Appendix F

River Bank Concept Design

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1 Introduction

Cardno has been engaged by Penrith Lakes Development Corporation (PLDC) to undertake flood modelling and analysis of the river bank of the Nepean River bordering the Penrith Lakes site. This report details the analysis of the river bank from Main Weir (Weir 1) to Hunts Gully. The analysis is concerned with peak velocities over the river bank, and the protection works required. Preliminary costings are provided for the discussed options.

2 Background

of this model are provided in our previous report (Cardno Lawson Treloar, December 2009.

As part of the analysis of the river bank area additional SOBEK models have been created. These include:

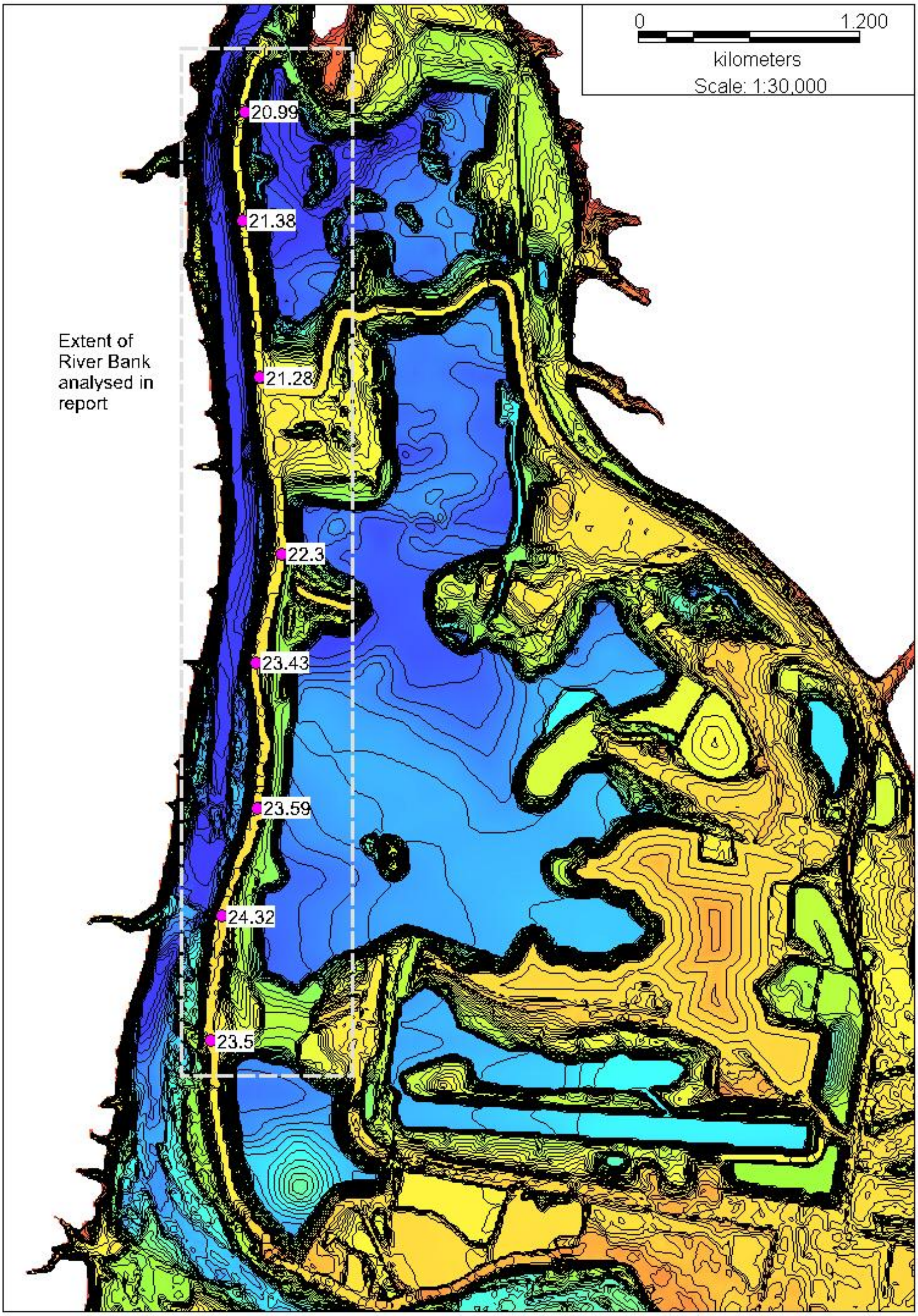
- 2D Preliminary design scenario using terrain supplied by PLDC (091030_Two Lakes V13d_triangles.dwg, received 30/10/09). The model utilises a 15m grid.
- An additional small scale detailed 2D model which focuses on the river bank to provide faster testing of options and greater resolution. The model utilises a 5m grid.

3 Base 2D Case

The Penrith Lakes development area borders the Nepean River along its southern and western sides, a distance of approximately 5.7km. This report is concerned with the western boundary, from the downstream end of Main Weir (Weir 1), to the northern end of the Wildlife Lake (refer **Figure**).

The bank level is highest near the Quarantine Weir (24mAHD) and steadily falls to approximately 21mAHD near hunts gully. This area and selected levels are shown in **Figure 1**.

In the preliminary design scenario, the 200yr event overtops the bank for almost the entire length of the PLDC boundary. The only area that is not is overtopped is a section at the upstream end of Main Lake (refer **Figure 2**).


0
1,200
kilometers
Scale: 1:30,000
Extent of
River Bank
analysed in
report
20.99
21.38
21.28
22.3
23.43
23.59
24.32
23.5

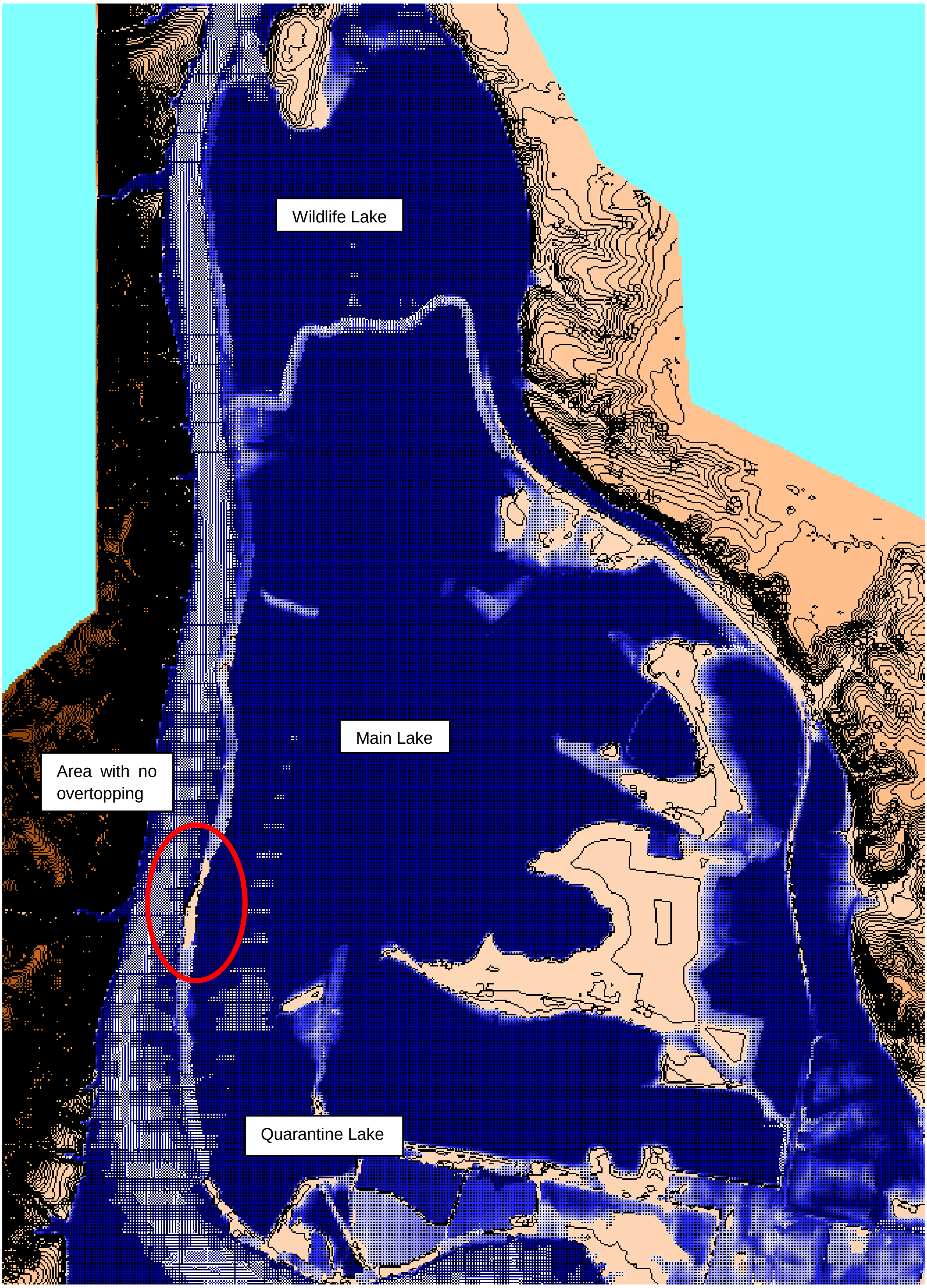


Figure 2: Overtopping of river bank in 200yr event (from SOBEK)

4 2D Weir Model

An additional model was constructed to model the flows over the river bank. The model provides greater definition of the velocity profile over the river bank, and allows different crest heights to be tested quickly, without the need to run the full 2D model of the lakes scheme. This model was based on the model that was established to test Weir 6 (Main to Wildlife weir). It utilises a 5m grid to provide greater definition of the flow behaviours. The model structure is shown in **Figure 3**.

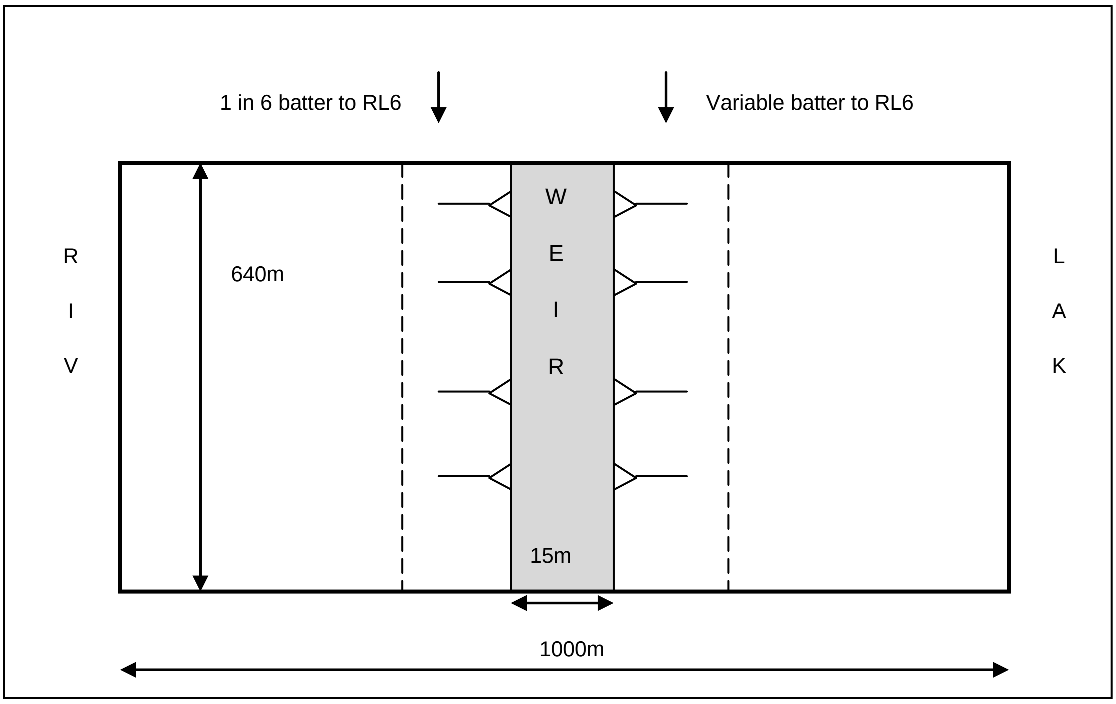


Figure 3: 2D Weir Model Layout

The model represents a generic cross section across the river bank. The river and lake boundaries are modelled as water level time series, taken from the full 2D model at points adjacent to the bank crest. The crest of the weir was set at RL21. To model the different locations, the water level time series was shifted so that the difference to the weir crest was consistent.

The analysis focuses on a 200yr ARI event, as overtopping is limited in the 100yr event. The analysis was first done with a batter slope to the lake of 1 in 10. A batter slope of 1 in 6 was also tested, and it was found that the slope did not significantly affect the peak velocity (refer **Table 1**). A batter slope of 1 in 10 was adopted for the concept design.

Table 1: Effect of changing batter slope on peak velocity

	US Main	Middle Main	DS Main	US Wildlife	DS Wildlife
1 in 10	1.90	1.93	1.84	1.91	1.97
1 in 6	1.92	1.93	1.85	1.93	1.99
Difference	1.00%	0.00%	0.43%	1.10%	0.76%

5 River Bank Analysis

To analyse the flow over the river bank, 5 points were chosen along the length to examine in detail. These locations are shown in **Figure 4**.

For each location, water level time series were extracted from the large 2D model within the river and the lakes adjacent to the location. These time series were then adjusted, and inputted into the 2D weir model in order to determine the velocities over the bank at that location.

Note that it is unlikely that the top of the riverbank would be irrigated, so it would be possible that poor to normal grass cover would be present in an overtopping event. Using CIRIA (CIRIA, 1985), we have assumed that:

- Poor Grass <1 m/s
- Good Grass 1-2 m/s
- Reinforced Grass 2-3 m/s
- RCC > 3m/s

This is based on the velocities being fairly constant during an overtopping event. In a 200yr event, the duration of overtopping is in the order of 20-24hrs.

The results of the analysis are summarised below in **Table 2**. Velocity longsections at each location are included in **Appendix A**. Note that the chainage is taken from the lip of the weir crest on the river side, that the weir crest runs from CH0 to CH15, and that the DS Main values are negative as the flow runs from the lake to river. Note also that these velocities are indicative only.

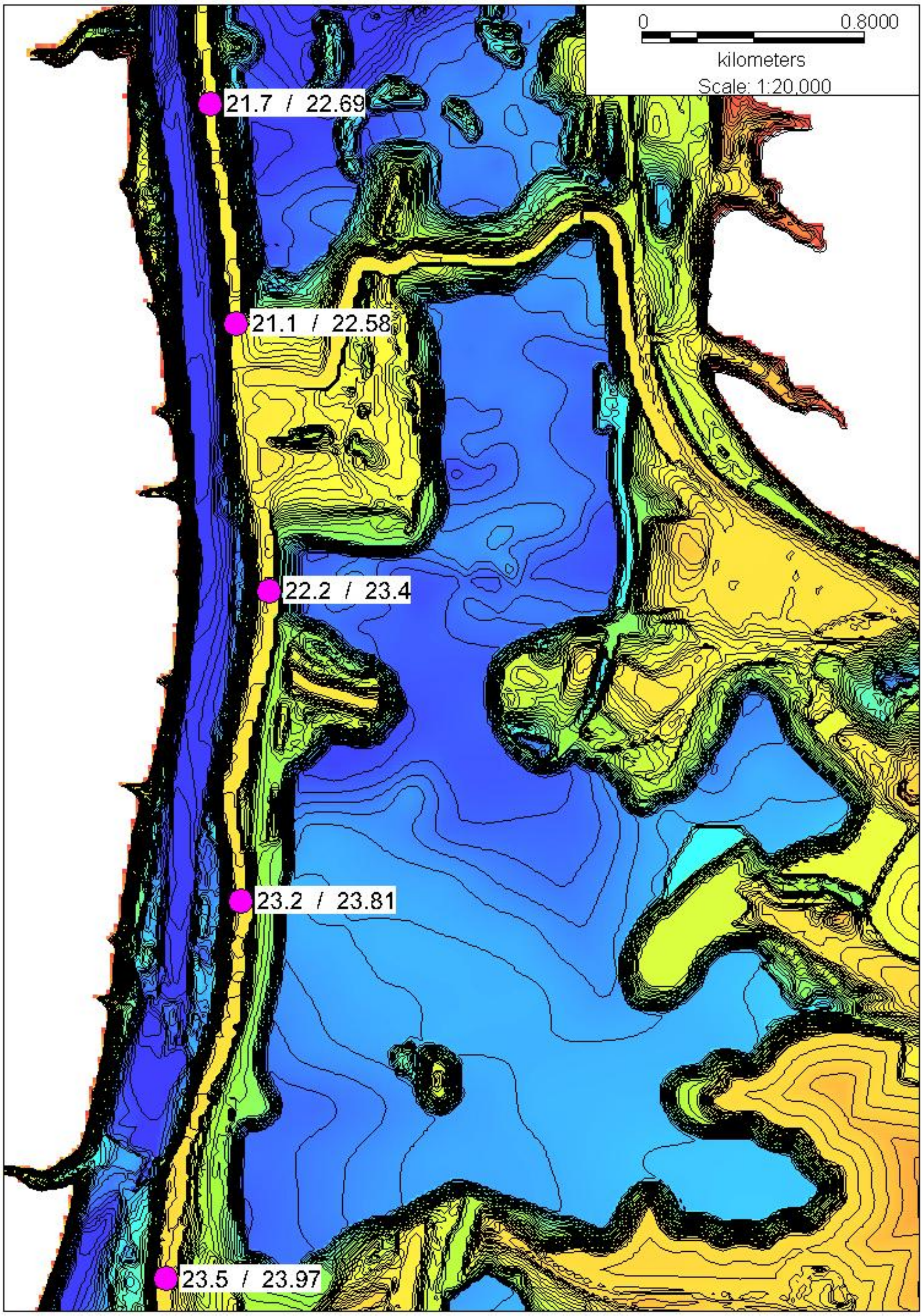


Figure 4: Analysis locations (Bank Crest mAHD / Peak Water Level over crest mAHD)

Table 2: Peak velocities across river bank in the 200yr event

Chainage	-10	-5	0	5	10	15	20	25	30	35	40	45
US Main Crest (23.5mAHD)	0.34	0.52	1.01	1.55	1.97	2.59	2.65	1.65	0.78	0.5	0.38	0.31
Middle Main Crest (23.1mAHD)	0.39	0.58	1.08	1.62	1.99	2.34	1.92	1.03	0.63	0.47	0.38	0.32
DS Main Crest (22.1mAHD)	-0.57	-1.46	-1.84	-1.47	-1.22	-0.86	-0.56	-0.42	-0.34	-0.29	-0.25	-0.22
US Wildlife Crest (21.1mAHD)	0.87	1.15	1.68	2.21	2.54	2.88	2.62	1.59	1.13	0.93	0.8	0.71
DS Wildlife Crest (21.7mAHD)	0.57	0.81	1.3	1.75	1.94	1.97	1.56	1.04	0.77	0.62	0.52	0.45

It was observed that velocities over the river bank exceed or closely approached 2m/s at 4 of the locations – US Main, Middle Main, and US Wildlife and DS Wildlife (highlighted in red in the above table). No locations had velocities over 3m/s.

Three options were investigated to manage these velocities:

- Option 1: Provide reinforced grass protection to areas with velocities above 2m/s
- Option 2: Raise the river bank to a level that reduced velocities below 2m/s
- Option 3: Raise the river bank above the 200yr event to prevent all flow across the bank

5.1 Option 1 – Provide Protection

Option 1 proposes to retain the existing bank levels, and to provide reinforced grass protection to areas which experience flows greater than 2m/s in a 200yr event. In order to estimate the area of coverage, the reinforcement was assumed to extend half way to the next location. For the end locations, it was assumed to extend an equal distance on each side. A summary of the protection lengths and areas is shown in **Table 3**.

Table 3: River bank protection work extents

	Protection Width – Across Bank(m)	Protection Length – Along Bank (m)	Protection Area (m^2)
US Main	15	1,390	20,850
Middle Main	15	1,280	19,200
US Wildlife	20	860	17,200
DS Wildlife	10	790	7,900

5.2 Option 2 – Raise bank to reduce velocities

Raising the river bank serves to delay flow occurring between the river and the lakes until their levels are closer to one another. This reduces peak velocities and the exposed backslope of the river bank they act on. Various crest heights were tested to find the height at which no protection was required. The required crest heights and the difference to existing levels for the 3 locations with high velocities are summarised in **Table 4**.

Table 4: Required bank crest changes to reduce velocities below 2m/s in a 200yr event

	Base Design Crest Level (mAHD)	Required Crest Level (mAHD)	Change (m)
US Main	23.50	23.80	0.30
Middle Main	23.10	23.35	0.25
US Wildlife	21.10	21.90	0.80
DS Wildlife	21.70	21.90	0.20

5.3 Option 3 – Raise bank to above 200yr levels

The third option investigated was to raise the river bank for the entire length to a level above the 200yr event. This would prevent any flow from moving between the river and the lakes other than by the weirs. The required crest heights and the difference to existing levels for each location are summarised in **Table 5**.

Table 5: Required bank crest changes to prevent flow across river bank in 200yr event

	Base Design Crest Level (mAHD)	Required Crest Level (mAHD)	Change (m)
US Main	23.50	24.16	0.66
Middle Main	23.10	23.83	0.73
DS Main	22.10	23.39	1.29
US Wildlife	21.10	22.78	1.68
DS Wildlife	21.70	22.80	1.10

6 Cost Considerations

Options 2 and 3 both rely on earthworks to adjust the river bank height to manage overtopping flows. Given the greater amount of earthworks required for option 3, it is likely to be significantly more expensive than option 2.

Providing reinforced grass protection (Option 1) will likely be more expensive than the earthworks associated with Option 2, but cheaper than those associated with Option 3.

7 500yr ARI Analysis

The options were also tested for the 500yr ARI event to investigate how effective they would be in managing the increased flows. **Table 6** below summarise the peak overtopping velocities for each option in the 200yr and 500yr event.

Table 6: Peak Overtopping Velocities (m/s)

	200yr Option 1	200yr Option 2	200yr Option 3	500yr v13d opt4	500yr Option 2	500yr Option 3
US Main	2.6	1.9	0.0	3.3	2.9	2.5
Middle Main	1.3	1.9	0.0	2.7	2.5	2.0
DS Main	1.8	1.8	0.0	1.2	1.2	0.8
US Wildlife	2.9	1.9	0.0	3.1	2.0	0.7
DS Wildlife	2.0	1.8	0.0	1.7	1.4	1.0

Outlined in **Table 7** are the protection extents required for each option in the 200yr and 500yr event. The results suggest that additional protection in the 500yr event is only required along the upstream banks of the Main Lake and Wildlife Lake. Elsewhere along the river bank, the 200yr protection measures provide sufficient protection in the 500yr event as well.

Note that all protection extents are for reinforced grass unless otherwise indicated.

Table 7: Required protection extents over river bank for 500yr event (m)

	200yr Option 1	200yr Option 2	200yr Option 3	500yr v13d opt4	500yr Option 2	500yr Option 3
US Main	15	0	0	25 (inc. 10m RCC)	20	15
Middle Main	15	0	0	20	20	5
DS Main	0	0	0	0	0	0
US Wildlife	20	0	0	25 (inc. 10m RCC)	5	0
DS Wildlife	10	0	0	0	0	0

7.1 Option 4 – Raise banks to reduce velocity in 500yr event

Similar to options 2 and 3 for the 200yr event, it was also tested how high the bank would need to be raised above existing levels to reduce overtopping velocities to less than 2m/s in the 500yr event. The results of this analysis are shown in **Table 8**.

Table 8: Required bank crest changes to reduce velocities below 2m/s in the 500yr event

	Base Design Crest Level (mAHD)	Required Crest Level (mAHD)	Change (m)
US Main	23.50	24.55	1.05
Middle Main	23.10	23.95	0.85
US Wildlife	21.1	22.78	1.68
DS Wildlife	21.70	21.90	0.20

8 Impacts of Proposed Options

The options proposed above have minor impacts. **Table 9** details 200yr event water levels at various locations in the PLDC area, and also shows the level difference at these locations compared to the base case.

It was observed that all options resulted in water level reductions in the Nepean River, and in Emu Plains and Penrith CBD compared to the base case. However, compared to the current design (v13d opt4), raising the river bank resulted in slight increases in Emu Plains and Penrith CBD, and a rise in water levels in the Nepean river upstream of the wildlife lake, alongside Main Lake and Quarantine Lake.

The proposed options also result in a minor increase in levels in the vicinity of the eastern lakes in the 200 year ARI event, in the order of 0.01 metres. However, this is minimal in comparison to the existing impacts in that area under the current 13d opt 4 design.

Table 9: Water Levels and Level Difference for Options in the 200yr event

		Option 1		Option 2		Option 3	
	Base case	Level (mAHD)	Difference (m)	Level (mAHD)	Difference (m)	Level (mAHD)	Difference (m)
Penrith CBD	27.02	26.86	-0.16	26.88	-0.14	26.89	-0.13
Emu Plains	25.41	24.63	-0.78	24.68	-0.73	24.75	-0.66
River at Quarantine Lake	25.22	24.42	-0.80	24.48	-0.74	24.54	-0.68
Main Lake	22.76	23.41	0.65	23.40	0.64	23.39	0.63
Wildlife Lake	22.57	22.61	0.04	22.62	0.05	22.55	-0.02
River at Hunts Gully	22.22	22.13	-0.09	22.13	-0.09	22.13	-0.09

9 River Bank Recommendations

Based on the above analysis, the recommended option is Option 2, raised banks to reduce velocities in the 200yr event. This option is the able to provide satisfactorily reduced flow velocities in the 200yr event, and is the lowest cost option based on preliminary estimates.

If protection up to the 500yr event is required, this option again represents the most cost effective way of managing bank velocities.

River bank levels for Option 2 are shown in **Figure 5**.

Note that the river bank requires “good grass” to provide protection. If irrigation is not going to be applied to this area, it is recommended that reinforcement be provided to stabilise the poor cover.

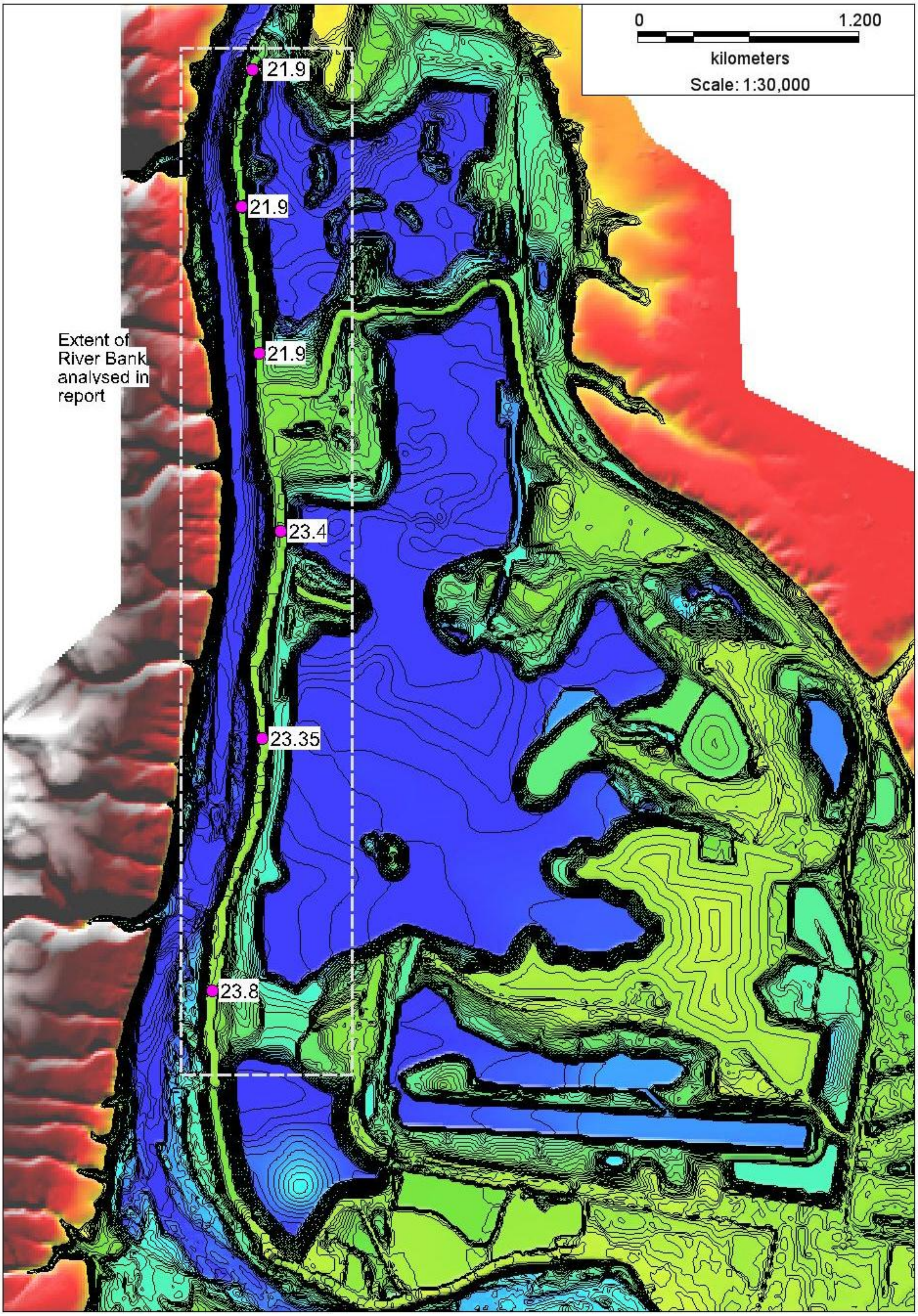


Figure 5: Option 2 River Bank Levels (mAHD)

10 Qualifications

The following qualifications apply to this report:

- The attached sketches are concept designs only, and would require detailed design at a later stage.
- No geotechnical analysis has been consulted in the preparation of this report. Only a broad appreciation of the soil types has been considered.
- The results presented in this report are based on the current design for the Penrith Lakes Development. Any changes to this design may result in different flow behaviour across the Regatta Lake weir and therefore may require different options for energy dissipation and scour protection.

11 References

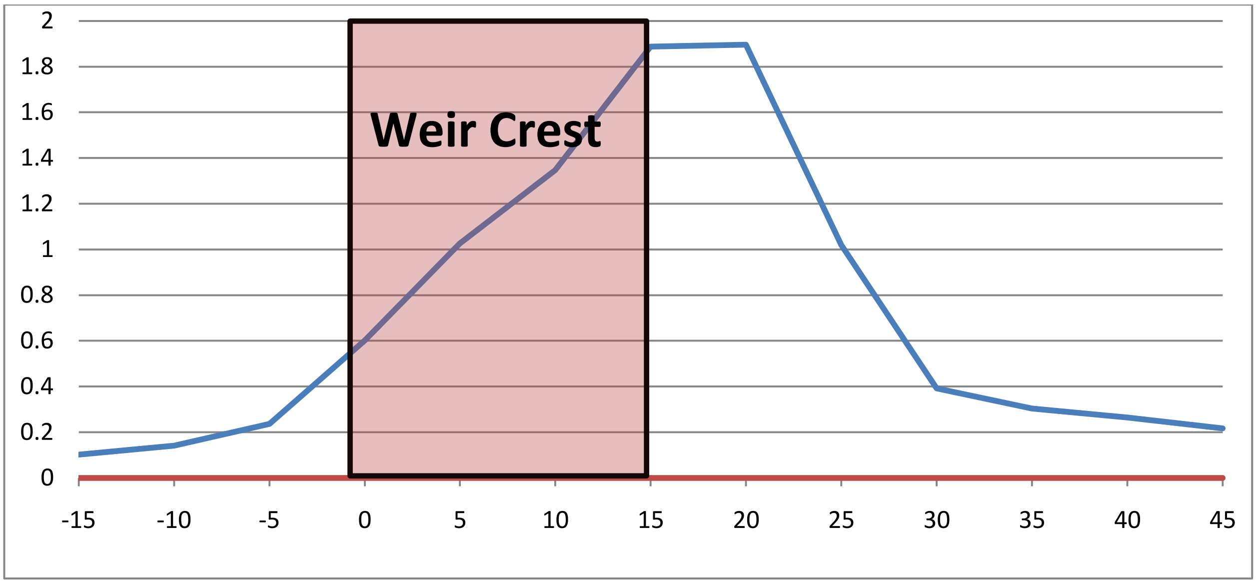
Cardno Lawson Treloar (2009). *Penrith Lakes Flood Modelling: Model Calibration and Verification*, December, prepared for Penrith Lakes Development Corporation, Final.

Cardno Lawson Treloar (2009). *Concept Design of Weir 6 (Letter)*, April, prepared for Penrith Lakes Development Corporation.

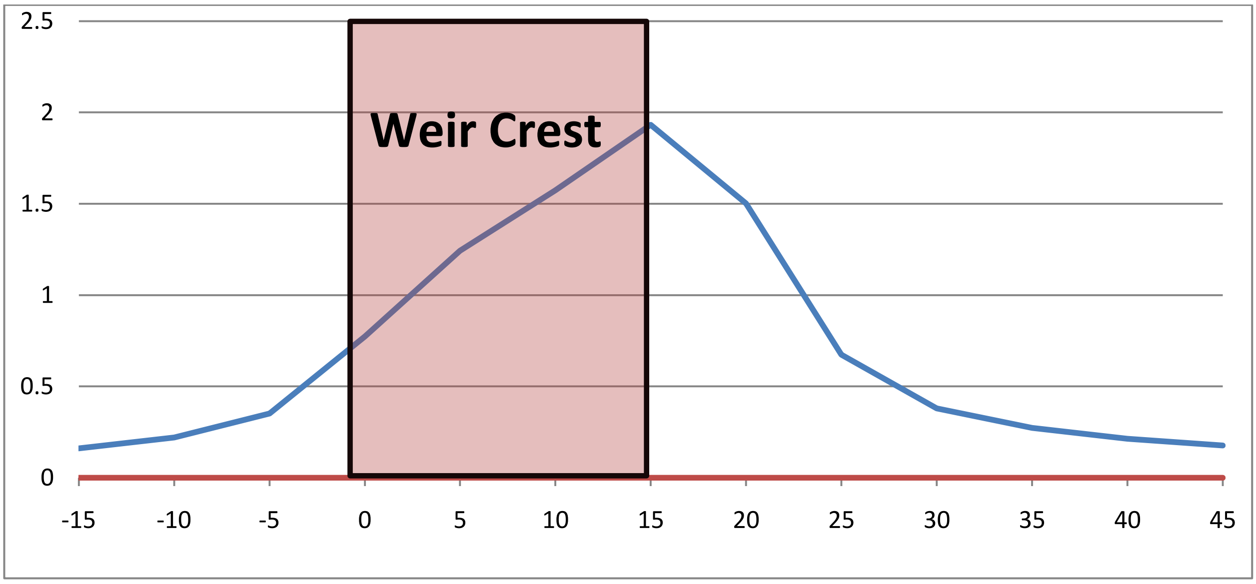
Construction Industry Research and Information Association [CIRIA] (1985). *Reinforcement of Steep Grassed Waterways: Review and Preliminary Design Recommendations*, Technical Note 120, London.

Attachment A

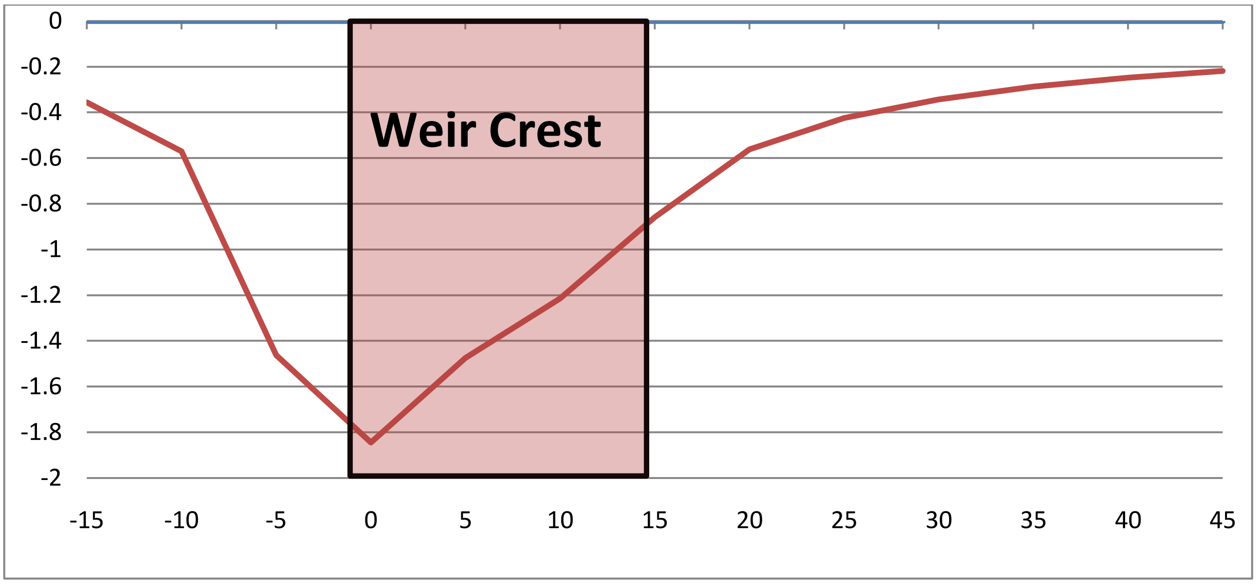
Velocity Longsections



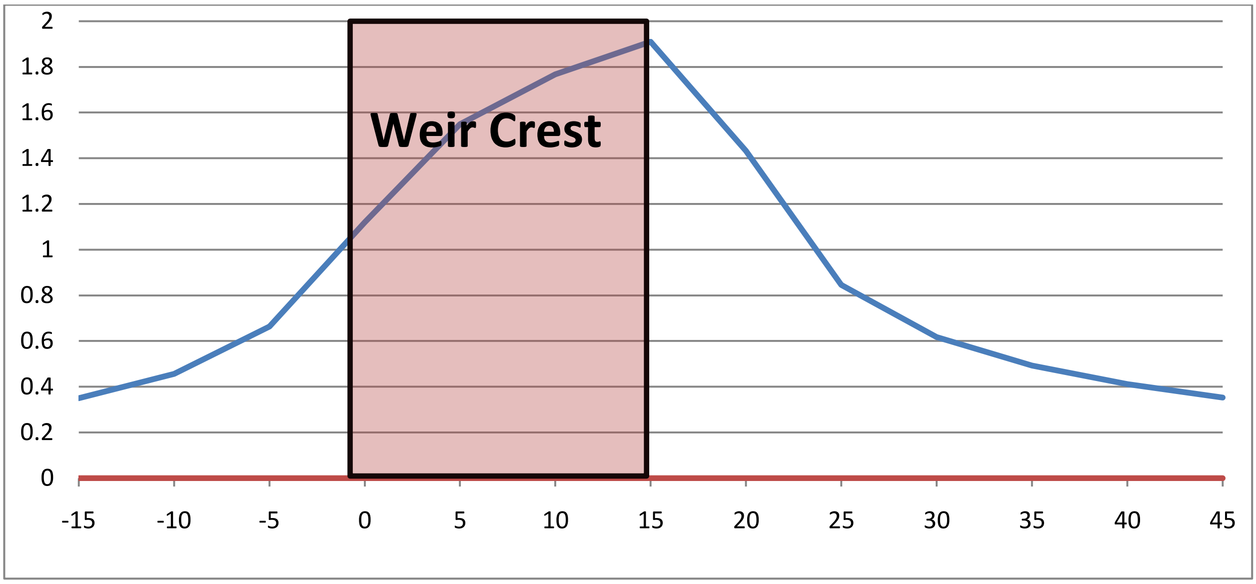
US Main Velocity Longsection



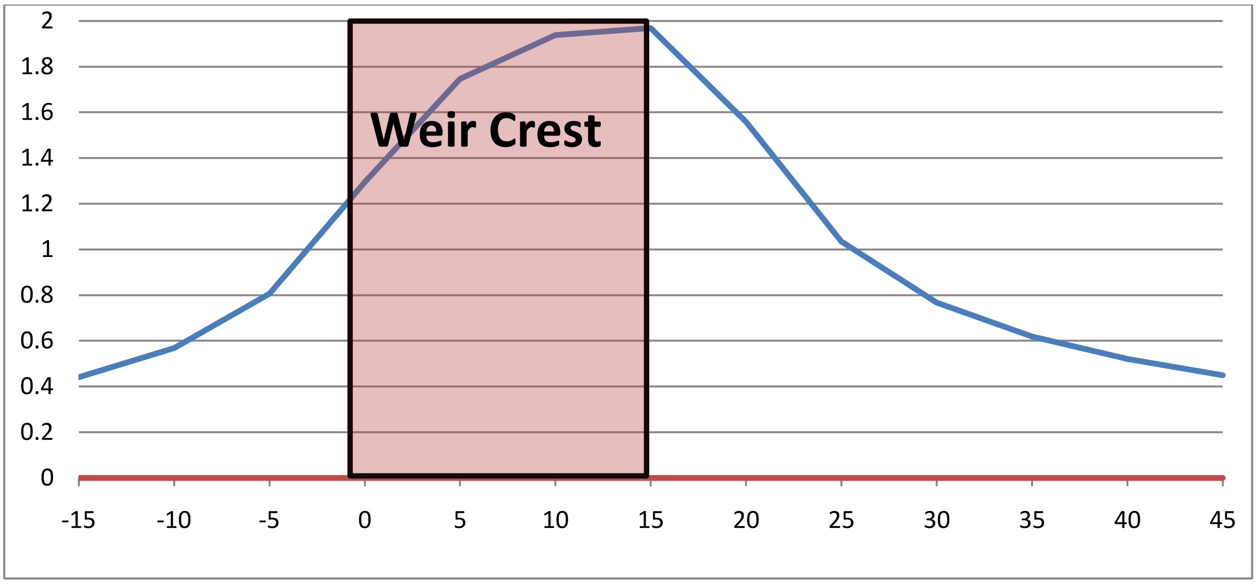
Middle Main Velocity Longsection



DS Main Velocity Longsection



US Wildlife Velocity Longsection



DS Wildlife Velocity Longsection