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Liden Brook
Modelling Study

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1 Introduction

The Environment Agency (EA) has commissioned Mott MacDonald (MM) to undertake a modelling study using the Upper Cole Section 105 ISIS model previously developed by PBA. As flooding is occurring upstream of the Liden Brook Storage pond, this modelling study was designed to investigate the reduction of flood levels upstream of the Liden Brook Storage Pond which could be achieved by lowering the crest level of the weir downstream of the lagoon. In addition to this, MM proposed and modelled the following options to assess their impacts on flood levels in the upper section of the Liden Brook Storage Pond:

1. Re-grading the river bed level between the downstream weir (LID.050SU) and the upstream weir (LID.054SU) to obtain a steeper bed slope (0.0033);

2. Re-grading the river bed level between the downstream weir (LID.050SU) and the bridge upstream (LID.058D) of the lagoon to obtain a steeper bed slope (0.0033);

3. Further re-grading the river bed level between the downstream weir (LID.050SU) and the upstream weir (LID.054SU) to obtain an even steeper bed slope (0.0049);

4. Further re-grading the river bed level between the downstream weir (LID.050SU) and the bridge upstream of the lagoon (LID.058D) to obtain an even steeper bed slope (0.0048);

The modelling study was carried out using the version 3.0 of ISIS software. The existing S105 ISIS model was slightly modified in order to obtain an adequate model for the purpose of this study. The model was run for the proposed engineering scenarios for the 5, 20, 50, 100-year and 100+20% flood events, and also the low and mean flow conditions.

2 Model Amendments

The existing S105 ISIS model included a QH Control unit (Liden.02) to represent the outlet from the Liden Brook Storage Pond back into the Liden Brook stream. As the QH Control unit does not take tail-water effects into account, it was proposed to replace this unit with a 450mm orifice (Liden.02) to represent the Linden Brook Storage Pond outlet.

It is worth noting that models with greater number of nodes require longer simulation time. The existing ISIS S105 model, which was developed for the Upper Cole River, was composed of 888 nodes, requiring an average simulation time of 30-45mins. Considering the number of scenarios to be run, it was decided to focus only on the upper section of the model to maintain a shorter simulation time. Therefore, the existing Upper Cole Section 105 ISIS model was truncated from downstream of cross-section LID.032 to only include the upper section of the Liden Brook.

In this analysis it was assumed that the storm is homogeneous over the River Cole and the Liden Brook catchments. It was considered very unlikely that a storm would occur only on the River Cole and not on the Liden Brook catchments. It was, therefore, determined acceptable to truncate the model from downstream and utilise a normal depth boundary at the downstream end of the model. The model was run for the 5, 20, 50, 100-year, 100+20% return periods, and also the low and mean flow conditions. Results were compared for the original and modified versions of the model. It was verified that backwater effects were negligible for a homogeneous storm over the River Cole and the Liden Brook catchments.

3 Model Network

The model network used in this modelling study originates from the upper section of the Liden Brook, cross-section LID.061, and extends downstream to cross-section LID.032. The model includes 124 nodes and two FEH boundary units.

Figure 3.1 and Figure 3.2 depict the representative plan and long-section bed profile of the Upper Cole Section 105 model at Liden Brook Storage Pond from cross-sections LID.061 to LID.032.

Figure 3.1: Plan Schematic of Upper Cole Section 105 ISIS Model at Liden Brook Storage Pond

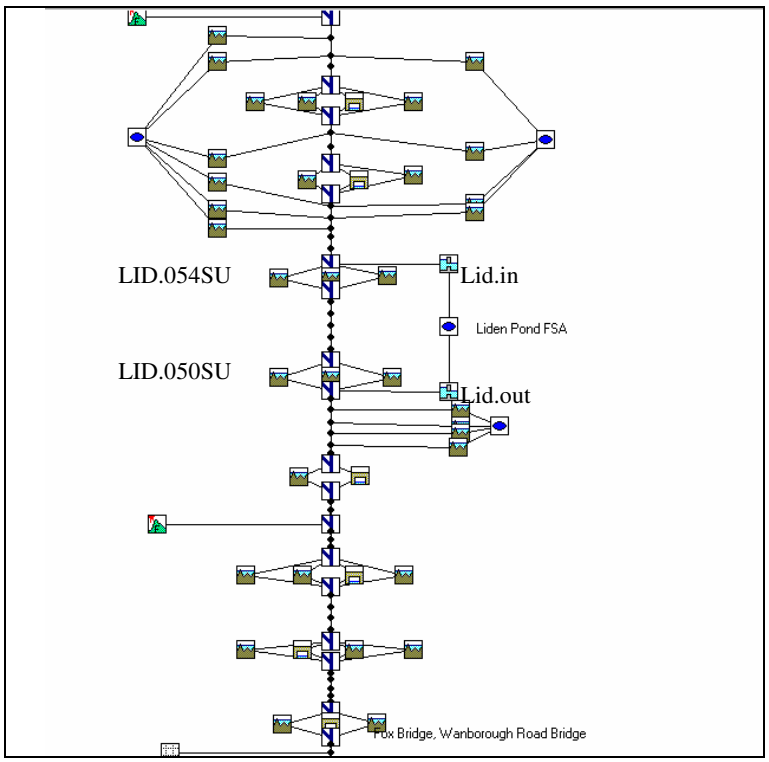
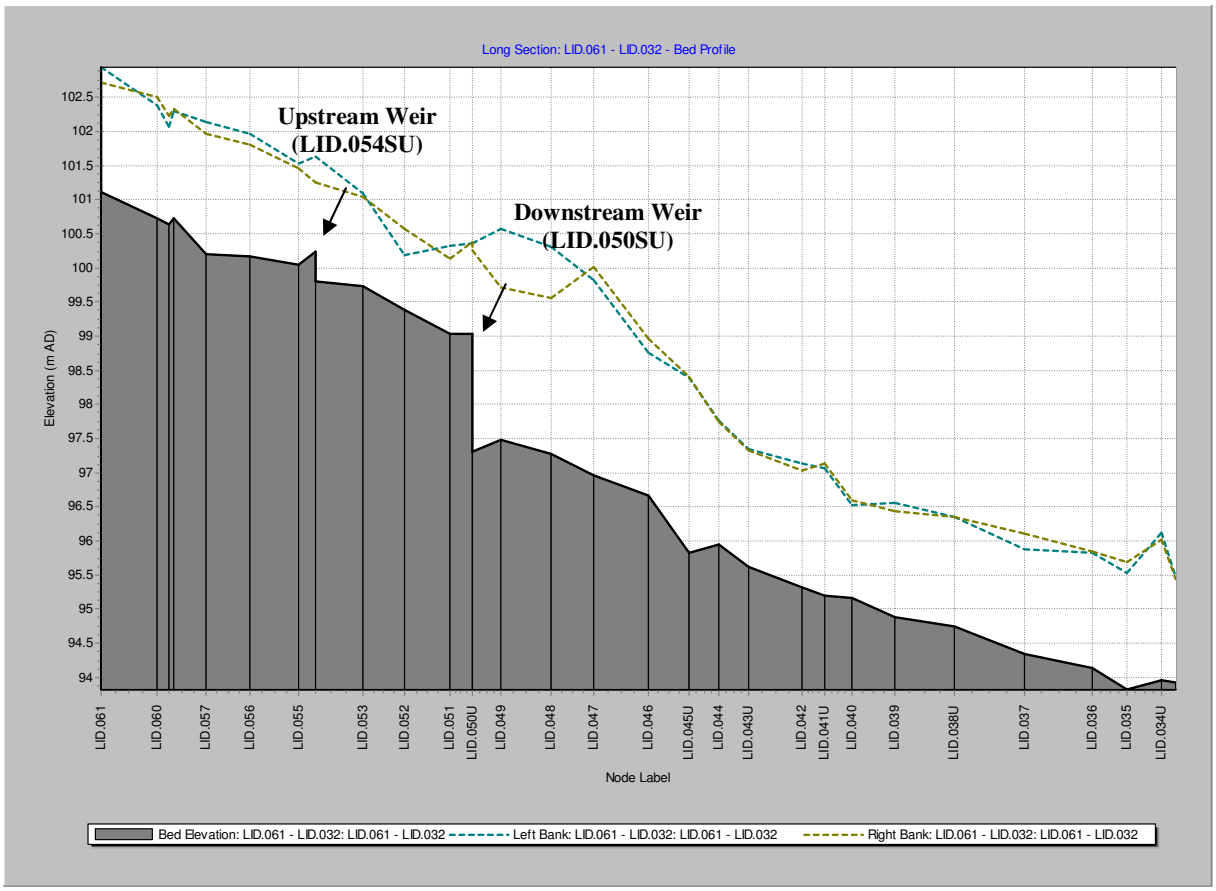


Figure 3.2: Long-section Profile of Upper Cole River at Liden Brook Storage Pond



4 Hydrology

The modelling study was undertaken for a number of return periods previously simulated by PBA and also the low and mean flow conditions.

4.1 Critical Storm Duration

Results obtained from the previous modelling study were employed to assess the critical storm duration for the study area. The 'max_levels_final.xls' spreadsheet provided by the Environment Agency for the River Cole model was used to verify the critical storm duration at the Liden Brook Storage Pond (Linden.01). The critical storm duration was identified to be 6.25 hours.

4.2 Low and Mean Flows

Spot gauging data for the Liden Brook were provided by the Environment Agency. The 'Hydraulic Modelling Report for River Cole Swindon' was also reviewed in order to obtain additional flow information with regard to the mean and low flows. However, as the review did not reveal any additional information, the mean and low flows were estimated using spot gauging data only.

As shown in Table 4.2, spot gaugings on the Liden Brook were recorded by the EA between 1952 and 2005. The number of spot gaugings surveyed during the winter months is greater than during the summer months. A mean flow value for the upstream part of the Liden Brook was estimated in two steps:

1. By averaging flow values individually for the summer and winter months;

2. By averaging the above seasonal averages.

The estimated mean flow is 0.44 m^3/s.

As shown in Table 4.2, the smallest flow is 0.01m^3/s. This value was initially employed to represent the low flow condition; however, the model could not be successfully operated given that the magnitude of flow was very small. For this reason, the second lowest value in Table 4.2, 0.04 m^3/s, was selected to simulate the low flow condition.

Table 4.1 summarises the estimated values of mean and low flows used in the ISIS model.

Table 4.1: Estimated Mean and Low Flows

Average Summer Flow m^3/s	Average Winter Flow m^3/s	Mean Flow m^3/s	Low Flow m^3/s
0.28	0.60	0.44	0.04

Table 4.2: Spot Gaugings – Liden Brook Stream

Status	Date / time	S [cm]	Q [m³/s]
unconfirmed	24/06/2005 14:30	94.5	0.27
confirmed	05/08/2004 17:08	94.7	0.54
confirmed	08/01/2004 12:20	94.7	0.82
unconfirmed	26/11/2003 12:20	94.5	0.24
confirmed	03/01/2003 10:46	94.7	0.99
confirmed	14/11/2002 12:10	94.9	1.18
confirmed	02/11/2002 12:10	94.5	0.16
confirmed	16/10/2002 12:15	94.5	0.21
confirmed	13/07/1992 12:00	-	0.04
confirmed	23/09/1959 12:06	-	0.01
unconfirmed	24/06/2005 14:30	94.5	0.27
confirmed	05/08/2004 17:08	94.7	0.54
confirmed	08/01/2004 12:20	94.7	0.82
unconfirmed	26/11/2003 12:20	94.5	0.24
confirmed	03/01/2003 10:46	94.7	0.99
confirmed	14/11/2002 12:10	94.9	1.18
confirmed	02/11/2002 12:10	94.5	0.16
confirmed	16/10/2002 12:15	94.5	0.21
confirmed	13/07/1992 12:00	-	0.04
confirmed	23/09/1959 12:06	-	0.01

Source: Environment Agency

Although the spot gauging data provided by the Environment Agency included additional information in relation to the area and velocity, only the data associated with the flow was used in this modelling study.

5 Model Scenarios

5.1 Introduction

This modelling study was initially designed to investigate lowering the crest of the weir (LID.050SU) downstream of the Liden Brook Storage Pond to assess its influence on flood levels upstream. The crest of the weir is above the bed level of the upstream cross-section (LID.050U) by 0.1m. Nonetheless, due to the configuration of the bed level, the level of weir crest could only be lowered by 0.07m at most. Examining the simulated results indicated no significant impact on water levels upstream of the Liden Brook Storage Pond. In addition to this, the crest level of the upstream weir (LID.054SU) was lowered by the same magnitude (0.07m). However, the modelled water levels indicated that lowering the crest levels of the weirs has insufficient impact on mitigating flooding upstream of the Liden Brook Storage pond. Therefore, MM proposed alternative engineering scenarios with the aim of mitigating flooding upstream of the Liden Brook Storage Pond.

In total, six scenarios were run for the 5, 20, 50, 100-year and 100+20% return periods, and also the low and mean flow conditions:

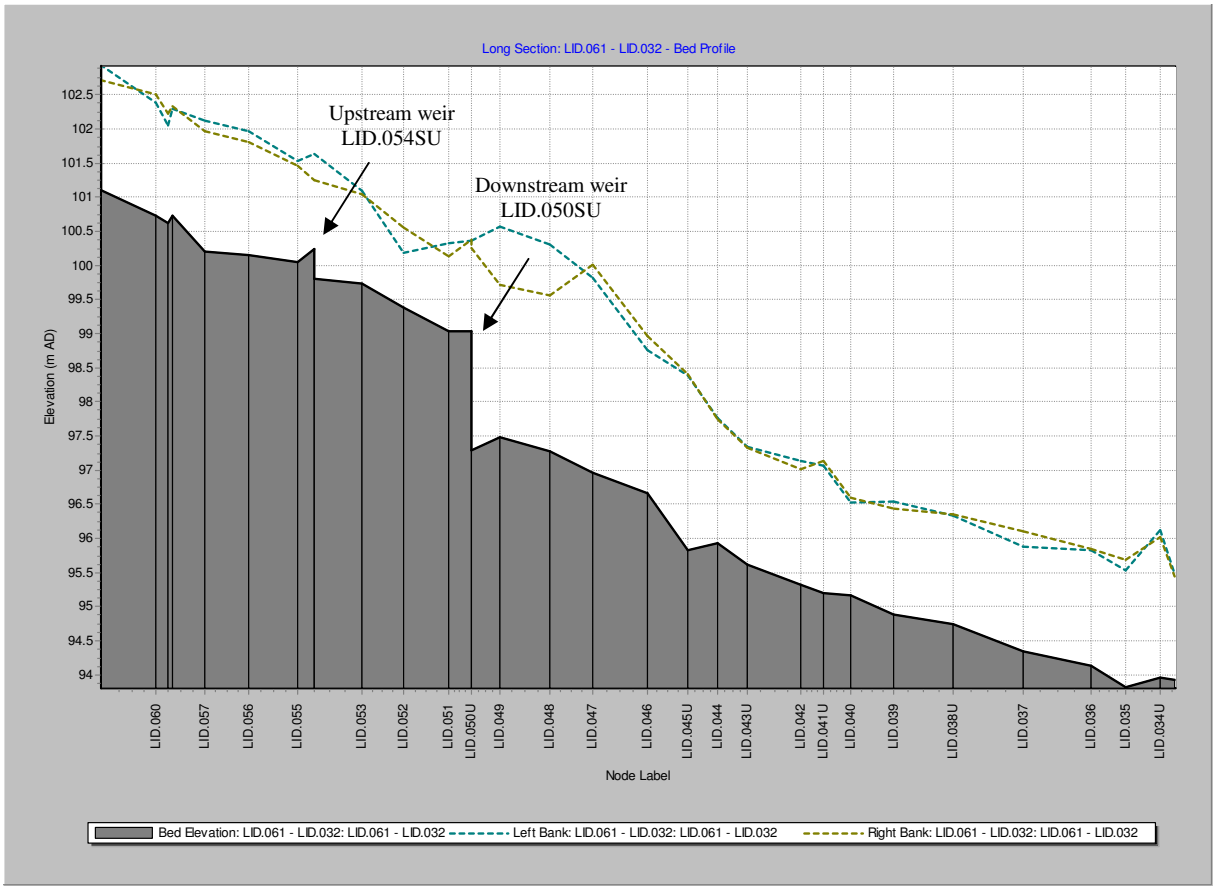
- **Scenario Nr.1** – Base scenario, corresponding to the truncated S105 ISIS model with a 450mm outlet orifice;
- **Scenario Nr.2** – Reducing the crest of the weir (LID.050SU) downstream of the Liden Brook Storage Pond by 0.07m;
- **Scenario Nr.3** – Re-grading the bed level between the downstream (LID.050SU) and upstream (LID.054SU) weirs to increase the bed slope to 0.0033;
- **Scenario Nr.4** - Re-grading the bed level between the downstream (LID.050SU) and upstream (LID.054SU) weirs to further increase the bed slope to 0.0049;
- **Scenario Nr.5** - Re-grading the bed level between the downstream (LID.050SU) weir and the bridge upstream (LID.058D) to increase the bed slope to 0.0033;
- **Scenario Nr.6** - Re-grading the bed level between the downstream (LID.050SU) weir and the bridge upstream (LID.058D) to further increase the bed slope to 0.0041.

It is worth noting that in Scenarios Nr.3 to Nr.6, the crests of the upstream (LID.054SU) and downstream (LID.050SU) weirs were lowered by the same amount as the bed level was lowered.

5.2 Scenario Nr.1

As stated in Section 2, the existing Upper Cole Section 105 ISIS model developed by PBA was truncated to include only cross-sections between LID.061 and LID.032. Moreover, the QH Control unit was replaced with a 450mm orifice. The corresponding bed profile is shown in Figure 5.1.

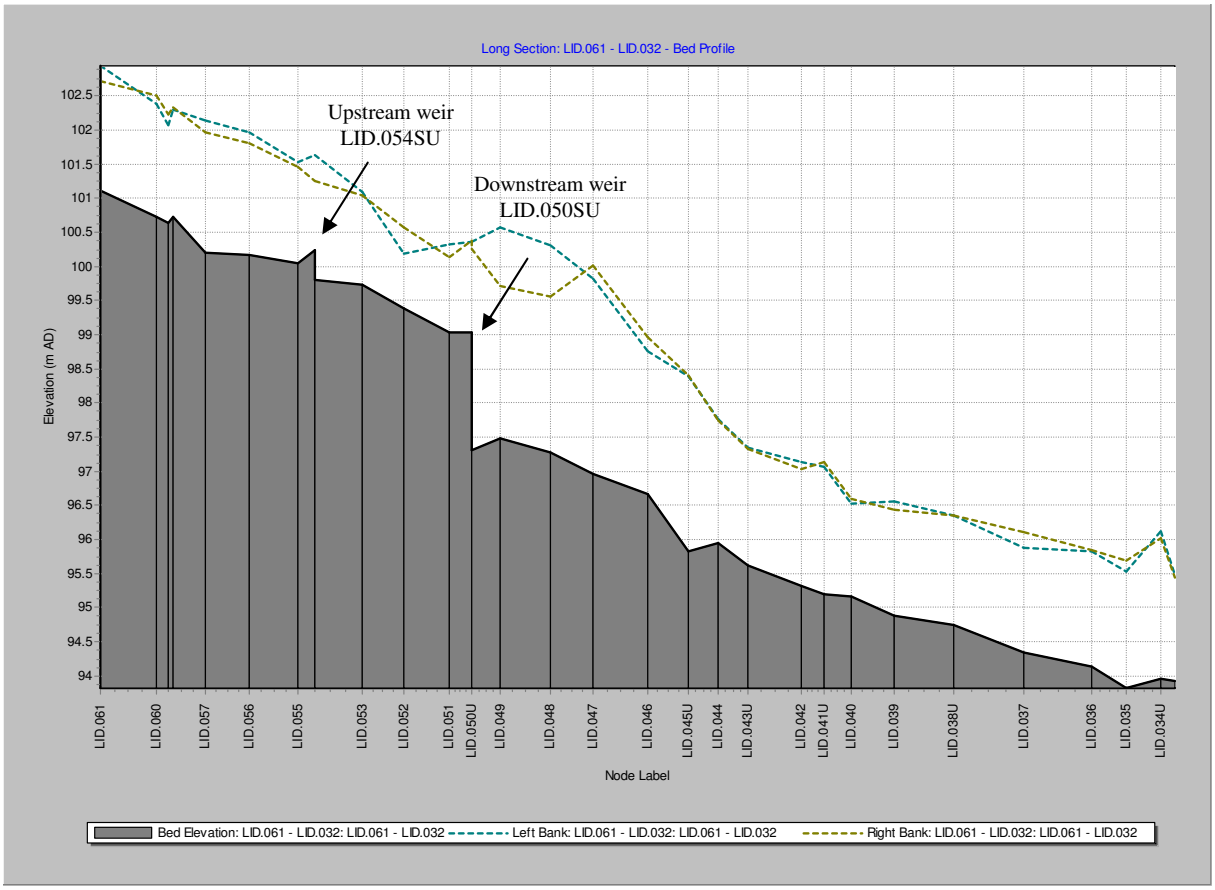
Figure 5.1: Long-section of Liden Brook – Scenario Nr.1



5.3 Scenario Nr.2

In Scenario Nr. 2, the crest of the downstream weir (LID.050SU) was lowered from 99.14mAD to 99.07mAD. The location of the downstream weir is depicted in Figure 5.2.

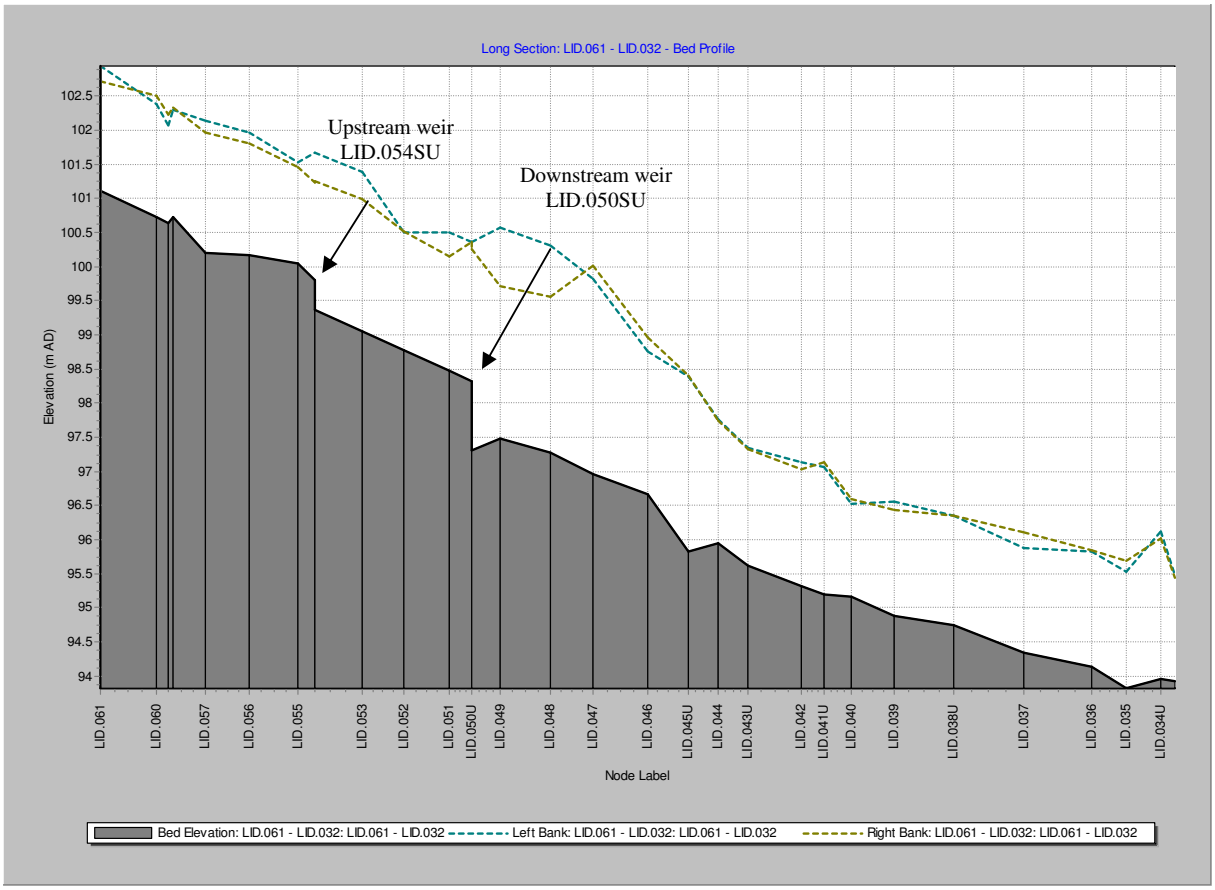
Figure 5.2: Long-section Profile of Liden Brook – Scenario Nr.2



5.4 Scenario Nr.3

Scenario Nr.2 did not significantly reduce the water levels upstream of the lagoon; therefore, MM proposed to re-grade the river bed level to create a steeper slope. In this case, the bed was re-graded in order to obtain a slope of 0.0033 between cross-sections LID.054D and LID.050U. The long-section profile with the adjusted bed level is shown in Figure 5.3.

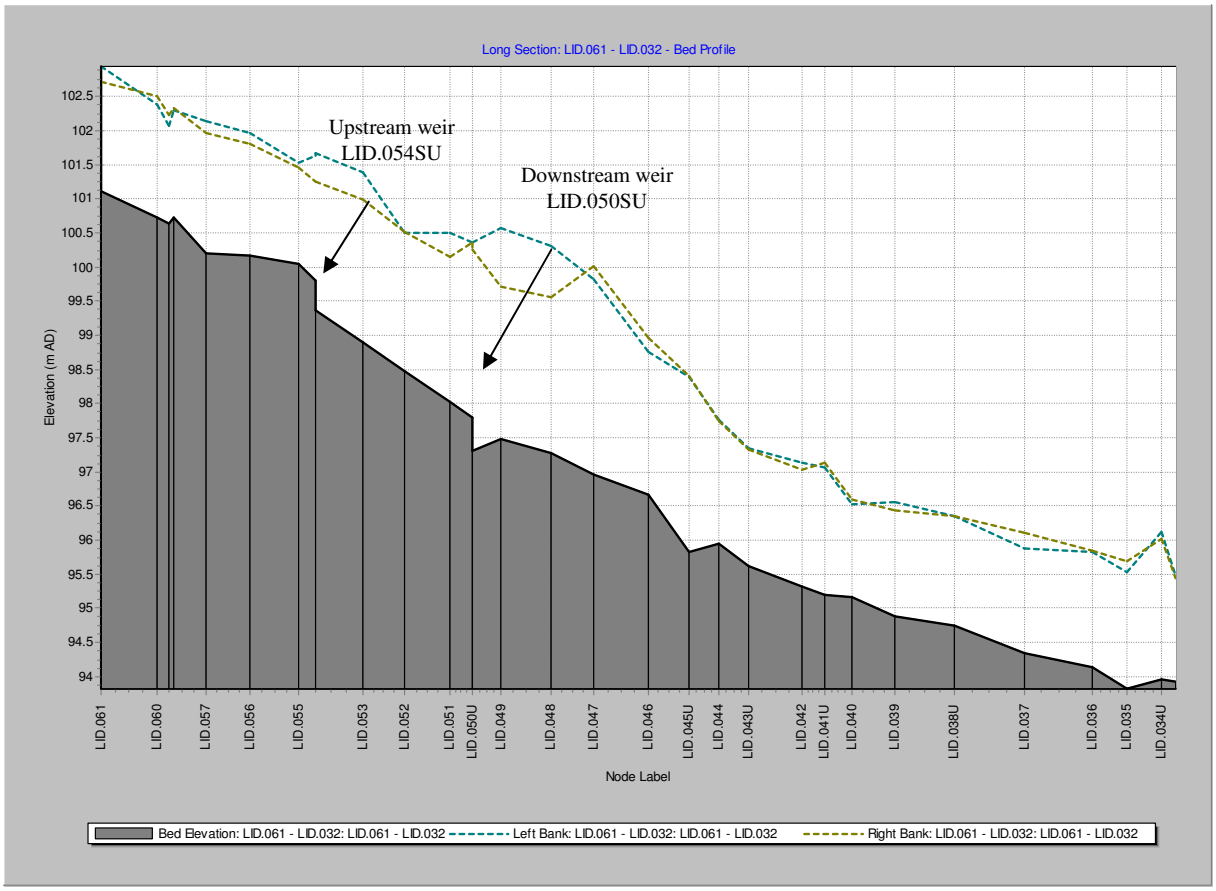
Figure 5.3: Re-graded Bed Level from Cross-sections LID.054D to LID.050U – Scenario Nr.3 (Slope 0.0033)



5.5 Scenario Nr.4

It was proposed to further increase the bed slope between the downstream (LID.050SU) and upstream (LID.054SU) weirs in order to further reduce water levels upstream of the Liden Brook Storage Pond. In this case, the bed was re-graded in order to obtain a slope of 0.0049 between cross-sections LID.054D and LID.050U. The long-section profile with the adjusted bed level is illustrated in Figure 5.4.

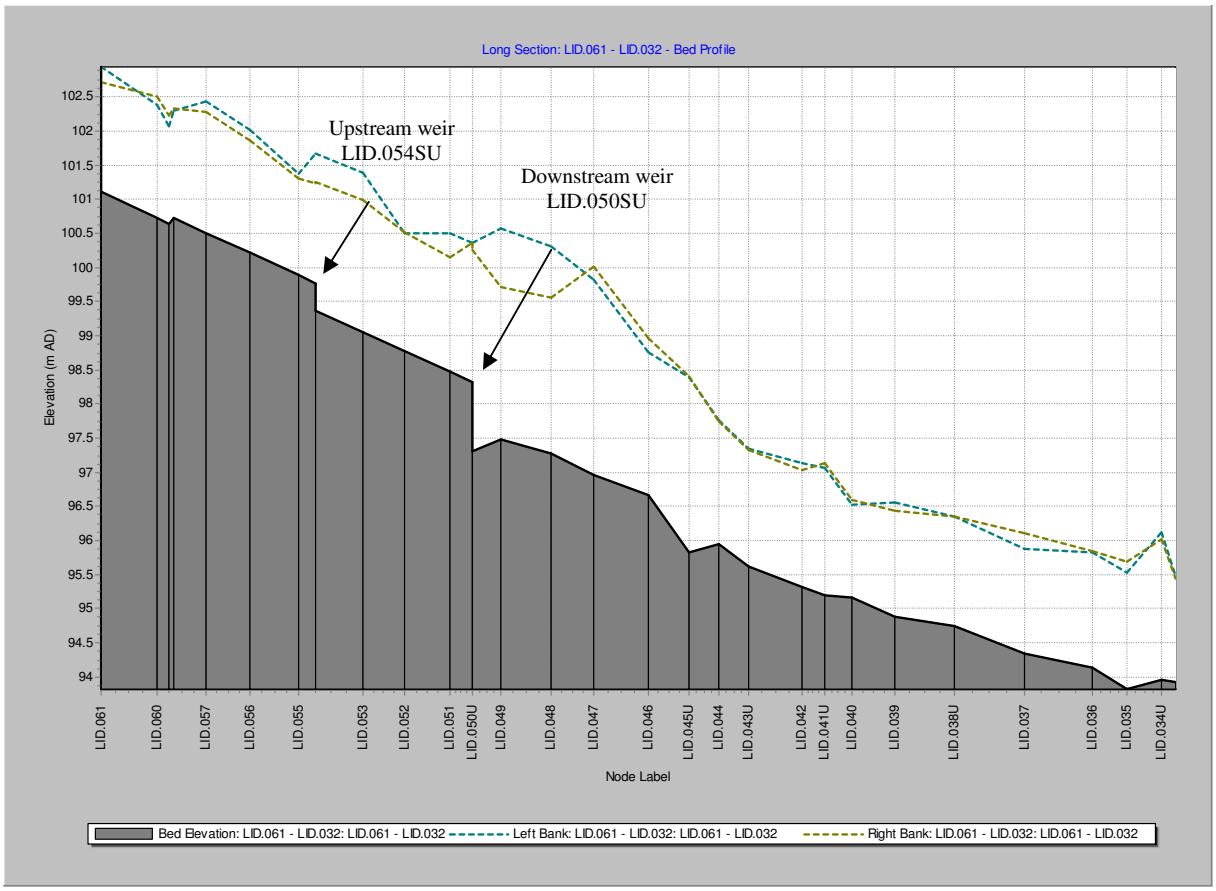
Figure 5.4: Re-graded Bed Level from Cross-sections LID.054D to LID.050U – Scenario Nr.4 (Slope 0.0049)



5.6 Scenario Nr.5

In this scenario, the bed level was re-graded between the downstream (LID.050SU) weir and the bridge upstream (LID.058D) of the lagoon. Similarly to Scenario Nr.3, the bed was re-graded in order to obtain a slope of 0.0033. The long-section profile with the adjusted bed level is shown in Figure 5.5.

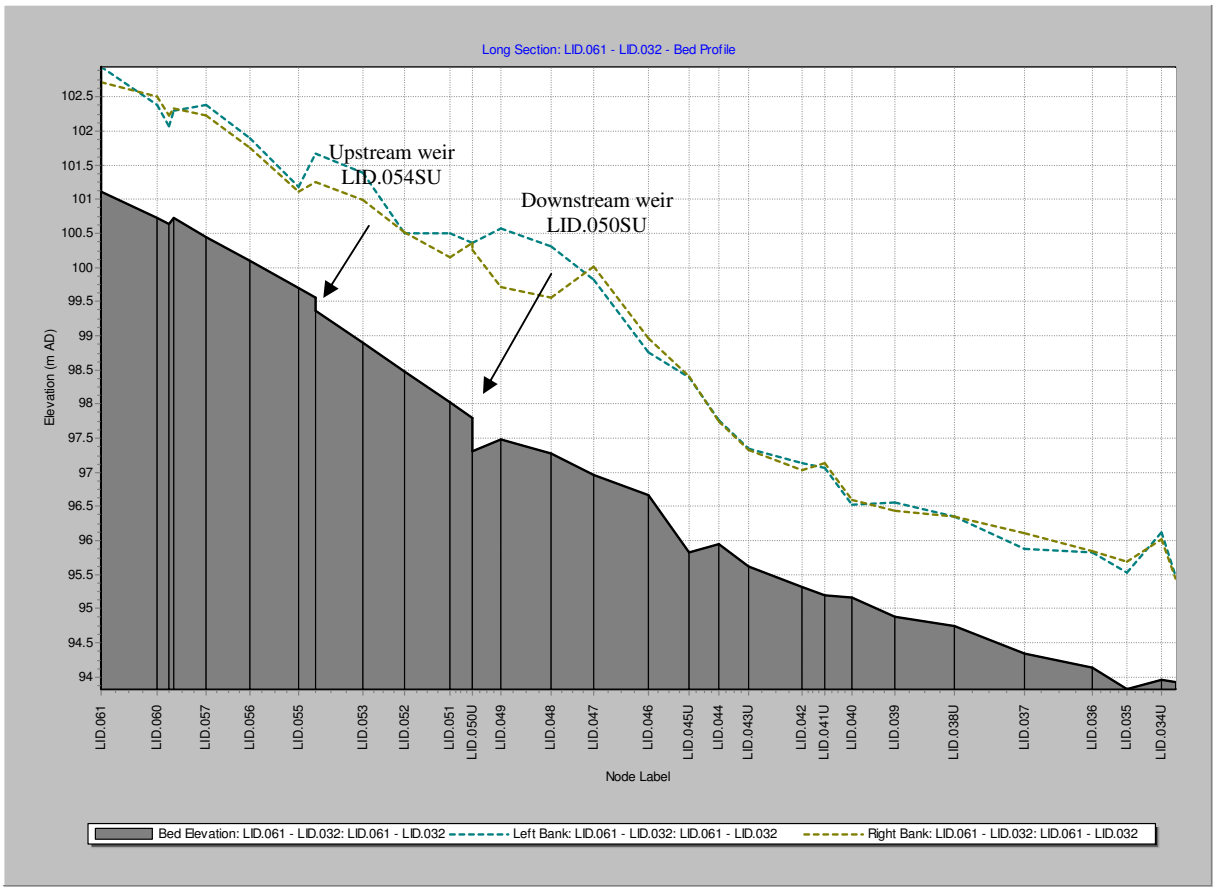
Figure 5.5: Re-graded Bed Level from Cross-sections LID.058D to LID.050U – Scenario Nr.5 (Slope 0.0033)



5.7 Scenario Nr.6

Similarly to Scenario Nr.5, the bed level was re-graded between the downstream weir (LID.050SU) and the upstream bridge (LID.058D). The bed was re-graded in order to obtain a slope of 0.0041. The long-section profile with the adjusted bed level is depicted in Figure 5.6.

Figure 5.6: Re-graded Bed Level from Cross-sections LID.058D to LID.050U – Scenario Nr.6 (Slope 0.0041)



5.8 Model Runs

The ISIS model runs encompass 7 baseline runs and 35 production runs for the flood design events and also the mean and low flow conditions. The details of model runs are summarised in Table 5.1.

Table 5.1: Model Runs - Baseline and Production Runs

Flow / Scenario	Low	Mean	625 Critical flow- 5yr	625 Critical flow- 20yr	625 Critical flow- 50yr	625 Critical flow- 100yr	625 Critical flow- 100ccyr
1	1sc_Low	1sc_Mean	1sc_5yr	1sc_20yr	1sc_50yr	1sc_100yr	1sc_100ccyr
2	2sc_Low	2sc_Mean	2sc_5yr	2sc_20yr	2sc_50yr	2sc_100yr	2sc_100ccyr
3	3sc_Low	3sc_Mean	3sc_5yr	3sc_20yr	3sc_50yr	3sc_100yr	3sc_100ccyr
4	4sc_Low	4sc_Mean	4sc_5yr	4sc_20yr	4sc_50yr	4sc_100yr	4sc_100ccyr
5	5sc_Low	5sc_Mean	5sc_5yr	5sc_20yr	5sc_50yr	5sc_100yr	5sc_100ccyr
6	6sc_Low	6sc_Mean	6sc_5yr	6sc_20yr	6sc_50yr	6sc_100yr	6sc_100ccyr

6 Results

The water level hydrographs were analysed at the Liden Brook Storage Pond (Liden.01). The flow hydrographs were examined at the inlet (Lid.in) and outlet (Liden.02) units of the Liden Brook Storage Pond. The hydrographs are shown in Appendix A.

In addition to the hydrographs, the peak values were extracted at the above model nodes and comparisons were made between the proposed scenarios. The results are discussed in sections below.

6.1 Flood Design Events

Water levels were predicted for the proposed scenarios for each flood design event. Peak water levels were extracted at the Liden Brook Storage Pond and are summarised in Table 6.1.

Table 6.1: Peak Water Levels at Liden Brook Storage Pond

Flood Event	Scenario	Storage Pond (Liden.01) Water Level (m AD)
5 Year	1	98.623
	2	98.626
	3	98.496
	4	98.477
	5	98.497
	6	98.456
20 Year	1	98.756
	2	98.758
	3	98.638
	4	98.625
	5	98.634
	6	98.596
50 Year	1	98.835
	2	98.834
	3	98.727
	4	98.713
	5	98.718
	6	98.680
100 Year	1	98.889
	2	98.889
	3	98.786
	4	98.771
	5	98.772
	6	98.736
100+20% Year	1	98.947
	2	98.945
	3	98.850
	4	98.833
	5	98.832
	6	98.795

Peak flow magnitudes extracted at the inlet (Lid.in) and outlet (Liden.02) units of the Liden Brook Storage Pond are listed in Appendix B.

6.2 Low and Mean Flow Design Events

Water level and flow were simulated for the proposed scenarios for both low and mean flow conditions. Table 6.2 summarises the water levels extracted at the Liden Brook Storage Pond (Liden.01).

Table 6.2: Water Levels at Liden Brook Storage Pond

Flow Design Event	Scenario	Storage Pond (Liden.01) Water Level (m AD)
Low Flow	1	98.260
	2	98.260
	3	98.174
	4	98.152
	5	98.174
	6	98.152
Mean Flow	1	98.365
	2	98.365
	3	98.190
	4	98.212
	5	98.190
	6	98.212

The flow magnitudes were extracted at the inlet and outlet units of the Liden Brook Storage Pond and are listed in Appendix B.

7 Result Analysis

7.1 Scenario Nr.2

In Scenario Nr.2, the crest level of the weir downstream (LID.050SU) of the Liden Brook Storage pond was reduced by 0.07m. It was observed that reducing the crest level of downstream weir does not have any significant impact on modelled water levels upstream of the storage pond. In fact, the reduction in water level is merely confined to the location of the downstream weir. The maximum drop is predicted to be 0.06m for the 100+20% flood event.

Furthermore, comparing Scenarios Nr.1 and Nr.2 indicated that the amount of water discharging into the Liden Brook Storage Pond remains virtually unchanged. The slight variations in peak water levels, as shown in Table 6.1, are mainly due to the accuracy limitations of the ISIS model.

It was subsequently proposed to decrease the crest level of the weir upstream of the lagoon (LID.054SU) in addition to crest of the weir downstream (LID.050SU). The crest levels of both weirs were decreased by 0.07m, and the model was run for the proposed flood design events, and also the low and mean flow conditions. The results indicated no significant reduction in water levels in the upper section of the Liden Brook. However, it was observed that by lowering the upstream weir crest, larger amounts of water flow through the Liden Brook, and therefore less water discharges into the lagoon. Predicted water levels associated with this unsuccessful scenario have not been included in this document.

7.2 Scenario Nr.3

As reducing the weir crest level was shown not to be an efficient solution to significantly reduce water levels upstream of the storage pond, it was proposed to re-grade the river bed between the upstream (LID.054SU) and downstream (LID.050SU) weirs to increase the river bed slope to 0.0033. It was anticipated that increasing the bed slope would cause the water to flow more rapidly through the Liden Brook, which in turn would lower the water levels in the upper section of the stream.

As shown in Appendix C, comparing the results with the baseline scenario (Scenario Nr.1) revealed that the maximum water level was reduced by approximately 0.54m between the downstream (LID.050SU) and upstream (LID.054SU) weir locations. However, it was observed that the re-grading of the bed level did not have any beneficial impact on the upper section of the Liden Brook.

Moreover, increasing the bed slope influenced the amount of water discharging into the Liden Brook Storage pond. As shown in Table 6.1, the peak water level is decreased by approximately 0.1m for all modelled flood events.

7.3 Scenario Nr.4

As Scenario Nr.3 was not successful, it was proposed to further increase the bed slope between the downstream (LID050SU) and upstream (LID.054SU) weirs to assess the impact on water levels upstream of the storage pond. Consequently, the bed level was reduced further to maintain a slope of 0.0049 between cross-sections LID.054D and LID.050U.

The maximum water levels were compared with the baseline scenario and also Scenario Nr.3 (See Appendix C). It was observed that by further increasing the river bed slope larger amounts of water flow through the Liden Brook, resulting in a higher reduction in water levels. The average reduction in water level was approximately 0.70m between the upstream (LID.054SU) and downstream (LID.050SU) weirs. However, similarly to Scenario Nr.3, the maximum water level in the upper section of the Liden Brook is slightly greater than that predicted for the baseline scenario.

As expected, it was observed that by further lowering the river bed level, a smaller amount of water discharges into the lagoon as a greater amount of water flows through the stream (see Table 6.1).

7.4 Scenario Nr.5

As discussed for Scenario Nr. 3 and Scenario Nr.4, lowering the river bed level between the locations of the upstream (LID.054SU) and downstream (LID.050SU) weirs could considerably lower the water levels at this particular location in the Liden Brook. However, as these modifications did not have any substantial impact on water levels in the upper section of the stream, it was proposed to re-grade the river bed level from the bridge upstream (LID. 058D) of the lagoon to the weir downstream (LID.050SU) of the lagoon.

The bed level was lowered with the same slope as Scenario Nr.3 (0.0033), and the model was run for the proposed flood design events, and also the low and mean flow conditions.

The results were compared with the previous scenarios and it was observed that modifying the river bed level from the upper section of the river reduces the water levels from the downstream weir (LID.050SU) to the location of the upstream bridge (LID.058D). The maximum water level was decreased by approximately 0.54m between the locations of the upstream and downstream weirs. The reduction in water level was slightly smaller in the upper section of the Liden Brook. The reduction is approximately 0.20m for the 100+20% flood event.

7.5 Scenario Nr.6

Following the encouraging observations from Scenario Nr.5, it was anticipated that an additional increase in the river bed slope could further reduce the water levels in the upper section of the Liden Brook. Therefore, the slope of the river bed was increased to 0.0041 between the bridge upstream (LID.058D) of the lagoon and the downstream weir (LID050SU). The model was run for the proposed flood design events as well as the low and mean conditions.

The maximum water levels were compared with the results from the previous scenarios, including the baseline scenario. As shown in Appendix C, the reduction in water level was relatively significant in the upper section of the river. The maximum water level was reduced by approximately 0.40m in the upper section of the river and by 0.70m between the upstream (LID.054SU) and downstream (LID.050SU) weirs for the 100+20% flood event.

7.6 Model Uncertainty

In general, it is expected to obtain similar inflow and outflow magnitudes following stabilisation of water level in the lagoon. However, as shown in Appendix A, the amount of flow leaving the storage area is greater than the inflow by maximum values of 0.03m^3/s and 0.02 m^3/s for the low and mean flow conditions, respectively. This is due to computation inaccuracies of the ISIS model for extremely small magnitudes of flow.

8 Conclusions

The modelling has shown that lowering the crest of the weir downstream (LID.050SU) of the Liden Brook storage pond does not have a major impact on reducing the flood levels in the upper section of the river. It was found that in order to decrease the water levels upstream, it is necessary to re-grade the river bed level in order to increase the magnitude of flow through the Liden Brook.

The following four scenarios were modelled to assess their individual impact on water levels in the upper section of the Liden Brook:

1. Scenario Nr.3 – Re-grading the bed level between the downstream (LID.050SU) and upstream (LID.054SU) weirs to increase the bed slope to 0.0033;

2. Scenario Nr.4 - Re-grading the bed level between the downstream (LID.050SU) and upstream (LID.054SU) weirs to further increase the bed slope to 0.0049;

3. Scenario Nr.5 - Re-grading the bed level between the downstream (LID.050SU) weir and the bridge upstream (LID.058D) to increase the bed slope to 0.0033;

4. Scenario Nr.6 - Re-grading the bed level between the downstream (LID.050SU) weir and the bridge upstream (LID.058D) to further increase the bed slope to 0.0041.

In Scenario Nr.3, the maximum water level was reduced by approximately 0.54m between the weirs upstream (LID.054SU) and downstream (LID.050SU) of the Liden Brook Storage pond for the 100+20% flood event. However, the level of water was slightly increased in the upper section of the river.

In Scenario Nr.4, the maximum water level was reduced by approximately 0.70m between the upstream (LID.054SU) and downstream (LID.050SU) weirs. However, similarly to Scenario Nr.3, the maximum water level was slightly greater than that predicted for the baseline scenario in the upper section of the river.

In Scenario Nr.5, the water level was reduced between the downstream weir (LID.050SU) and the bridge upstream of the lagoon (LID.058D). The maximum water level was decreased by approximately 0.54m between the locations of the upstream (LID.054SU) and downstream (LID.050SU) weirs, and by approximately 0.20m for the upper section of the Liden Brook for the 100+20% flood event.

In Scenario Nr.6, the reduction in water level was significant in the upper section of the river. The maximum water level was reduced by approximately 0.4m in the upper section of the river and by 0.7m between the upstream (LID.054SU) and downstream (LID.050SU) weirs for the 100+20% flood event.

The adjustments in river bed level allow for a larger magnitude of water flowing through the Liden Brook, and therefore a decrease of the flood levels upstream of the Liden Brook Storage pond. However, these adjustments also lead to a lower amount of water being discharged into the Liden Brook Storage Pond and a reduction of its water level.

Appendix A

A.1 Water Level Hydrographs

Figure A.1: Water Level Hydrographs at Liden Brook Storage Pond for all Scenarios – 5 year Return Period Flood Event

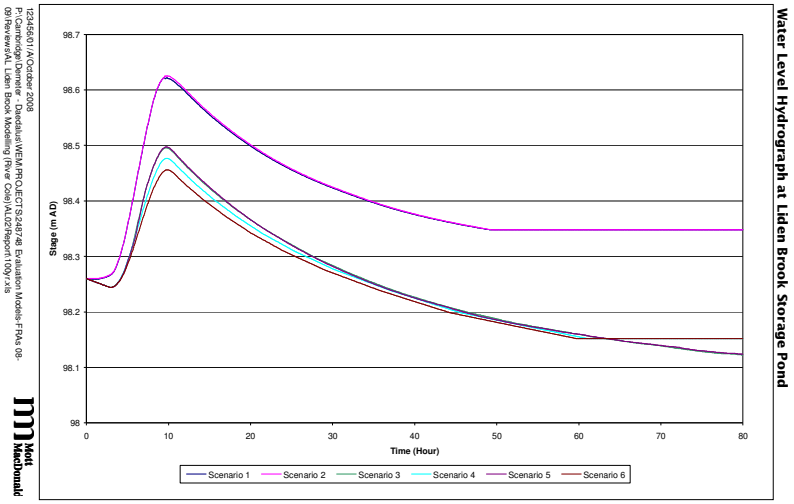


Figure A.2: Water Level Hydrographs at Liden Brook Storage Pond for all Scenarios – 20 year Return Period Flood Event

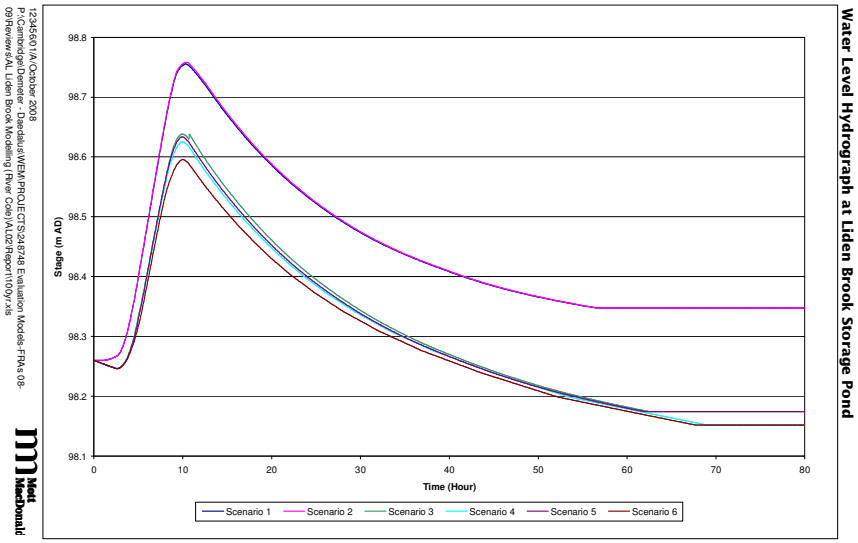


Figure A.3: Water Level Hydrographs at Liden Brook Storage Pond for all Scenarios – 50 year Return Period Flood Event

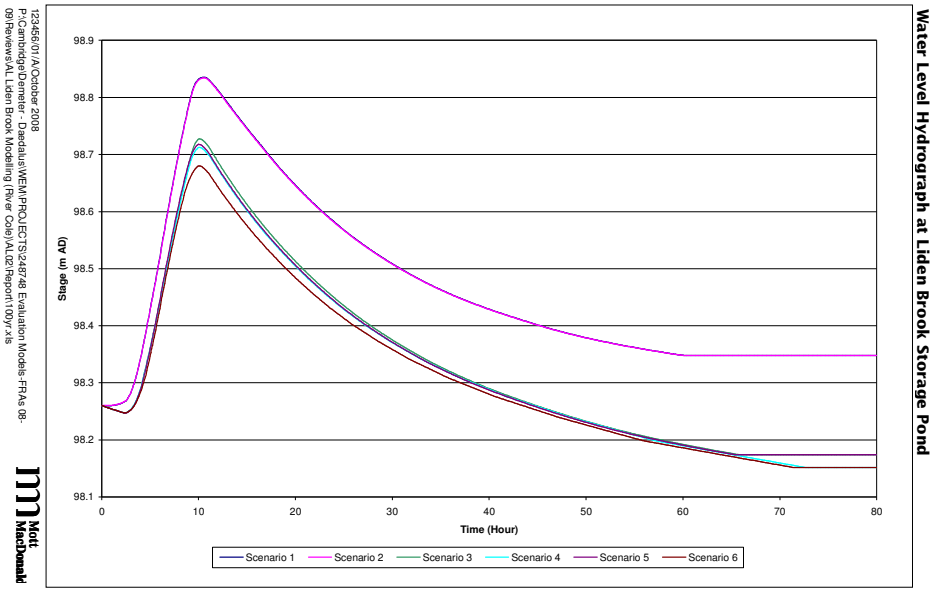


Figure A.4: Water Level Hydrographs at Liden Brook Storage Pond for all Scenarios – 100 year Return Period Flood Event

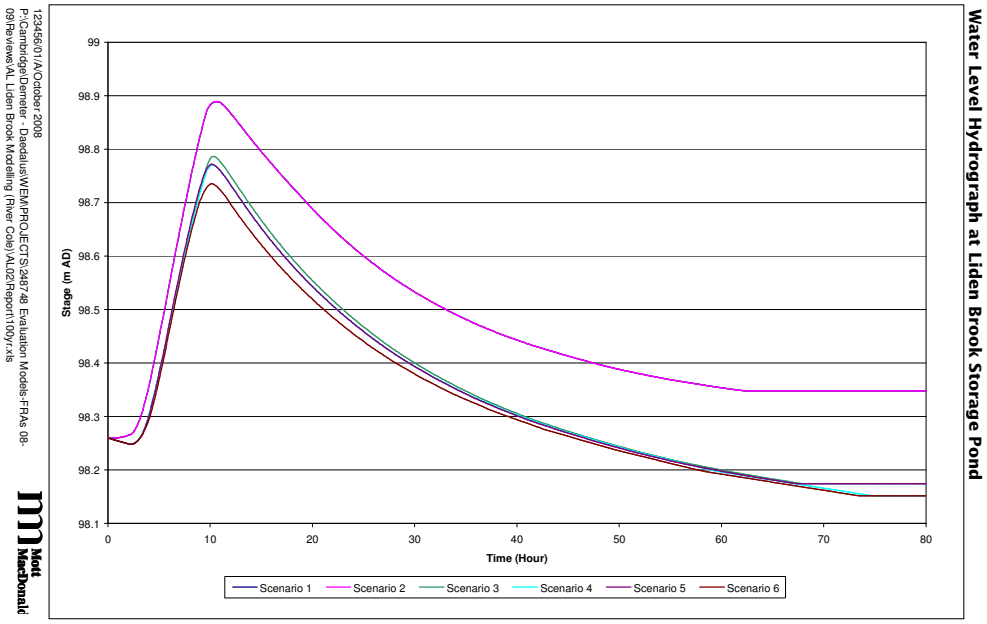
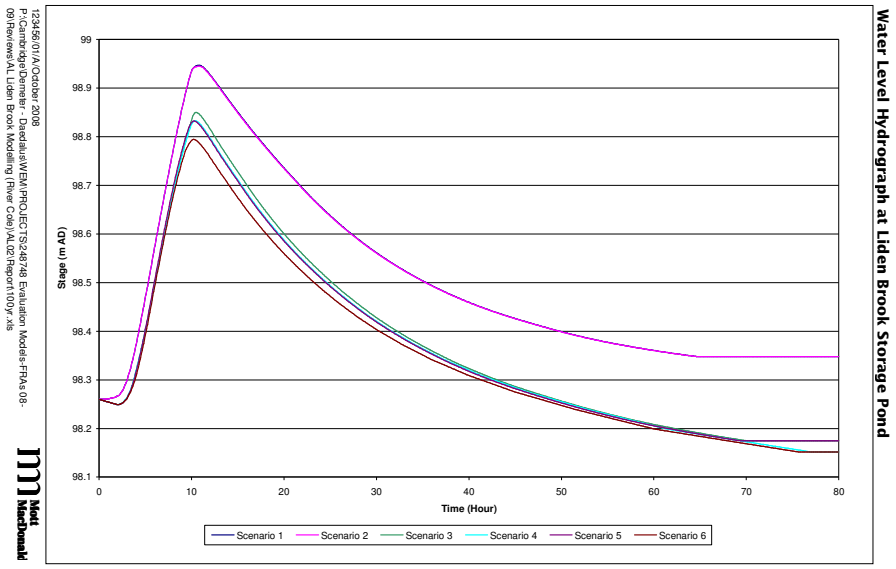


Figure A.5: Water Level Hydrographs at Liden Brook Storage Pond for all Scenarios – 100+20% year Return Period Flood Event



A.2 Flow Hydrographs

Figure A.6: Flow Hydrographs at the Inlet unit (Lid.in) for all Scenarios – 5 Year Return Period Flood Event

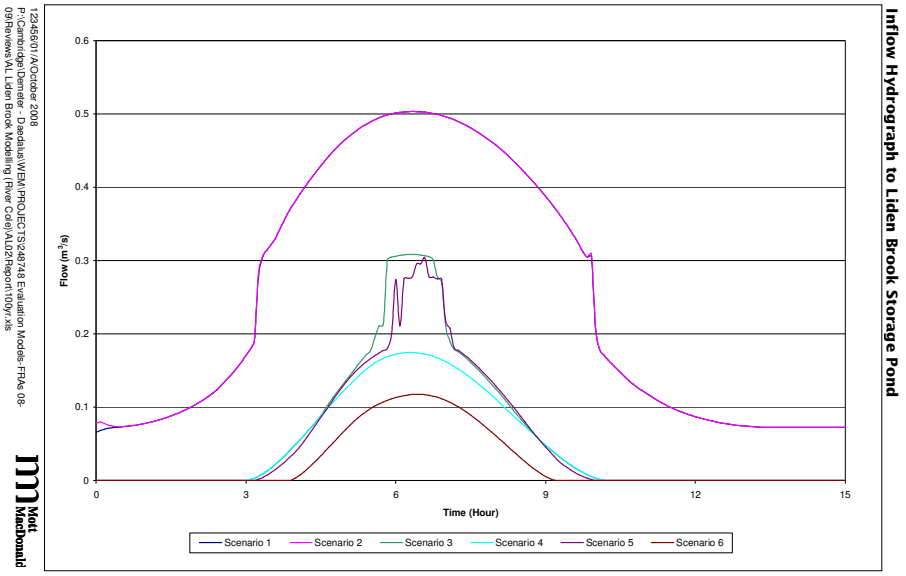


Figure A.7: Flow Hydrographs at the Outlet unit (Liden.02) for all Scenarios – 5 Year Return Period Flood Event

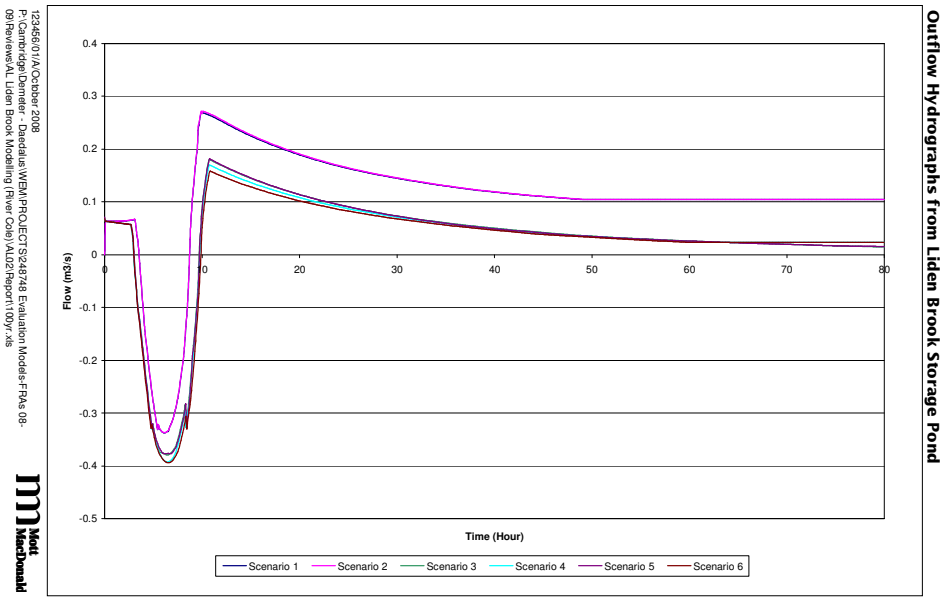


Figure A.8: Flow Hydrographs at the Inlet unit (Lid.in) for all Scenarios – 20 Year Return Period Flood Event

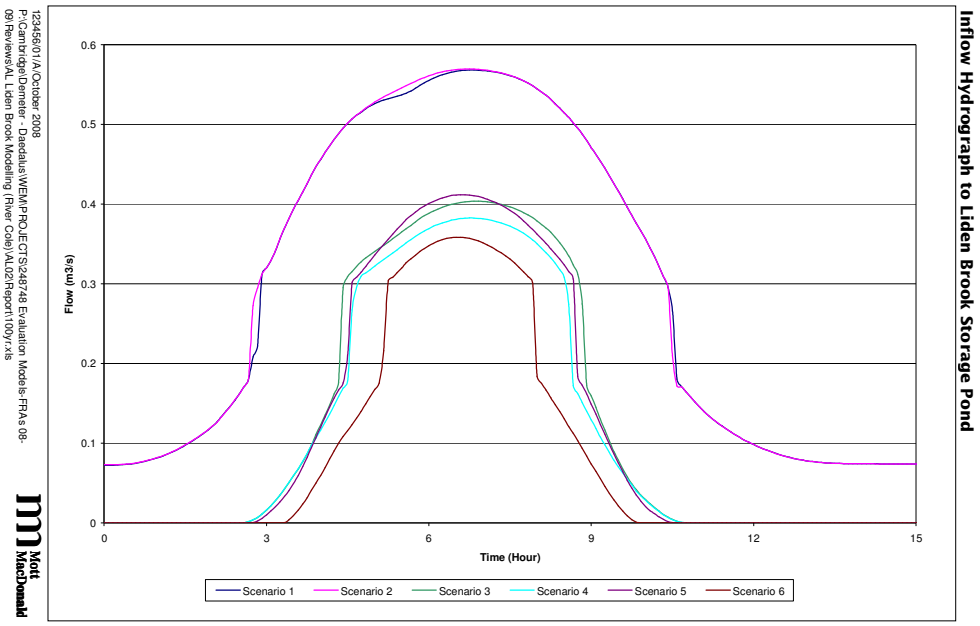


Figure A.9: Flow Hydrographs at the Outlet unit (Liden.02) for all Scenarios – 20 Year Return Period Flood Event

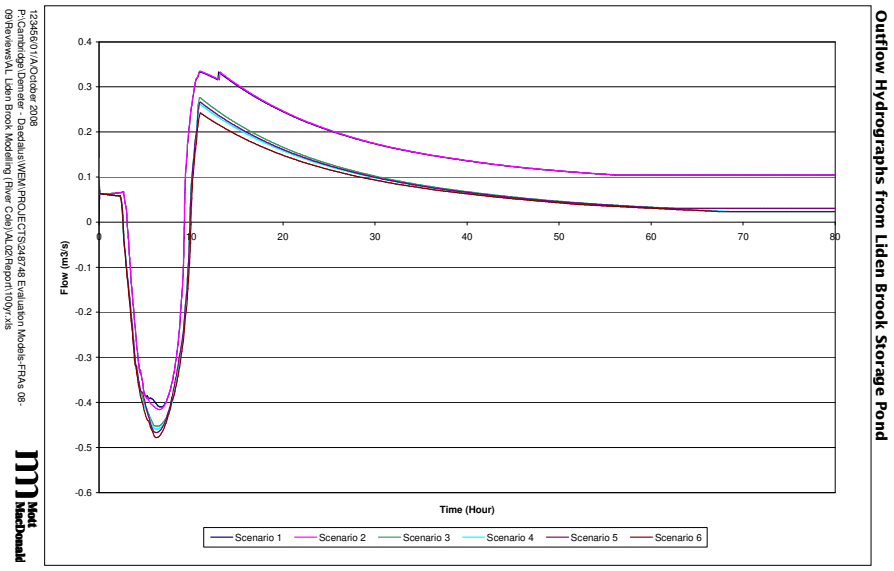


Figure A.10: Flow Hydrographs at the Inlet unit (Lid.in) for all Scenarios – 50 Year Return Period Flood Event

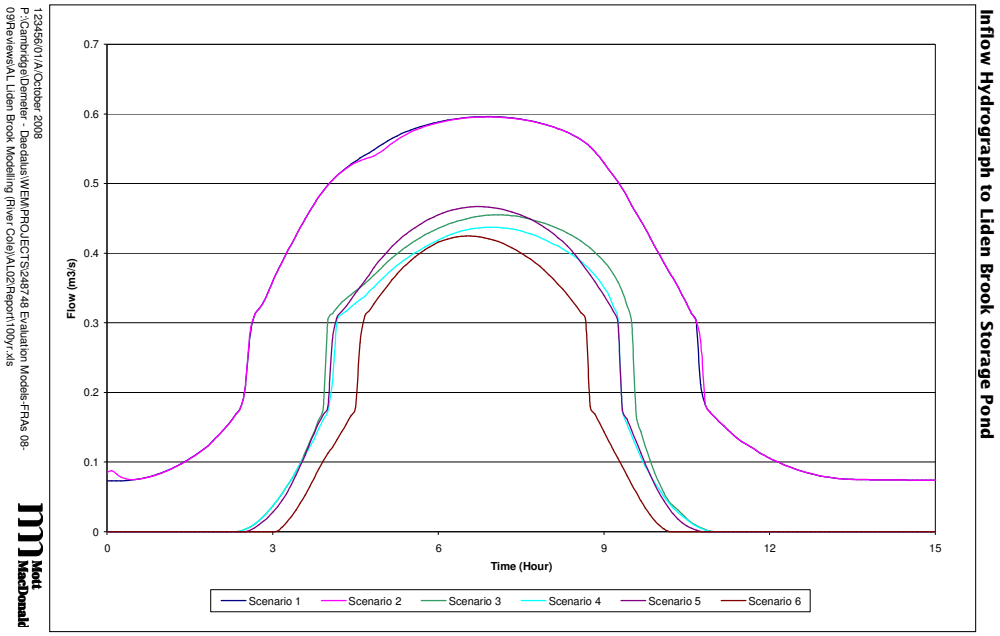


Figure A.11: Flow Hydrographs at the Outlet unit (Liden.02) for all Scenarios – 50 Year Return Period Flood Event

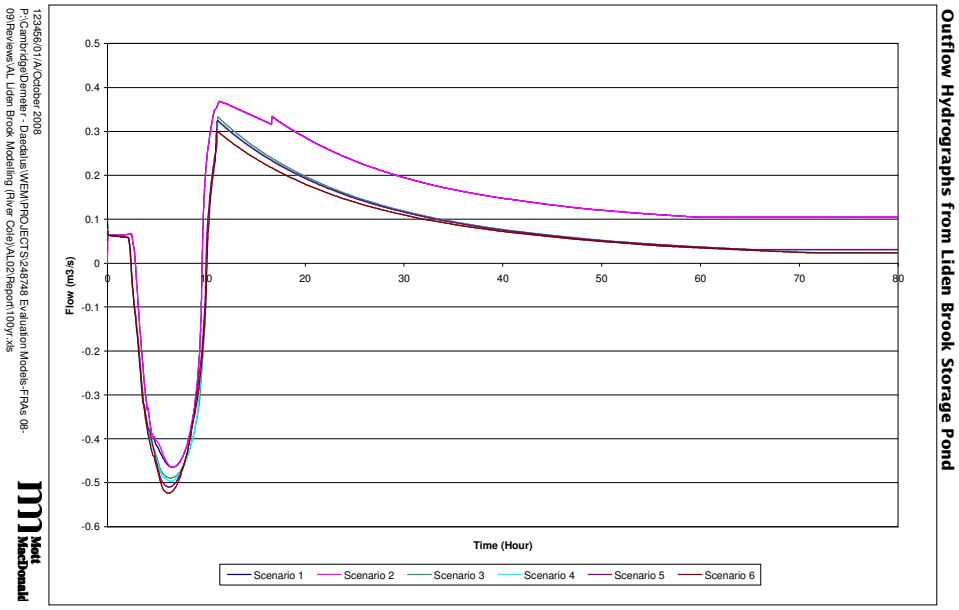


Figure A.12: Flow Hydrographs at the Inlet unit (Lid.in) for all Scenarios – 100 Year Return Period Flood Event

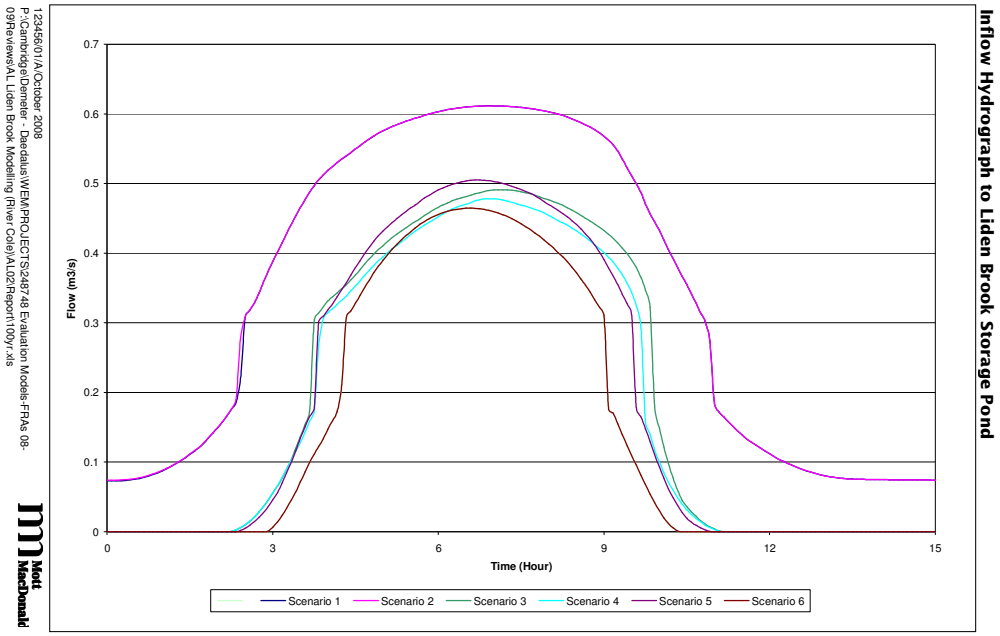


Figure A.13: Flow Hydrographs at the Outlet unit (Liden.02) for all Scenarios – 100 Year Return Period Flood Event

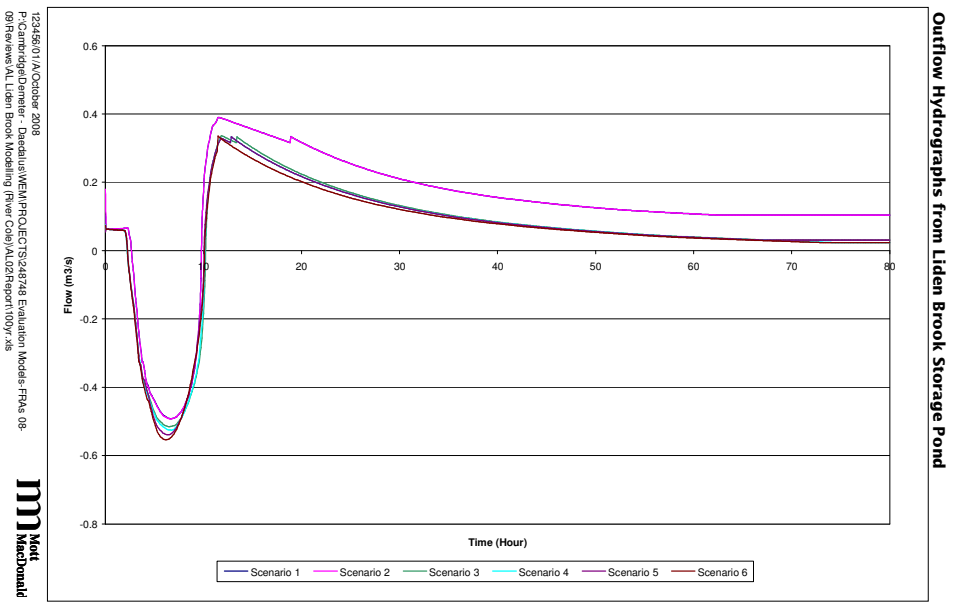


Figure A.14: Flow Hydrographs at the Inlet unit (Lid.in) for all Scenarios – 100+20% Year Return Period Flood Event

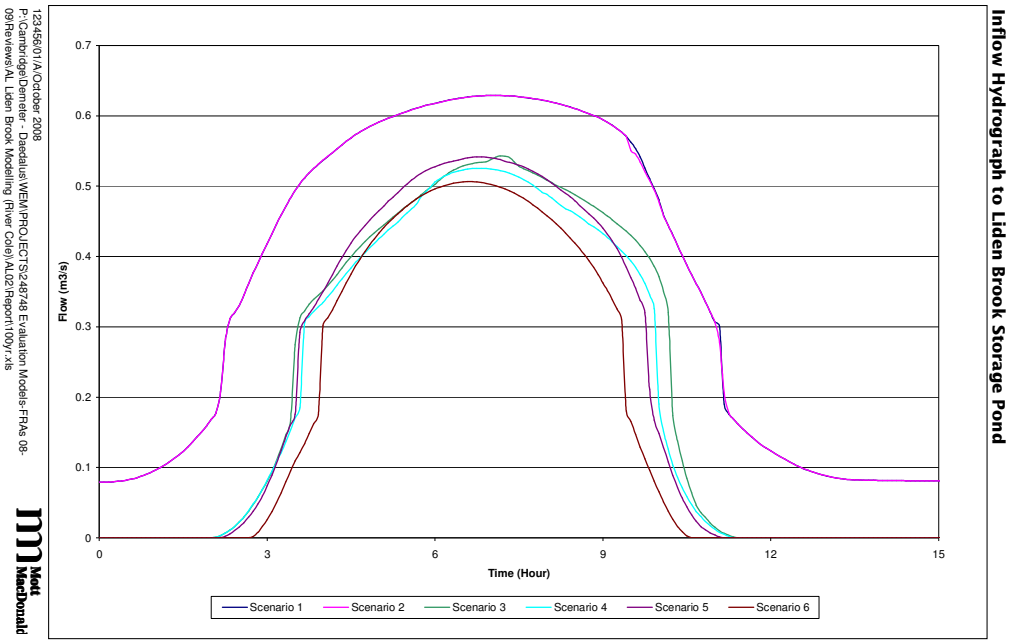
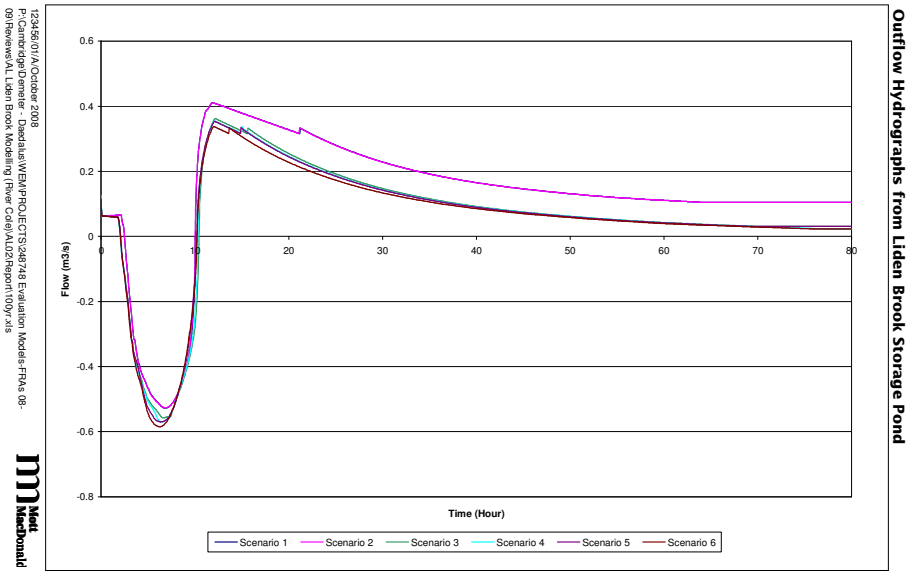


Figure A.15: Flow Hydrographs at the Outlet unit (Liden.02) for all Scenarios – 100+20% Year Return Period Flood Event



Appendix B

B.1 Flood Events

Table B.1: Peak Flow Magnitudes at Inlet and Outlet Units of Liden Brook Storage Pond

Flood Event	Scenario	Inflow to Storage Pond (Lid.in) (m^3/s)	Outflow from Storage Pond (Liden.02) (m^3/s)
5 Year	1	0.503	0.269
	2	0.503	0.272
	3	0.308	0.180
	4	0.175	0.170
	5	0.304	0.182
	6	0.118	0.158
20 Year	1	0.568	0.334
	2	0.570	0.335
	3	0.404	0.276
	4	0.382	0.261
	5	0.412	0.266
	6	0.358	0.242
50 Year	1	0.596	0.369
	2	0.596	0.368
	3	0.455	0.333
	4	0.437	0.323
	5	0.467	0.325
	6	0.425	0.300
100 Year	1	0.612	0.390
	2	0.612	0.390
	3	0.491	0.337
	4	0.478	0.333
	5	0.505	0.333
	6	0.465	0.335
100+20% Year	1	0.629	0.412
	2	0.629	0.411
	3	0.543	0.362
	4	0.525	0.355
	5	0.542	0.354
	6	0.506	0.338

B.2 Low and Mean Flows

Table B.2: Flow Magnitudes in the Vicinity of Liden Brook Storage Pond

Flow Design Event	Scenario	Inflow to Storage Pond (Lid.in) (m^3/s)	Outflow from Storage Pond (Liden.02) (m^3/s)
Low Flow	1	0.040	0.063
	2	0.040	0.063
	3	0.000	0.031
	4	0.000	0.023
	5	0.000	0.031
	6	0.000	0.023
Mean Flow	1	0.137	0.113
	2	0.137	0.113
	3	0.000	0.011
	4	0.000	0.023
	5	0.000	0.011
	6	0.000	0.023

Appendix C

C.1 Maximum Water Levels – Flood Events

Figure C.16: Maximum Water Levels between LID.061 to LID.032 for all Scenarios – 5 Year Return Period

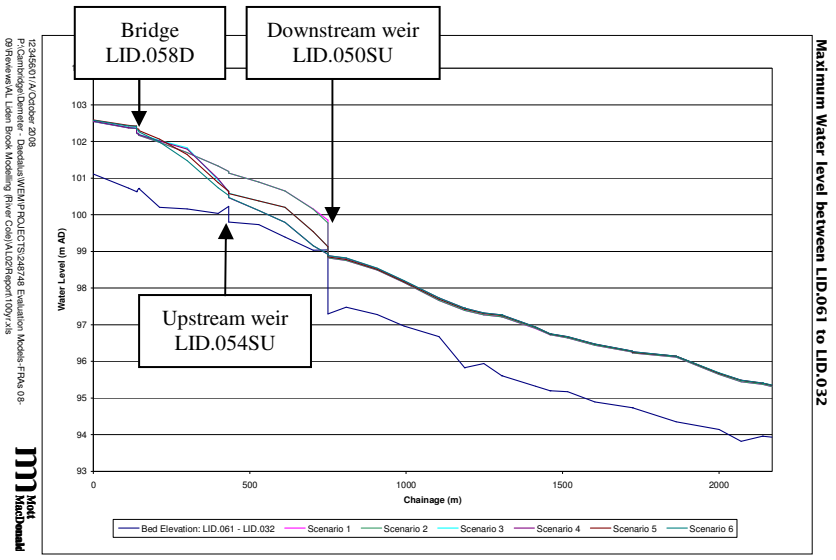


Figure C.17: Maximum Water Levels between LID.061 to LID.049 for all Scenarios – 5 Year Return Period

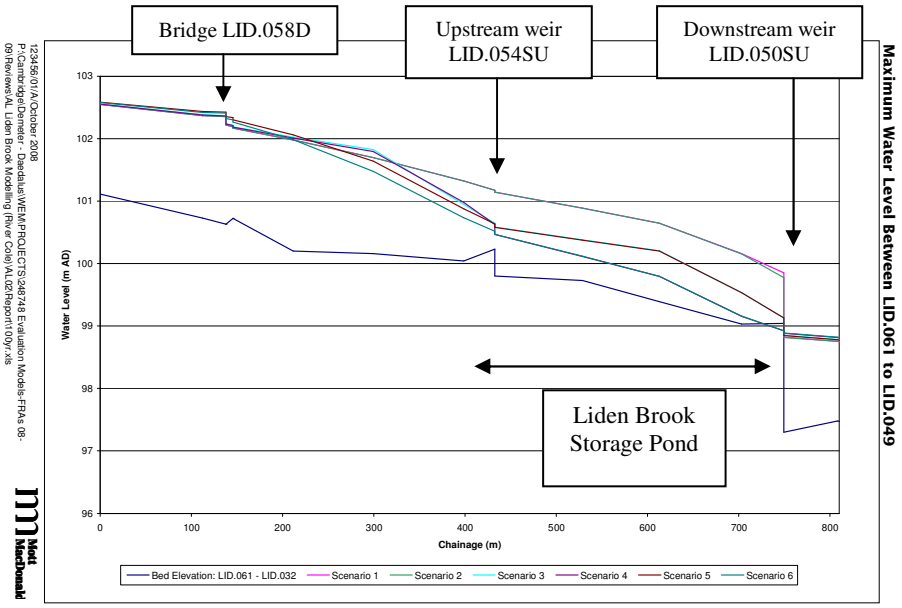


Figure C.18: Maximum Water Levels between LID.061 to LID.032 for all Scenarios – 20 Year Return Period

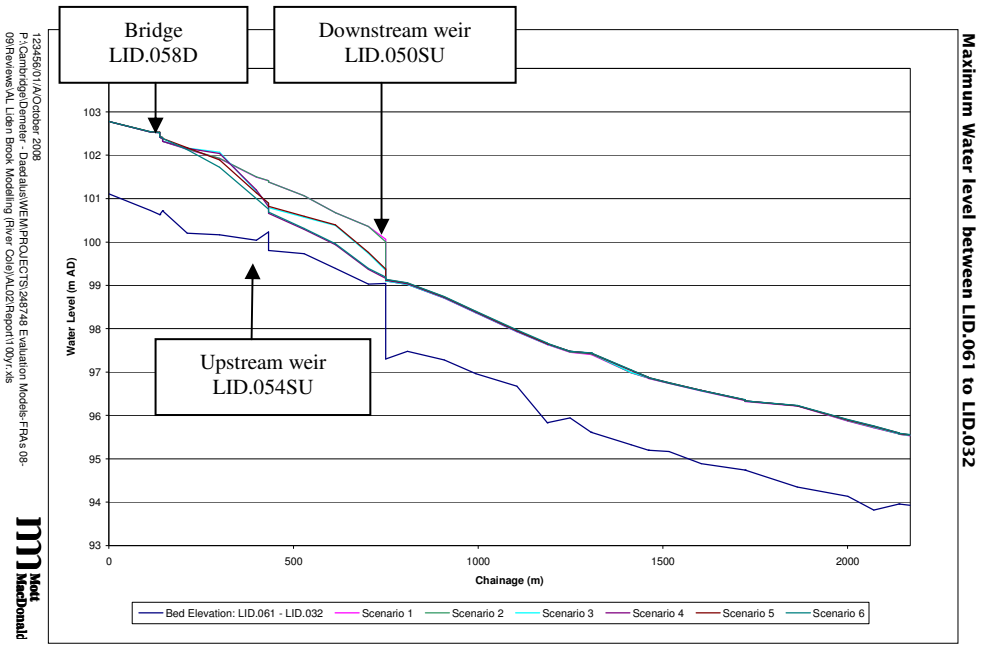


Figure C.19: Maximum Water Levels between LID.061 to LID.049 for all Scenarios – 20 Year Return Period

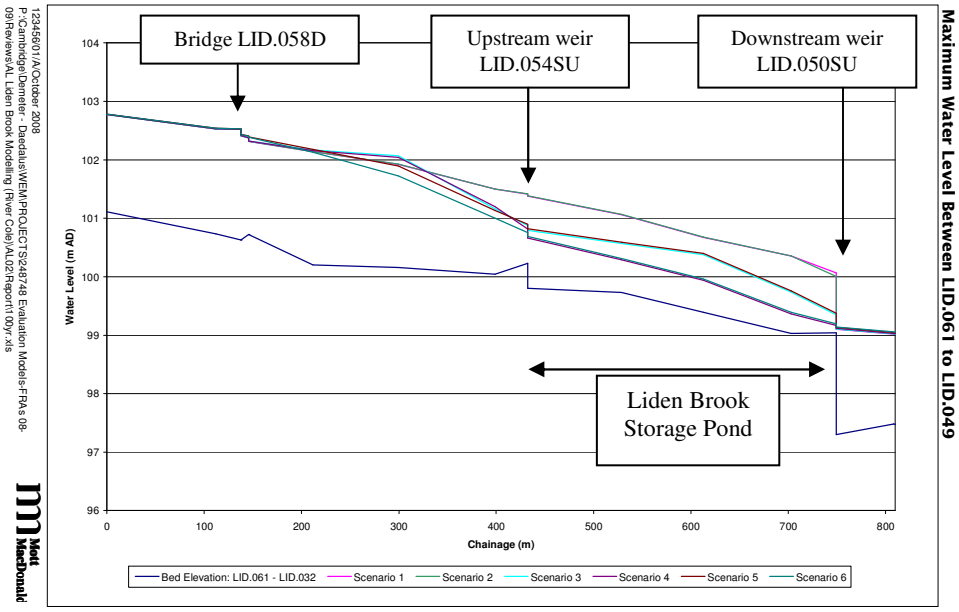


Figure C.20: Maximum Water Levels between LID.061 to LID.032 for all Scenarios – 50 Year Return Period

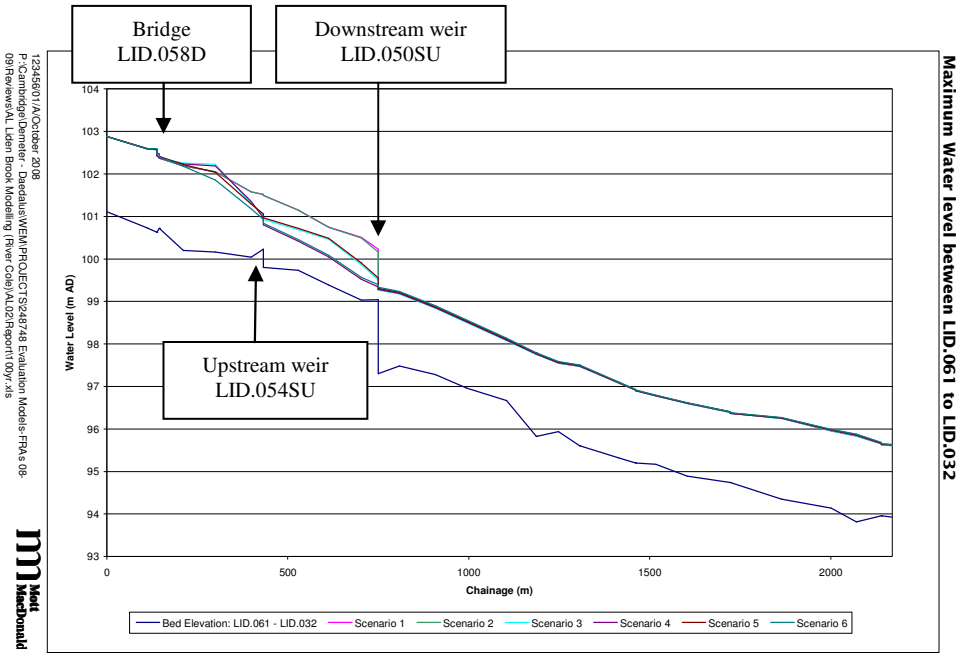


Figure C.21: Maximum Water Levels between LID.061 to LID.049 for all Scenarios – 50 Year Return Period

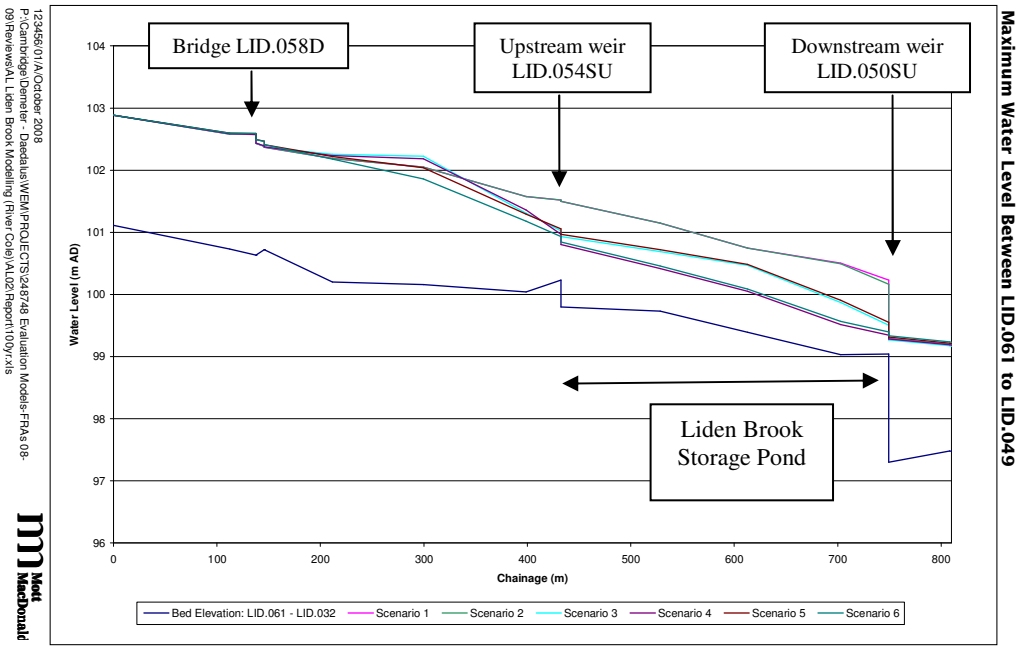


Figure C.22: Maximum Water Levels between LID.061 to LID.032 for all Scenarios – 100 Year Return Period

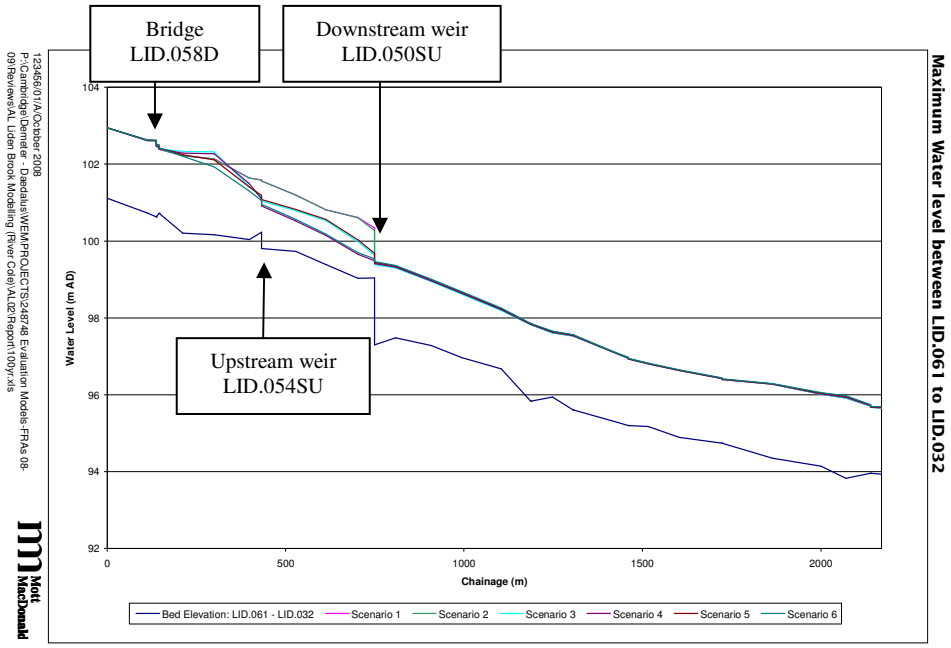


Figure C.23: Maximum Water Levels between LID.061 to LID.049 for all Scenarios – 100 Year Return Period

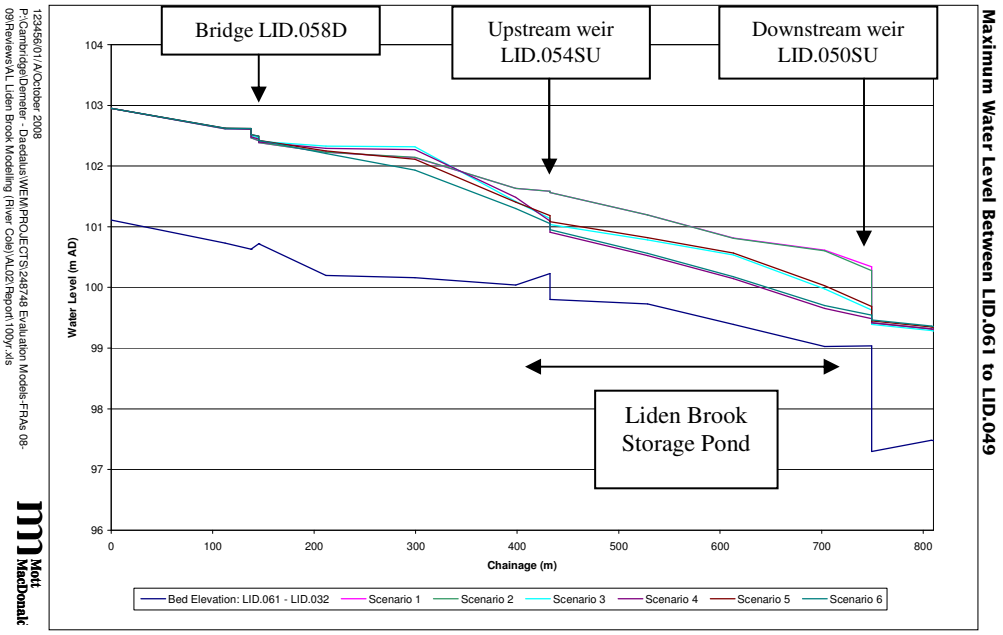


Figure C.24: Maximum Water Levels between LID.061 to LID.032 for all Scenarios – 100+20% Year Return Period

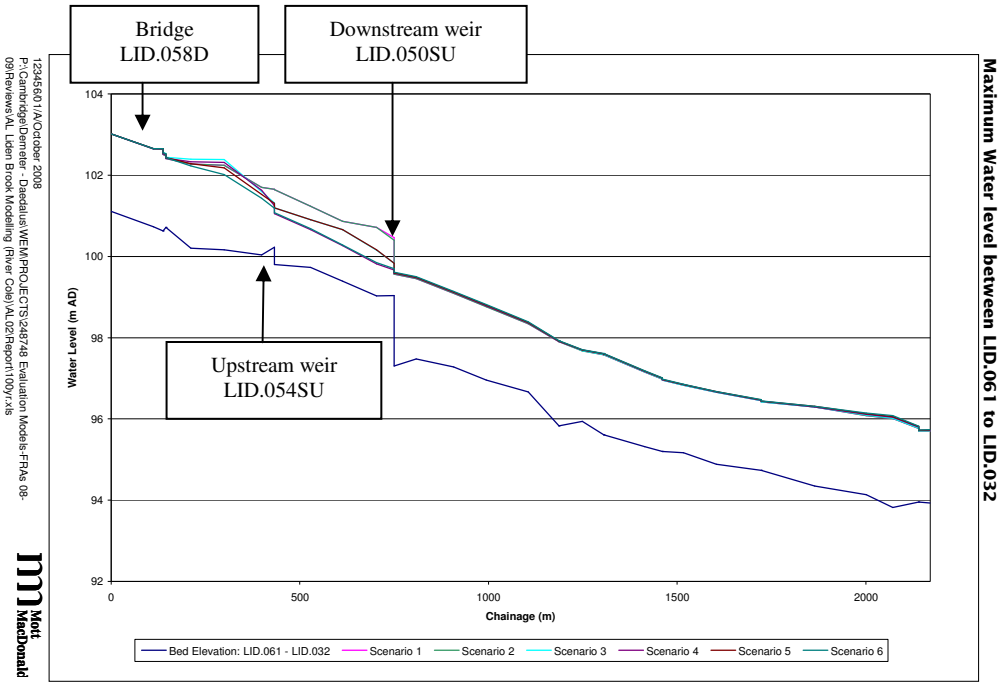
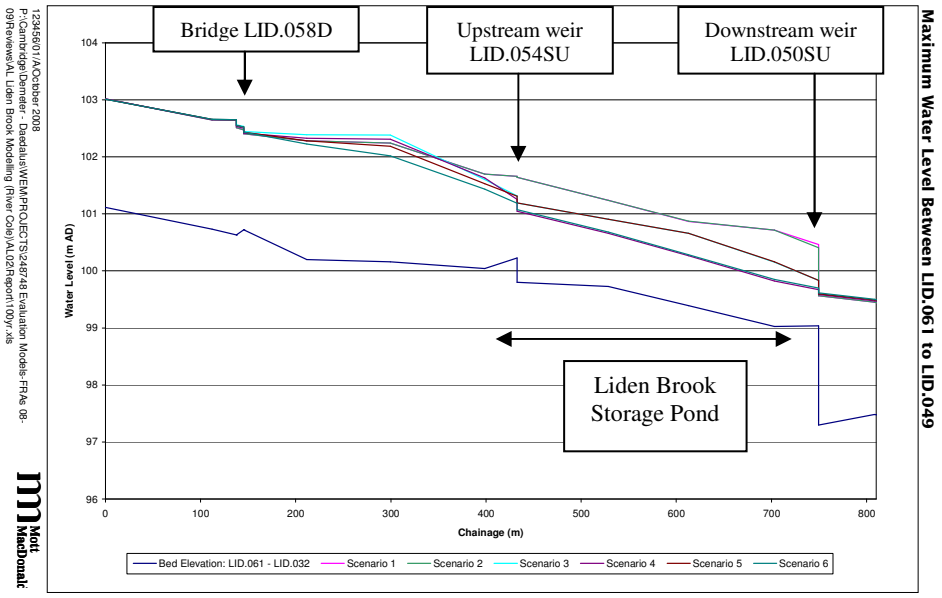


Figure C.25: Maximum Water Levels between LID.061 to LID.049 for all Scenarios – 100+20% Year Return Period



C.2 Maximum Water Levels – Mean and Low Flows

Figure C.26: Maximum Water Levels between LID.061 to LID.032 for all Scenarios – Low Flow

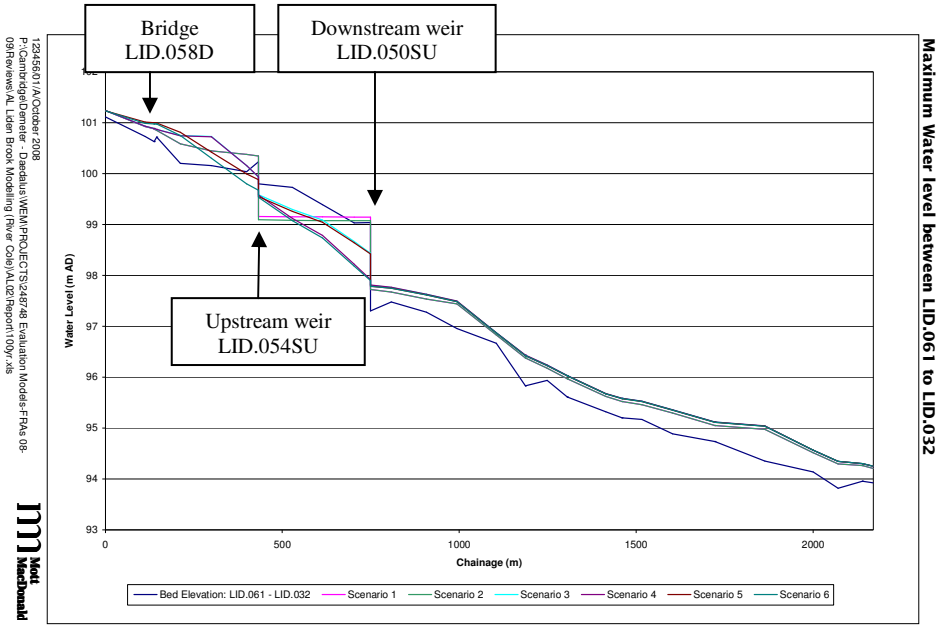


Figure C.27: Maximum Water Levels between LID.061 to LID.049 for all Scenarios – Low Flow

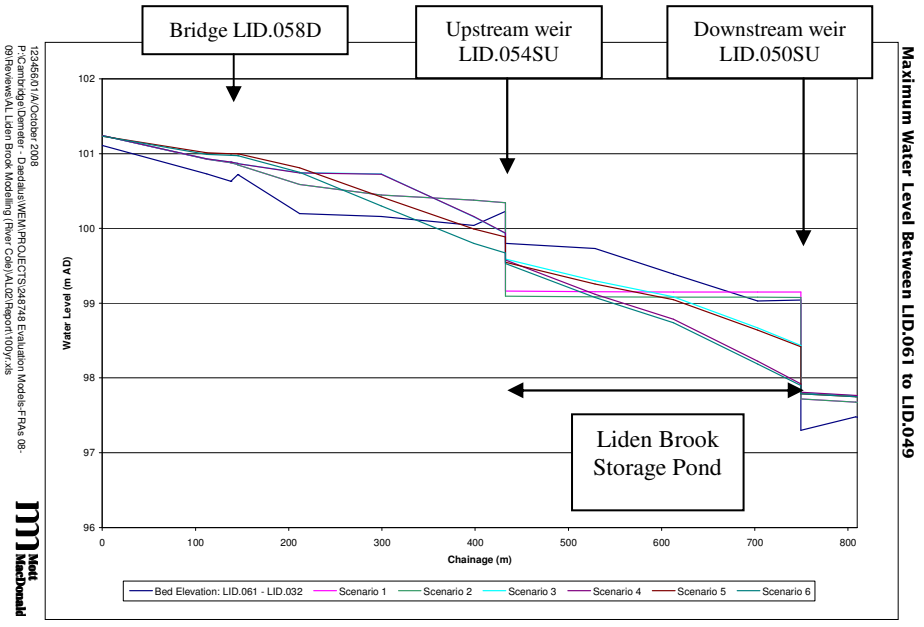


Figure C.28: Maximum Water Levels between LID.061 to LID.032 for all Scenarios – Mean Flow

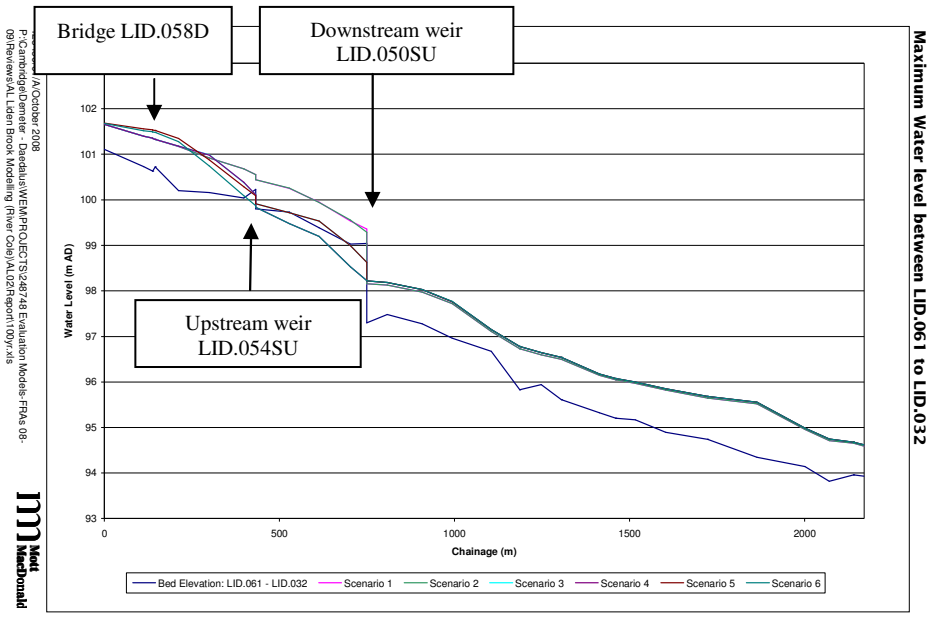


Figure C.29: Maximum Water Levels between LID.061 to LID.049 for all Scenarios – Mean Flow

