood inundation run. Eventually the heads and flows return to the steady state levels of the base run. These runs are used to represent the discharge to the springs and streams of water which has infiltrated during the heavy rainfall or flood inundation runs. They provide estimates of the period for which the spring flows are above the threshold for the required electrical conductivity.

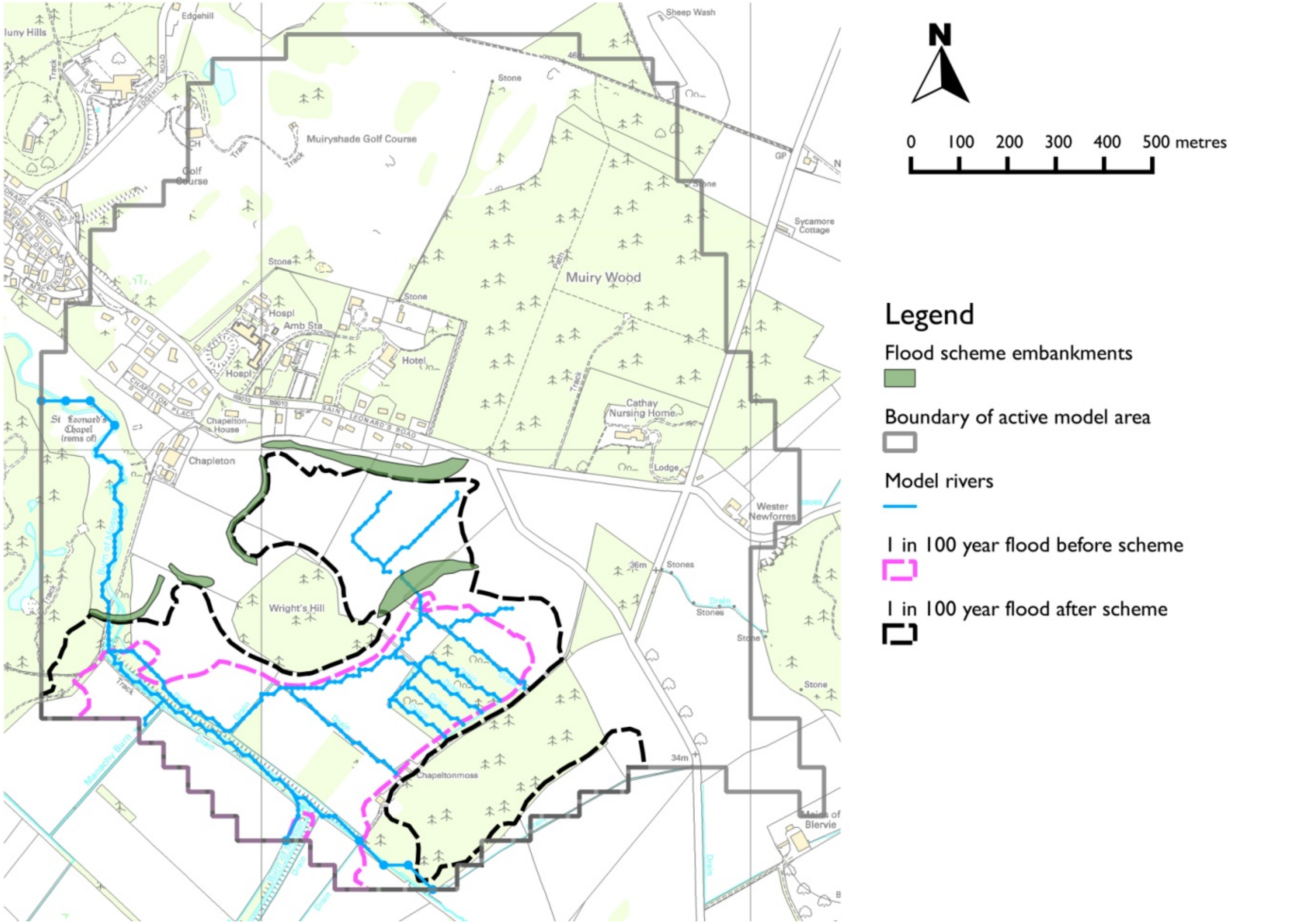

Figure 10. Map showing the area covered by the 1 in 100 year flood before the flood alleviation scheme (magenta dashed line) and after construction of the flood alleviation scheme (black dashed line). These areas were used in the flood inundation runs.

4.3 RESULTS FROM THE PREDICTION 'SCENARIOS'

The prediction runs in Table 3 were used to construct a variety of 'scenarios' where individual runs were linked together. For example, the scenario to represent heavy rainfall with 50% run-off followed by recession was created by linking runs A and E together. The heads at the end of the heavy rainfall run (A) were used as the starting heads for the recession run (E).

4.3.1 Heavy rainfall with 50% run-off (recharge = 43.5 mm) followed by recession (runs A and E)

During the heavy rainfall the modelled groundwater heads rise by between 0.16 and 0.17 m (Figure 11, where the blue shading shows that the head rise is roughly the same across the whole model). During the recession they fall back to the steady state long-term average heads of the base run described in Section 3.

The modelled flows in Spring 1 rise to a maximum of 326 m^3/d (3.8 L/s) at the end of one day's heavy rainfall and never rise above 335 m^3/d (3.9 L/s), which is 25% above the steady state flow and is used as a threshold for the other prediction runs (Figure 16).

4.3.2 Heavy rainfall with zero run-off (recharge = 87 mm) followed by recession (runs B and E)

During the heavy rainfall the groundwater heads rise by about 0.34 m fairly uniformly across the whole model (Figure 12). The modelled flows in Spring 1 rise to a maximum of 387 m^3/d (4.5 L/s) at the end of one day's heavy rainfall and fall to within 25% of the steady state flow (335 m^3/d, 3.9 L/s) after about 40 days (Figure 16).

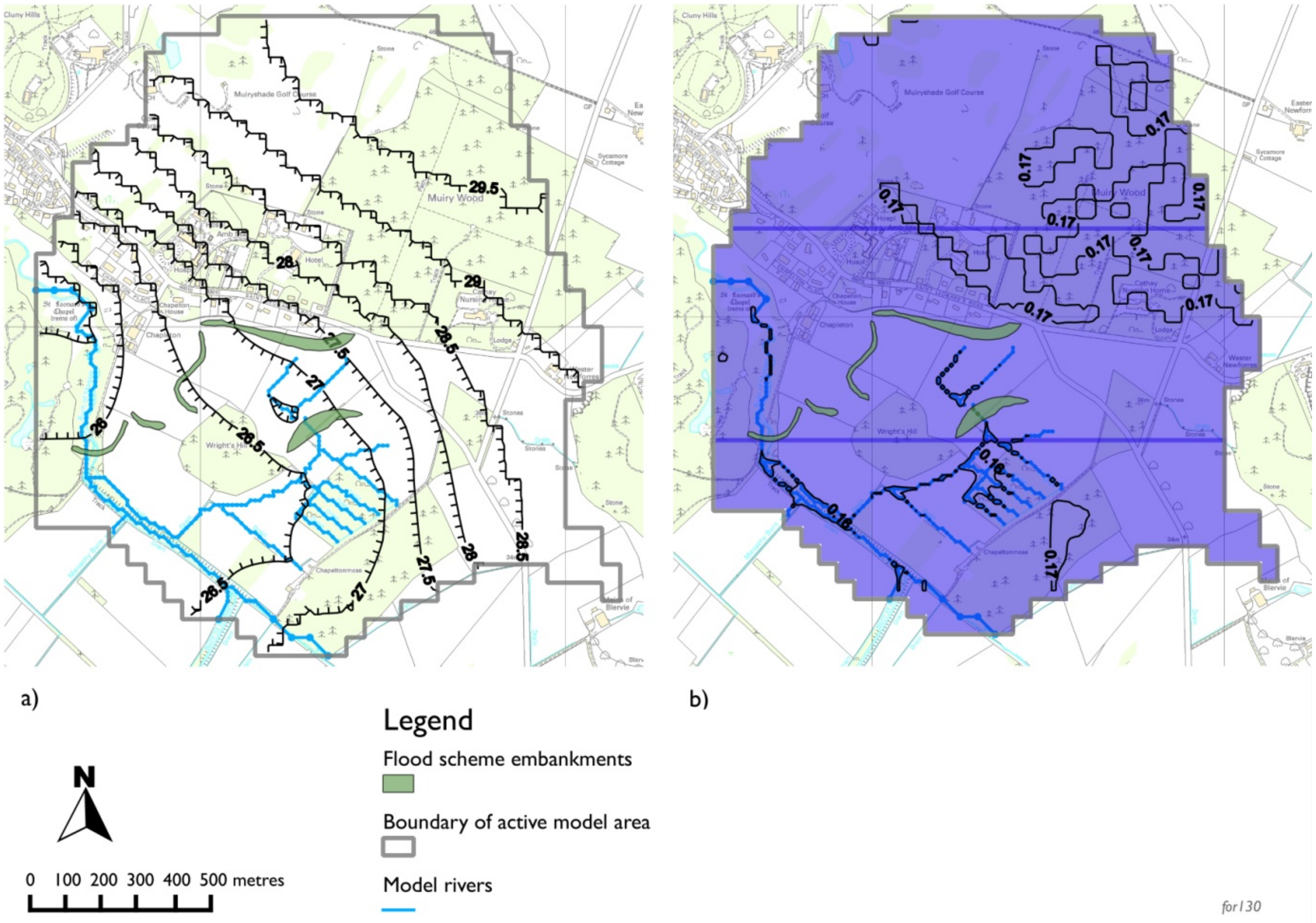

Figure 11. Response of modelled groundwater heads to recharge of 43.5 mm/d for 1 day: a) groundwater head contours (m aOD); b) head rise (m), blue shading = low values (<0.7 m), red shading = higher values (>0.7m).

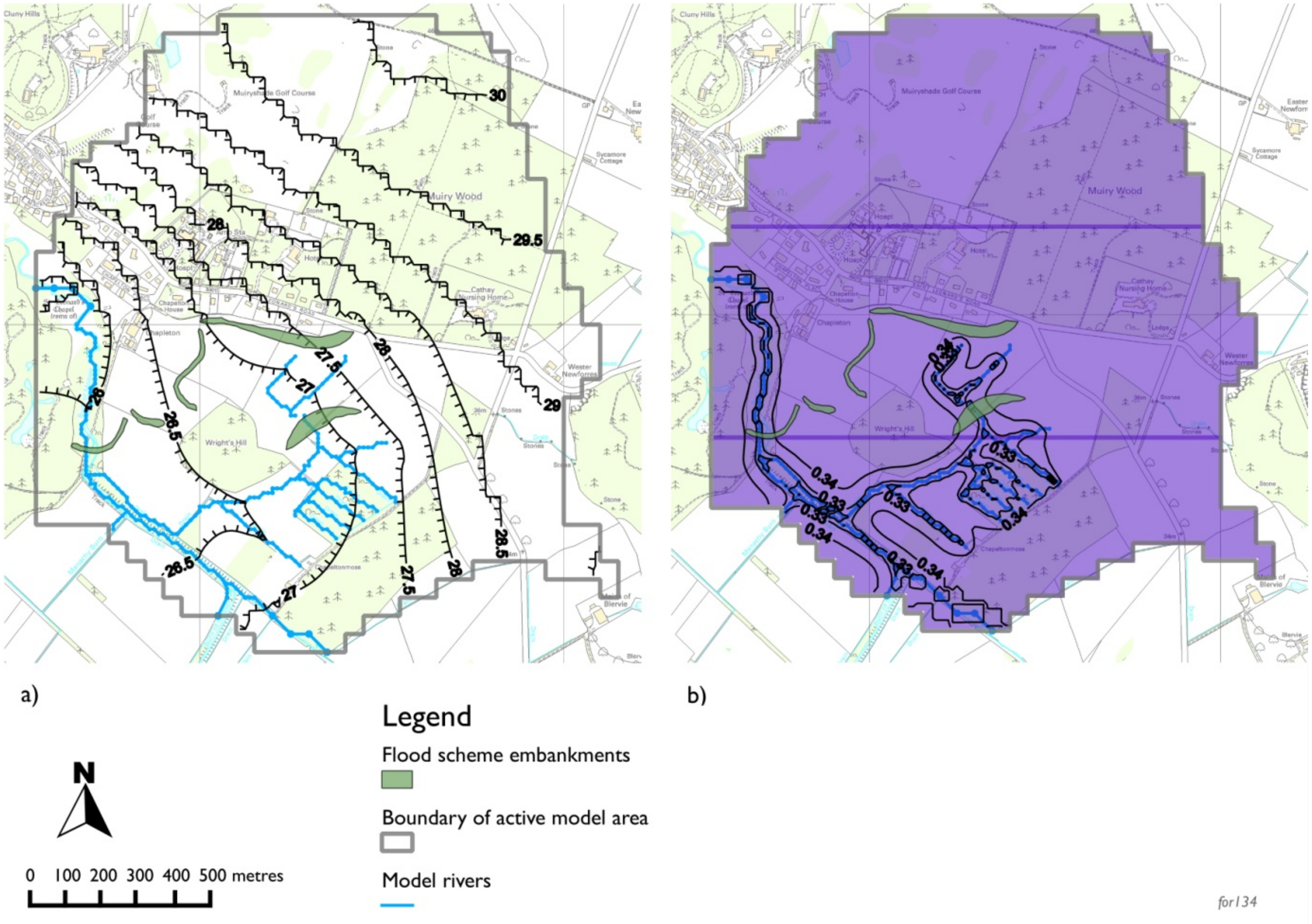

Figure 12. Response of modelled groundwater heads to recharge of 87 mm/d for 1 day: a) groundwater head contours (m aOD); b) head rise (m), blue shading = low values (<0.7 m), red shading = higher values (>0.7m).

4.3.3 Before the flood alleviation scheme: rainfall, flood inundation and subsequent recession (runs B, C and E)

This scenario represents heavy rainfall (recharge = 87 mm/d), flood inundation for one day and the subsequent recession before the construction of the flood alleviation scheme. Recharge of 87 mm/d for one day results in a recharge volume of 184,000 m^3 over the whole model domain. As described in Section 4.1.2, recharge is spatially distributed according to the unsaturated zone thickness and the total volume of recharge applied during the period of flooding is 35,000 m^3over the pre-scheme flooded extent of 232,000 m^2. Assuming porosity is 25%, this corresponds to filling up the unsaturated zone to about 0.6 m. The volume of water entering the superficial deposit in the area behind the bund (black cross-hatched area in Figure 15) is zero because the pre-scheme flooded area (Figure 13) does not extend this far.

The rise in heads due to the heavy rainfall alone is shown in Figure 12. The head rise due to both heavy rainfall and flood inundation (Figure 13) is about 1 m and is mainly beneath the flooded area but there is also a small rise in heads at the margins of this area due to the water in the superficial deposits beginning to flow laterally away from the higher heads.

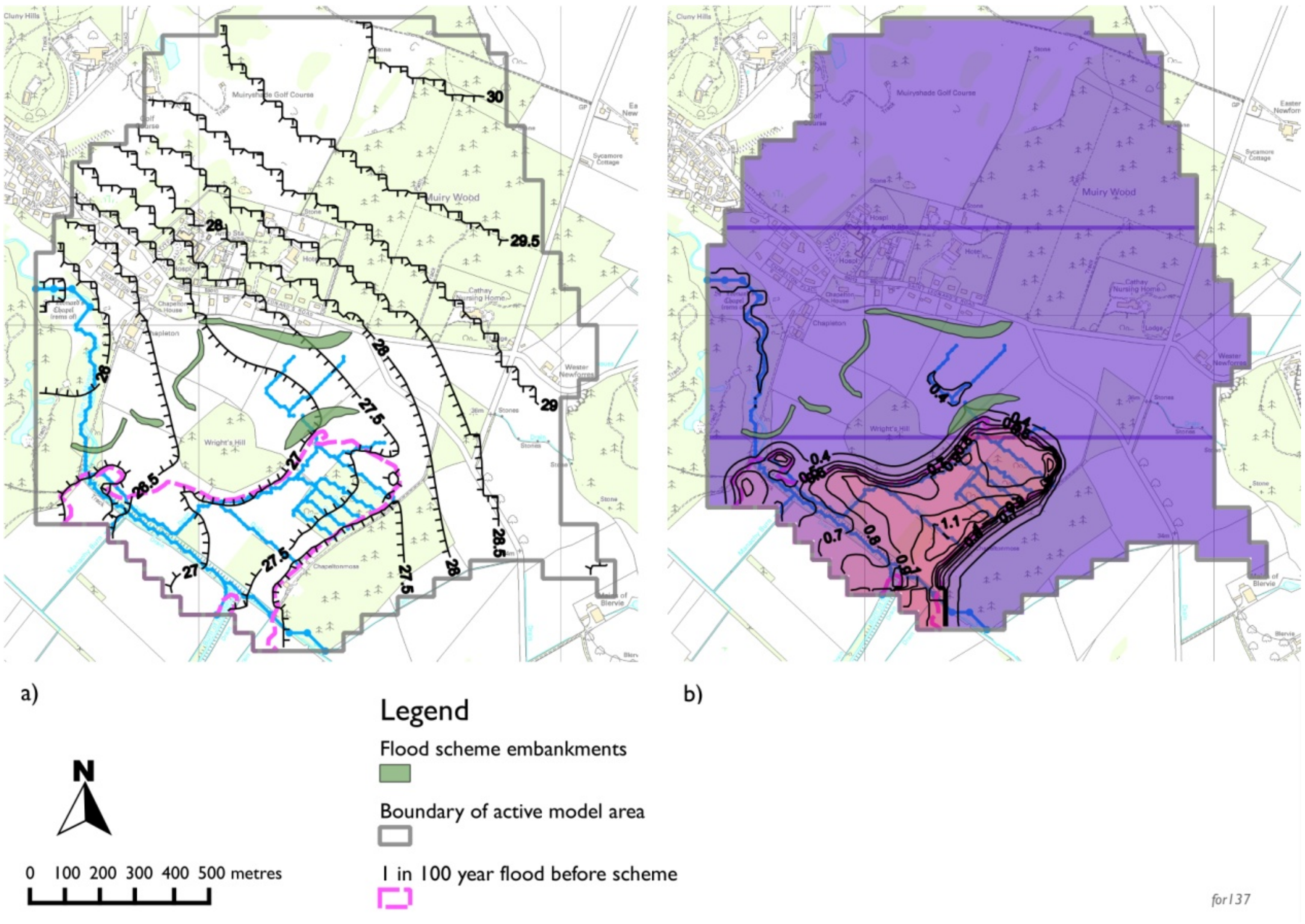

Figure 13. Before the flood alleviation scheme. Response of modelled groundwater heads to recharge of 87 mm/d for 1 day and flood inundation for one day over the 1 in 100 year flooded extent: a) groundwater head contours (m aOD); b) head rise (m), blue shading = low values (<0.7 m), red shading = higher values (>0.7m).

4.3.4 After the flood alleviation scheme: flood inundation and subsequent recession (runs D and E)

This scenario represents flood inundation for six days due to the overtopping of the bund by the flood waters from the Burn of Mosset followed by recession. Again recharge is varied spatially according to the unsaturated zone thickness. The total volume of recharge applied over the flooded extent (460,000 m^2) during the six days of flooding is 211,000 m^3 and the volume of water entering the superficial deposits in the area behind the bund (black cross-hatched area in Figure 15) during the six days of is 45,000 m^3.

The rise in heads due to six day's flood inundation is about 1.5 m and is mainly beneath the flooded area (Figure 14). The modelled flow in Spring 1 rises to a maximum of 695 m^3/d (8 L/s) at the end of the six days flood inundation and falls to 25% above the steady state flow about 80 days after the start of the recession (Figure 16 and Table 4).

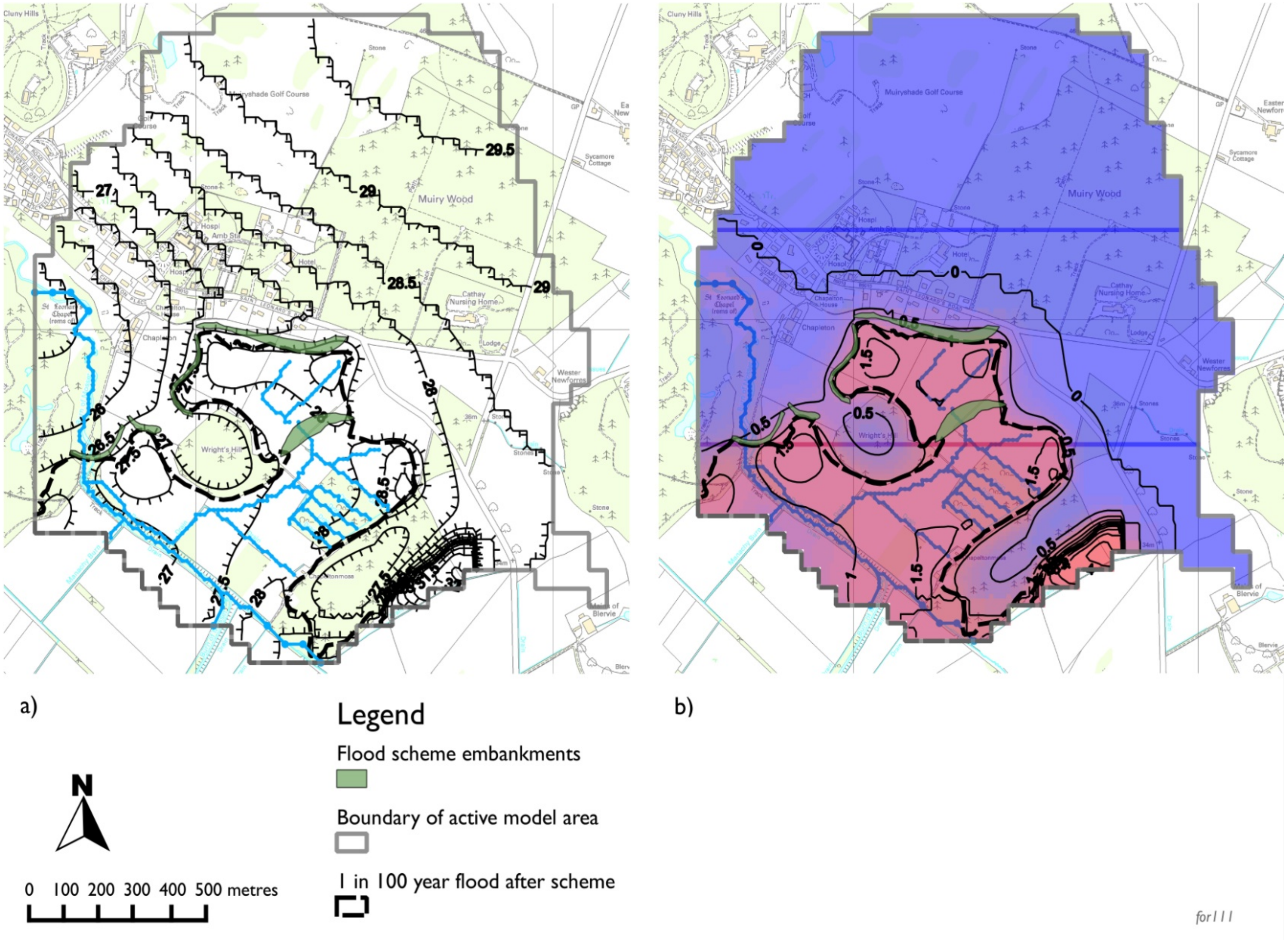

Figure 14. After the flood alleviation scheme. Response of modelled groundwater heads to flood inundation for six days over the 1 in 100 year flooded extent: a) groundwater head contours (m aOD); b) head rise (m), blue shading = low values (<0.7 m), red shading = higher values (>0.7m).

4.3.5 After the flood alleviation scheme: rainfall, flood inundation and subsequent recession (runs B, D and E)

This scenario represents a combination of three runs that have already been described: heavy rainfall for one day (recharge = 87 mm), flood inundation for six days and subsequent recession.

The rise in groundwater head due to both one day's heavy rainfall and six day's flood inundation is between 1.5 and 2 m over most of the flooded area (Figure 15) but because the unsaturated thickness is higher in the south east, more recharge is applied here (due to the factoring by the unsaturated zone thickness) and consequently the head rise is larger (maximum of 5 m).

The maximum modelled flow in Spring 1 is 818 m^3/d (9.5 L/s) after both the heavy rainfall and the flood inundation. This falls to within 25% of the steady state flow after about 140 days (Figure 16 and Table 4).

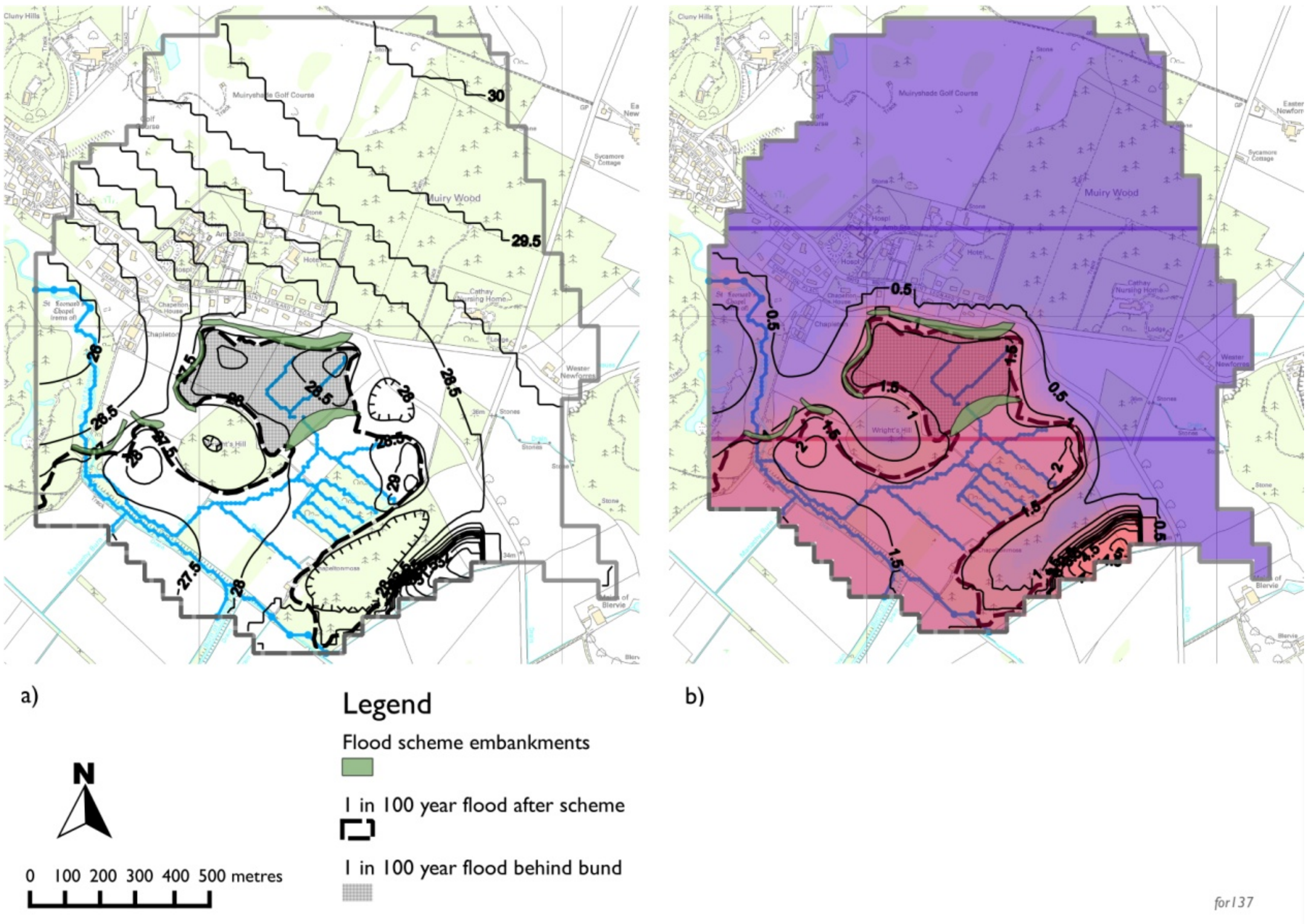

Figure 15. After the flood alleviation scheme. Response of modelled groundwater heads to recharge of 87 mm/d for 1 day and flood inundation for six days over the 1 in 100 year flooded extent: a) groundwater head contours (m aOD); b) head rise (m), blue shading = low values (<0.7 m), red shading = higher values (>0.7m).

Table 4. Time till flow falls to 25% above steady state

Scenario	Run ID *(run number)*	Time after start of recession for flow to reach 25% above steady state flow (days)	
		old spring	**Spring 1**
Recharge 43.5 mm 1 day	A + E *(for130, 131)*	20	0
Recharge 87 mm 1 day	B + E *(for134, 135)*	80	40
Before the scheme, recharge 87 mm 1 day and flood inundation for 1 day	B + C + E *(for134, 137, 138)*	100	NA
After the scheme, flood inundation for 6 days	D + E *(for111, 112)*	NA	80
After the scheme, recharge 87 mm and flood inundation for 6 days	B + D + E *(for134, 139, 140)*	NA	140
Sensitivity - After the scheme, flood inundation for 6 days (T x 1.5)	D + E *(for204,205)*	NA	100

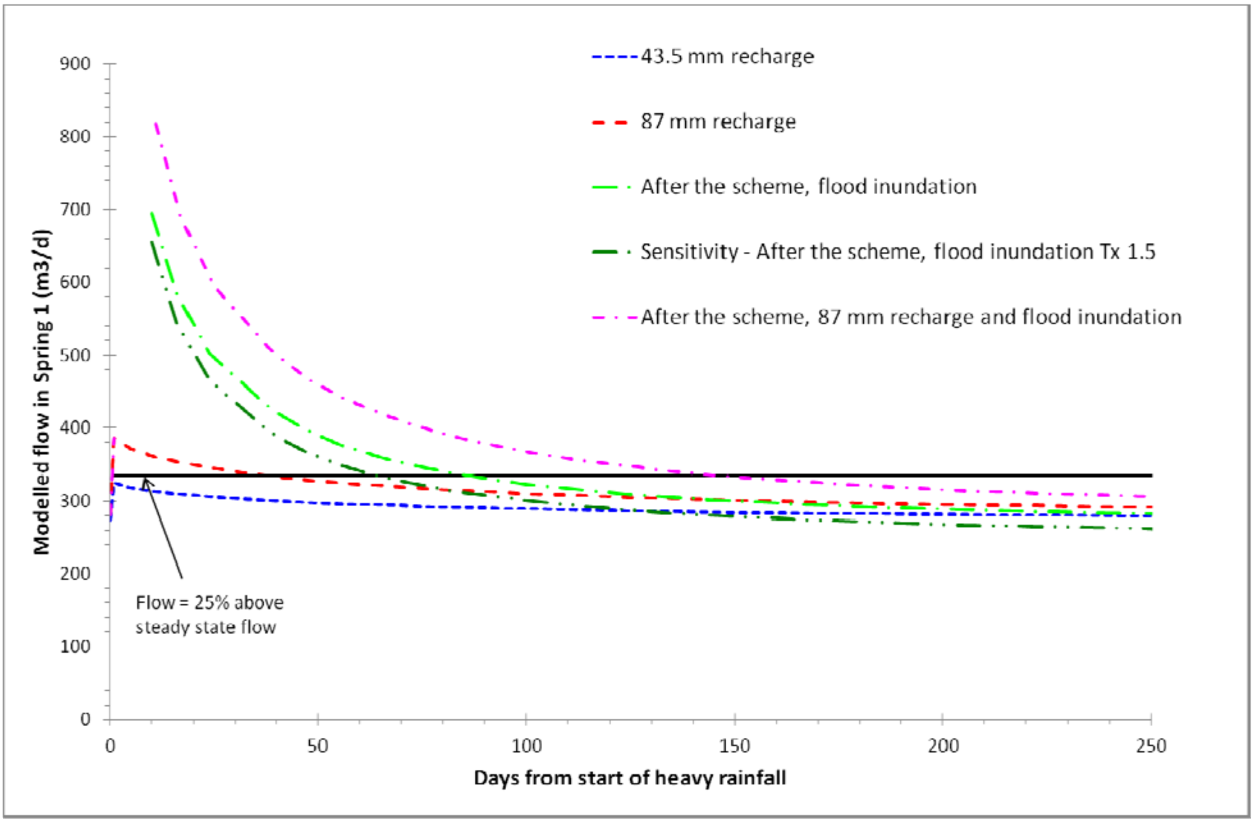

Figure 16. Modelled flows in Spring 1

4.3.6 Flows in the Old Spring system

Prior to the flood alleviation scheme the discharges from Spring 1 and Spring 2 were routed via a combination of open and covered drains (Figure 12, MacDonald et al. 2006) to the Chapelton Spring outlet (the Old Spring). Figure 17 and Table 4 show the modelled flows from the Old Spring, which are the sum of the discharges from Spring 1, Spring 2 and the flow in the drains at the location marked 'Old Spring' in Figure 6. The steady state flow here is 658 m^3/d (7.6 L/s).

For recharge of 43.5 mm, the maximum modelled flow at the Old Spring is 961 m^3/d (11.1 L/s) and it falls to within 25% of the steady state flow after about 20 days after the start of the recession. Increasing the recharge to 87 mm increases the maximum flow at the old spring to 1293 m^3/d (15 L/s) and it reaches 25% of the steady state flow after about 80 days of recession. When heavy rainfall (recharge = 87 mm) and flood inundation are combined the maximum flow is 1759 m^3/d (20.4 L/s) and it takes about 100 days to fall to within 25% of the steady state flow.

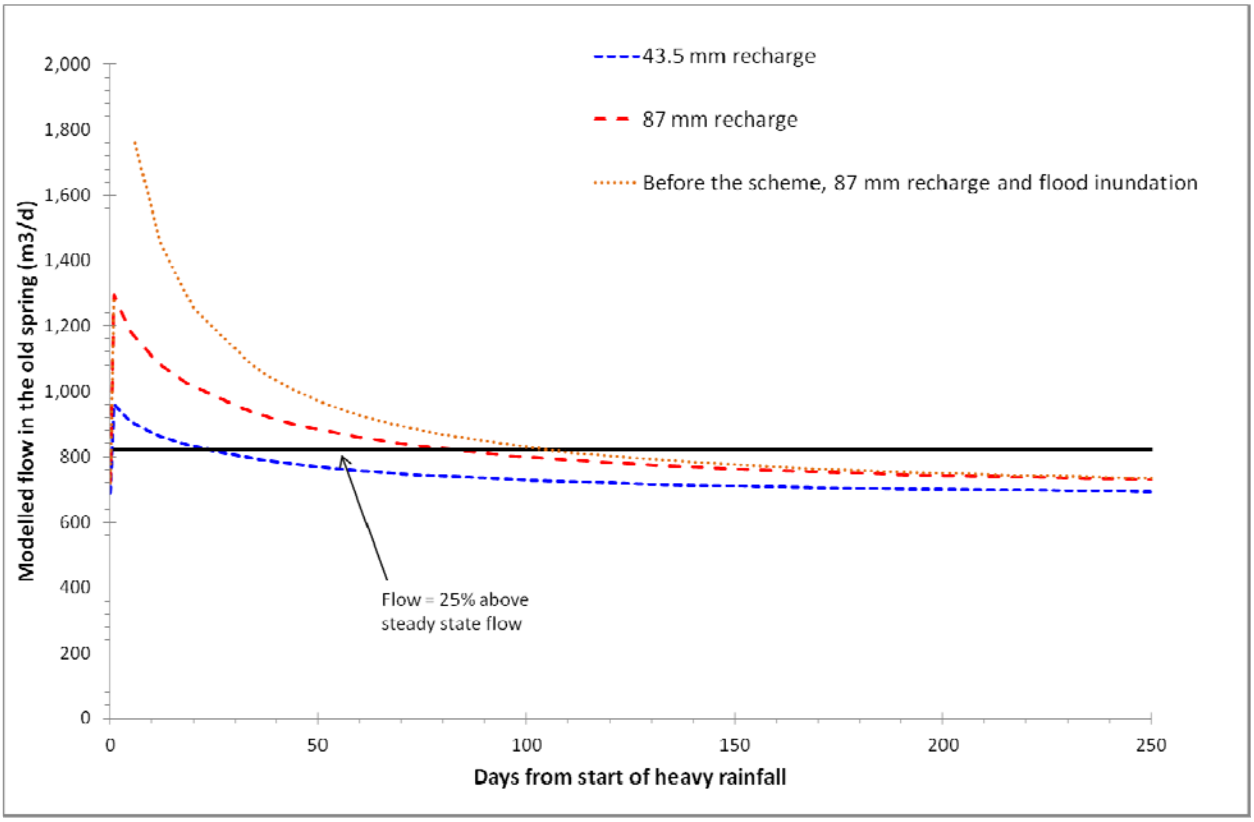

Figure 17. Modelled flows in the Old Spring

4.3.7 Sensitivity to changes in transmissivity

As described in Section 3.3 sensitivity of the base run to transmissivity and the geometry of Spring 1 was carried out. The run where transmissivity was multiplied by a factor of 1.5 was carried forward to a predictive sensitivity run using a scenario of heavy rainfall (recharge = 87 mm for 1 day) followed by recession that is runs D and E. The results are shown in Figure 16 and Table 4. The maximum Spring 1 flow is 655 m^3/d (7.6 L/s) and it falls to within 25% of the new steady state flow (i.e. 296 m^3/d, 3.4 L/s about 100 days after the start of the recession.

5 Summary and conclusions

5.1 MODEL CONSTRUCTION AND REFINEMENT

A groundwater model has been built using ZOOM to represent groundwater flow to the Spring system around Wright's Hill. A three layer model has been constructed which represents the superficial deposits by the upper two layers and the sandstone bedrock as layer 3. Few groundwater level data exist in the area so the model was refined to match the springflow at Spring 1. Using the T distribution from previous work, and a recharge model based on rainfall 20% above LTA, a springflow of 3.1 L/s was obtained for Spring 1.

The important aspects of the system identified during model refinement include decreasing the size of the model, improving the estimate of recharge and ensuring that the drains and springs were represented properly.

5.2 PREDICTION RUNS

The main aim of the study is to determine the impact of a flood event on the Chapleton springs. A number of prediction runs have been undertaken to examine the response of the spring system to:

- A high rainfall event either with no run-off (87 mm in one day) or 50% run-off (43.5 mm in one day).
- Surface inundation for natural flooding and that is predicted to occur as a result of the FAS

In both cases this was represented in the model using enhanced recharge.

The impact of rainfall and flood inundation related to a 1 in 100 year event on the spring system was assessed against the length of time that the flow was 25% greater than the steady state value. This value was chosen as a reasonable value for the springflow given that the decay in flow is exponential. The discussion of the prediction results is in relationship to the time it takes to reduce to 25%.

For the original spring system ("Old Spring" in Table 4), results from the groundwater model indicate that moderate infiltration (43.5 mm) will result in the flow above 25% for 20 days. Higher infiltration in line with a 1 in 100 year flood event will result in the springflow being above 25% for 80 days, or 100 days if the inundation from the Burn of Mosset is included.

Modelling of the effect of heavy rainfall on Spring 1 indicates that moderate infiltration (43.5 mm) will now be unlikely to cause the springflow to increase above 25%, and higher infiltration will increase the springflow to above 25% for 40 days. Therefore the modifications to the spring system has reduced the number of days that the water quality in the spring is unacceptable for heavy rainfall events that do not give rise to overtopping of the bund.

Modelling of infiltration from flood waters which overtop the bund and give rise to 45,000 m^3 of infiltration behind the bund suggest that the flow in the spring will be above 25% for 80 days after overtopping. If the effect of local rainfall is included (87 mm infiltration) then the springflow will be above 25% for 140 days.

The sensitivity runs undertaken using higher transmissivity (by 50%: multiplied by 1.5) show that the response time of the spring is increased to above 100 days.

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