Cardno
Shaping the Future

Appendix D

Regatta Weir Concept Design

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1 Introduction

Cardno has been engaged by Penrith Lakes Development Corporation (PLDC) to undertake flood modelling and concept design of flood structures at Penrith Lakes. This report details the analysis of the Regatta Weir, being the weir that connects the Main Lake with the Regatta Lake. The analysis includes velocities along the flowpath, peak water level impacts and preliminary costings and concept sketches of some design options.

2 Background

As part of the analysis of the Regatta Weir additional SOBEK models have been created. These include:

- Preliminary 1D model to test different weir options and flowpath geometries to select the more suitable options for 2D modelling
- Base 2D case, terrain supplied PLDC (091030_Two Lakes V13d_triangles.dwg, received 30/10/09).
- 3 weir options modelled in 2D to analyse the velocities across the weir and along the flowpath in order to determine suitable protection requirements.

The above 2D models all utilise a 15m grid.

In addition to these models, a small scale detailed 2D model which focuses on the weir crest was created to provide greater resolution of velocities over the weir crest. 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 (Cardno Lawson Treloar 1, 2009).

3 Concept Design

In the base terrain there are two flowpaths connected to the Regatta Lake. The first runs from the Quarantine Lake via the existing 30m bridge on Old Castlereagh Road. The invert of this bridge is 18mAHD. The second flowpath connects the Regatta Lake to the Main Lake via a 50m channel, set at 16.5mAHD. **Figure 1** shows the base terrain in this area and highlights the aforementioned flowpaths.

The analysis of the Regatta Lake flowpaths had a number of aims. These included:

- Minimising weir width to reduce construction costs
- Minimising weir velocities to reduce protection works
- Utilising only one flowpath to reduce construction and protection costs
- Minimising the visual impact by reducing the amount of heavy protection (RCC) required

The critical velocities were adapted from scour velocity plots in CIRIA Report 116 (CIRIA, 1987). This plot is included in **Appendix A**. The critical velocities were adopted for selected durations of inundation and are shown in **Table 1**. These points are marked on the graph in **Appendix A**. For the 2hr peak comparison the peak velocity from the model was used, assuming conservatively that the peak velocity occurred over a 2hr period. For the average comparisons, velocities were averaged over 5, 10 and 30 hour periods. These durations were chosen to provide a reasonable range for concept design. It is recommended that these velocities be reviewed in detailed design, with input from appropriate manufactures.

Table 1: Limiting Velocities for Protection Measures

	RCC, if greater than... (m/s)	Reinforced Grass, if greater than... (m/s)	Good Grass, if greater than... (m/s)
2hr Peak	6.0	5.0	4.0
5hr Average	4.5	3.5	2.0
10hr Average	4.0	3.0	1.5
30hr Average	3.0	2.5	1.0

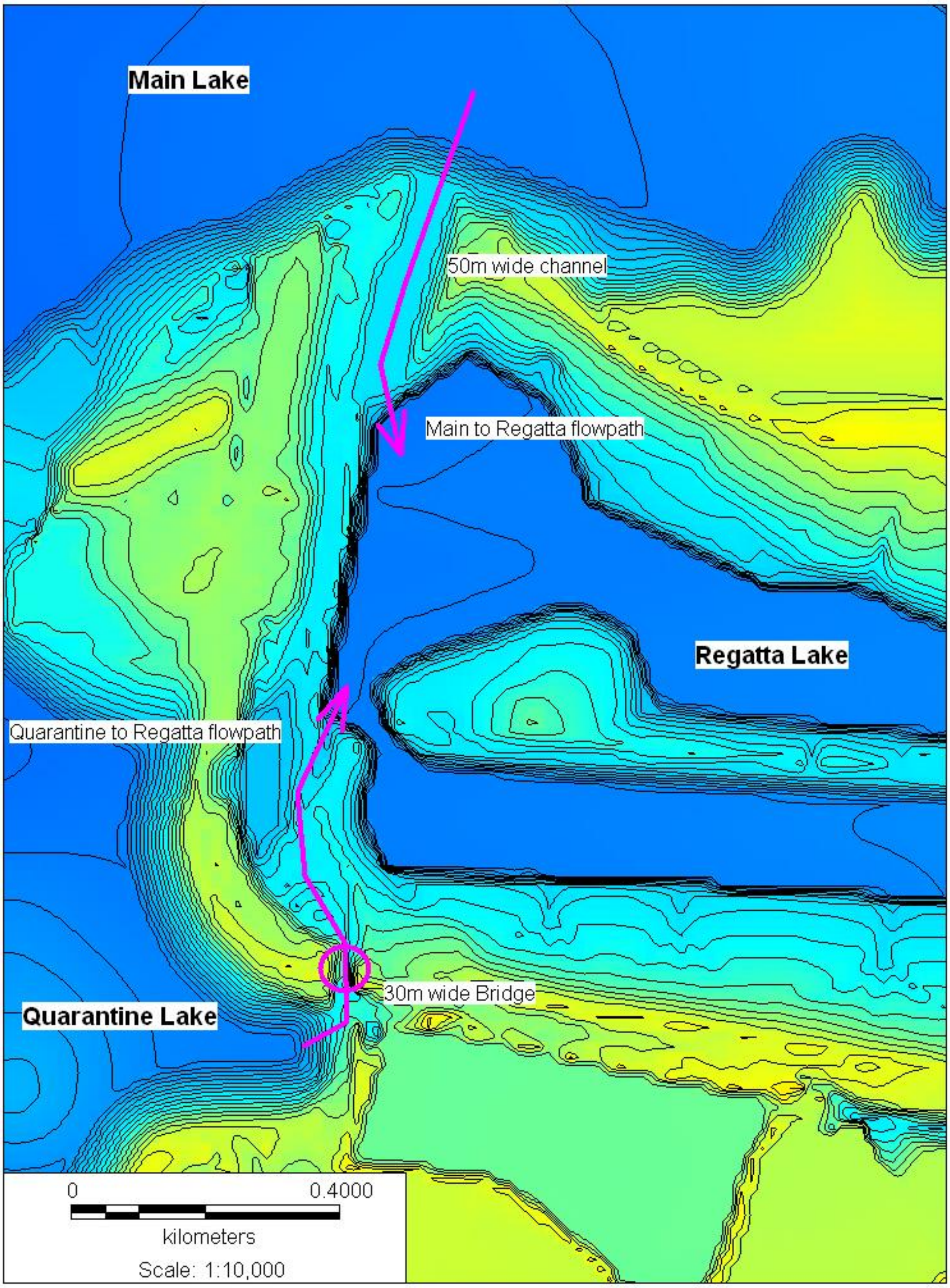


Figure 1: Terrain Details of the Regatta Lake

4 Preliminary 1D Model

4.1 Quarantine Lake to Regatta Lake Flowpath

A 1D SOBEK model was established to conduct preliminary testing on channel configurations for the regatta weir and flowpath. The model layout is shown in **Figure 2**. The purpose of the 1D model was to allow preliminary testing of different designs in order to determine which designs should be further investigated by the 2D model. The 1Dmodel was used to assess the effects of utilising individual flowpaths, the affect of channel slopes and channel geometry on the velocities within the flow path, and the peak levels and filling rates of the lakes.

Preliminary testing was undertaken using the 100yr ARI flows.

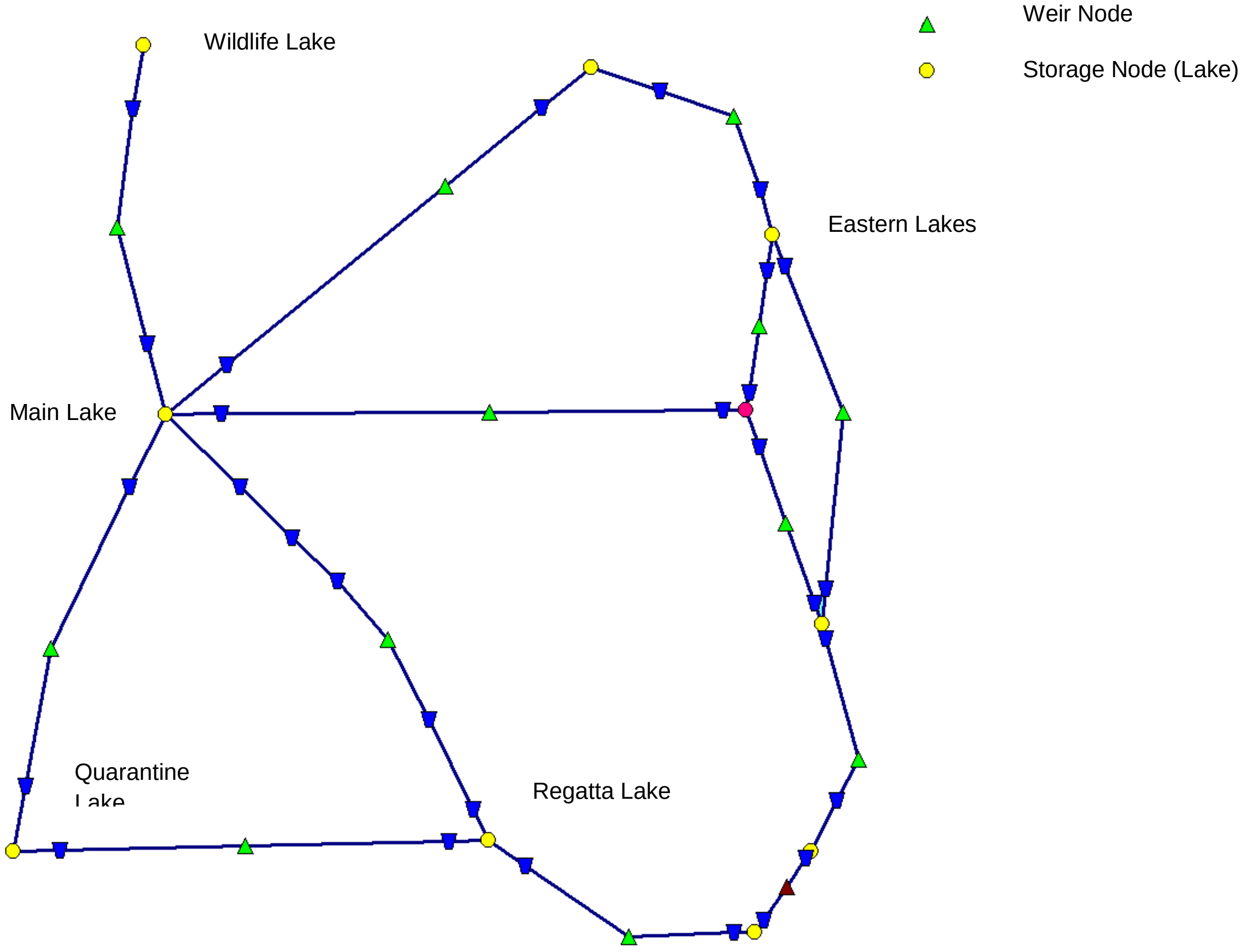


Figure 2: SOBEK 1D Model Layout

The effect of only using the Quarantine Lake to Regatta Lake flowpath was first investigated using the 1D model. During these model runs, the connection between Main Lake and Regatta Lake was closed, making the Quarantine flowpath the only connection to the Regatta Lake. The model was run for the existing 30m bridge, and then for bridge widths of 100m, 200m and 300m. The results show that the existing width is insufficient to carry the required volume into the Regatta Lake (refer **Figure 3**). The model predicts that a bridge width of 100m is required to convey the appropriate volume of flow to ensure that the filling rates of the lakes remain comparable to the design preliminary design scenario.

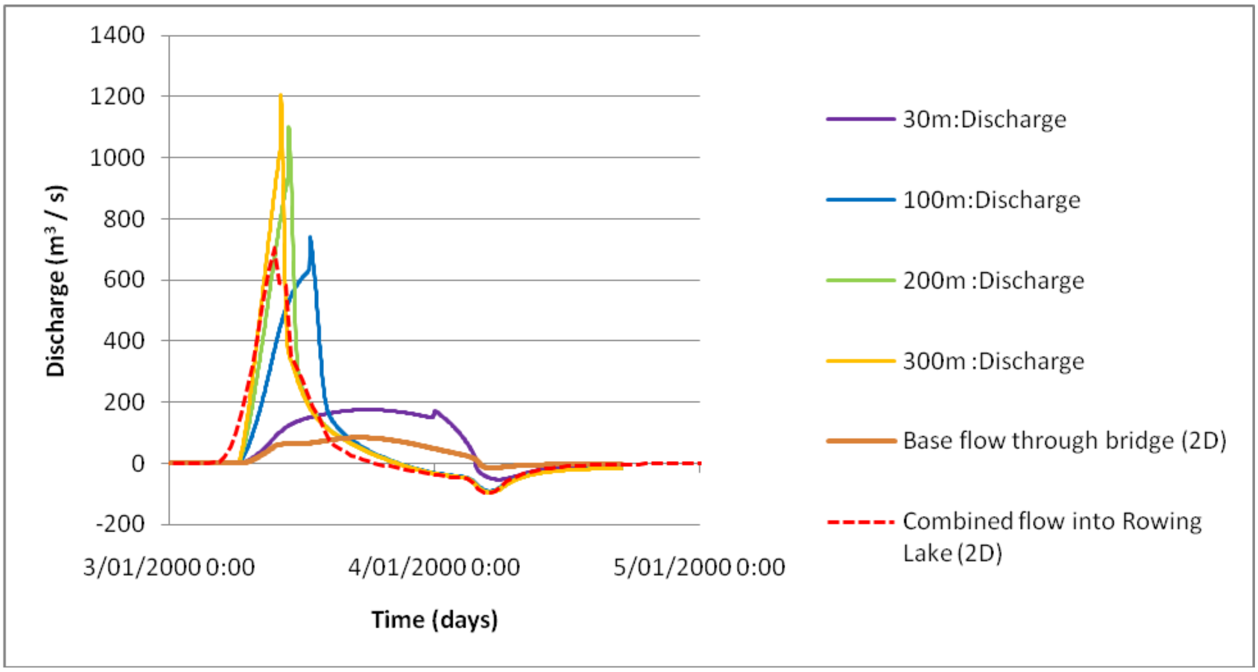


Figure 3: Discharge Time Series for Various Bridge Widths

The results also showed velocities of greater than 3m/s through the bridge. This would require RCC or reinforced concrete protection within the bridge, and likely for a length upstream and downstream.

A preliminary cost estimate for this work is in the order of \$3.5M. This is based on a rate of \$2,500/m^2 of bridge deck for bridge works. This does not include other protection works that would likely be required within the flowpath, particularly in the area between the bridge and Regatta Lake.

Due to the high cost and visual impact associated with making the bridge flowpath the sole overland route, this option was not considered viable. The analysis suggests that the final solution should utilise the flowpath between the Main Lake and the Regatta Lake.

4.2 Channel Bed Slope

The 1D model was then used to compare possible channel slope options for the Regatta Weir. Two configurations were tested. The first was a gradual, constant slope from the Main Lake to the weir crest, and a 1 in 6 fall into the Regatta Lake. The second option was a weir structure of 1 in 6 slopes on both sides, and minimal grade (0.5%) between the weir structure and the Main Lake (refer **Figure 4** & **Figure 5**). The 1 in 6 slope on the downstream edge was adopted as the maximum slope for grassed areas. If an RCC or block-work structure is incorporated at the weir, it would be possible to utilise a steeper slope.

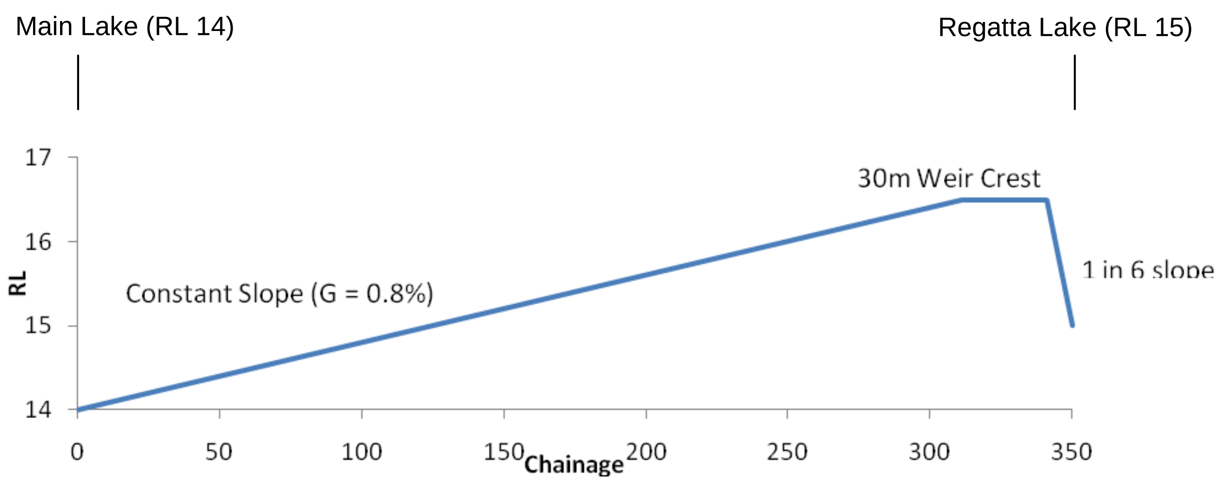


Figure 4: Option 1 Channel Grades

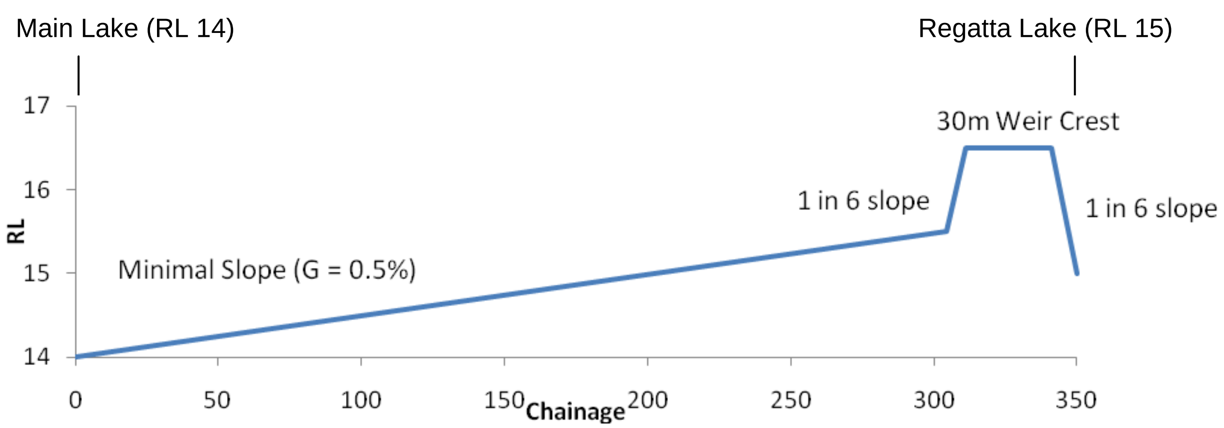


Figure 5: Option 2 Channel Grades

The results of these two options, at various chainages, are shown in **Table 2**. It was observed that there was very little difference in the two options. Option 2 has slightly lower velocities through the channel but a slightly increased velocity prior to the weir. There was no significant difference in peak water levels for the two options (refer **Table 3**).

Table 2: Peak Velocities (m/s) along the flowpath

	Ch 5	Ch 50	Ch 100	Ch 150	Ch 200	Ch 250	Ch 300	Weir
Channel Grades Option 1	1.09	1.17	1.29	1.43	1.6	1.64	1.51	4.75
Channel Grades Option 2	1.08	1.13	1.2	1.28	1.38	1.48	1.6	4.75

Table 3: Peak Water Levels (mAHD) in Selected Lakes

	Quarantine	Main	Regatta
Channel Grades Option 1	22.71	22.71	22.71
Channel Grades Option 2	22.71	22.71	22.71
Difference	0	0	0

As the options were so similar, Option 1 was adopted for the concept design. This option is likely to be easier to construct and would provide better potential for local drainage with the higher slopes.

4.3 Channel Geometry

The last variable that the 1D model was used to test was the channel geometry. A total of six different geometries were analysed (refer **Figure 6**).

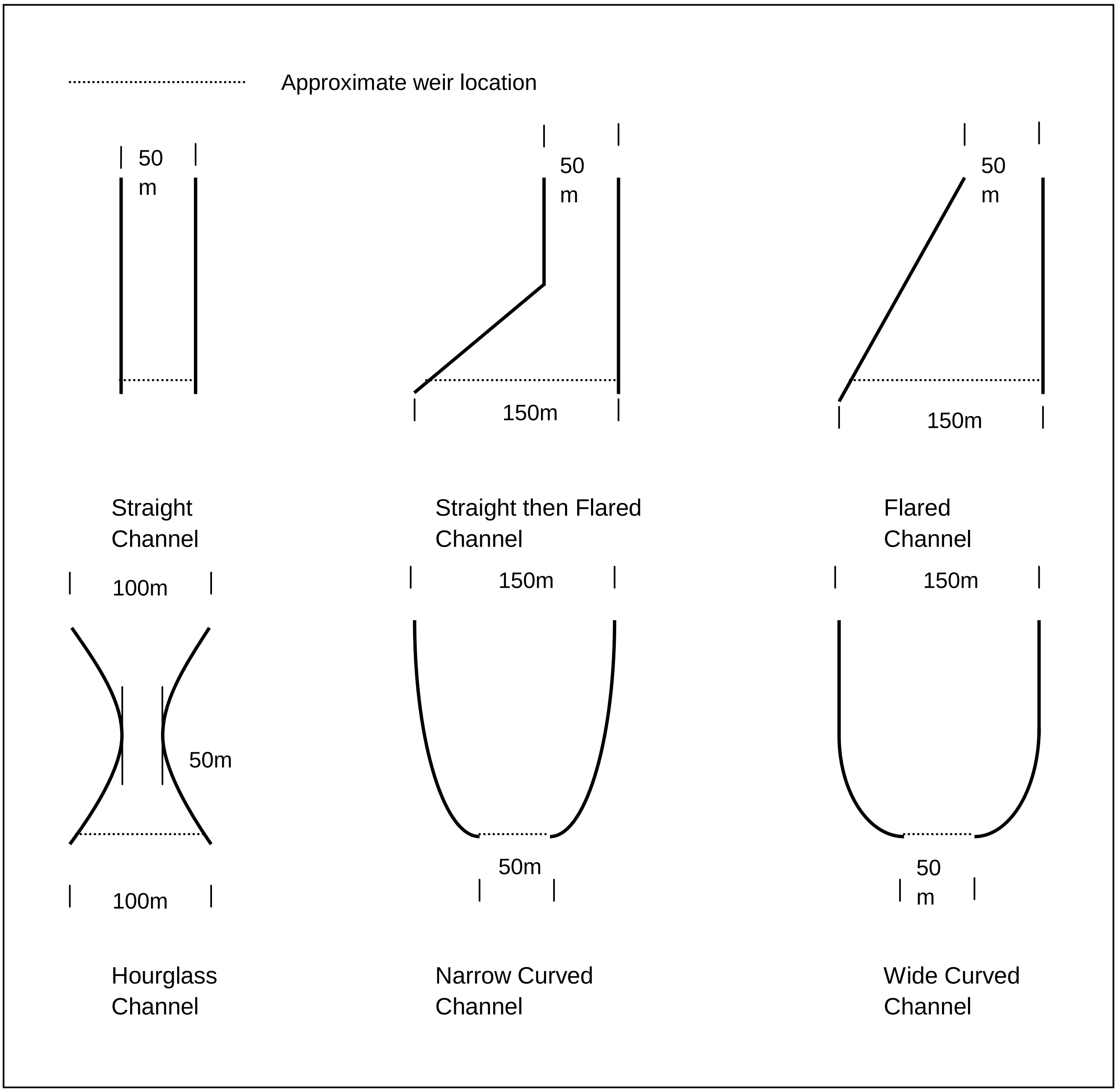


Figure 6: Channel Geometries Tested in 1D Model

A variety of channel widths were tested for the straight channel option, namely 50m, 75m, 100m and 200m. It was found that all the channels had acceptable velocities within the channel; remaining below 2m/s up until approximately 50m from the weir (refer **Table 4**). Increasing the width of the weir served to reduce the peak velocity across the weir, but even a 200m width failed to reduce the velocity to below 3m/s, and as such all options would require RCC protection along the weir crest.

Table 4: Peak Channel Velocities at 50m Intervals

Width	Ch 5	Ch 50	Ch 100	Ch 150	Ch 200	Ch 250	Ch 300	Weir
50	1.09	1.17	1.29	1.43	1.6	1.64	1.51	4.75
75	1.04	1.13	1.25	1.39	1.57	1.62	1.48	4.2
100	0.97	1.05	1.16	1.31	1.49	1.54	1.39	3.86
150	0.84	0.91	1.02	1.15	1.32	1.36	1.22	3.43
200	0.74	0.8	0.9	1.02	1.19	1.23	1.09	3.17

The 50m wide channel was selected as the preferred option as it has satisfactory channel velocities for the majority of the length, minimised earthworks and minimised the area requiring protection.

The 50m straight channel was then used as a base case to compare other channel geometry options against (refer **Table 5**). It was observed that the two flared options significantly increased velocities along the length of the channel, in some cases to such an extent that protection works became necessary within the flowpath.

The hourglass channel served to reduce velocities in the first half of the channel, and over the weir, but increased velocities for the second half of the channel to a level that would require protection.

Both the narrow and wide curved channels greatly reduced velocities within the channel. The wide curved channel more than halved velocities in the channel up to chainage 300. Both options had only a minimal effect on the peak velocity across the weir.

Table 5: Channel Velocities for Different Configurations

	Ch 5	Ch 50	Ch 100	Ch 150	Ch 200	Ch 250	Ch 300	Weir
Straight 50m	1.09	1.17	1.29	1.43	1.6	1.64	1.51	4.75
Flared w straight 50m to 120m	1.71	1.89	2.17	2.57	2.37	2.28	1.59	3.69
% Change (wrt straight channel)	57	61	68	80	48	39	5	-22
Flared 50m to 150m	1.97	1.87	1.81	1.79	1.84	1.94	1.45	3.51
% Change (wrt straight channel)	80	60	40	26	15	18	-4	-26
Hourglass 100m to 50m	0.92	1.04	1.32	1.35	1.33	1.69	2.18	3.87
% Change (wrt straight channel)	-16	-11	2	-5	-16	3	15	-19
Narrow curved 150m to 50m	0.51	0.58	0.69	0.83	1.01	1.28	1.32	4.74
% Change (wrt straight channel)	-53	-50	-47	-42	-37	-22	-12	0
Wide curved 150m to 50m	0.92	0.5	0.52	0.57	0.61	0.76	1.22	4.74
% Change (wrt straight channel)	-16	-57	-60	-60	-62	-54	-19	0

Based on this analysis it was decided to further investigate the narrow curved channel and the wide curved channel. These options were chosen due to the significantly reduced velocities within the channel.

4.4 Conclusions

Based on the 1D analysis of the flowpath, three options were selected to be more comprehensively tested in the 2D model. These options were:

- Option 1: 50m straight channel, 50m weir, gradual channel slope
- Option 2: Narrow curved channel, 50m weir, gradual channel slope
- Option 3: Wide curved channel, 50m weir, gradual slope

5 2D Model

Three different design options were considered for the Regatta Weir based on the results of the 1D hydraulic modelling. These options are discussed below. The crest width for all options was set at 30m based on the resolution of the physical model. Alternative crest widths could be utilised.

In all options, the flowpath between the Quarantine Lake and the Regatta Lake has been blocked off so that all the flow entering Regatta Lake is from Main Lake. This is so that only one flowpath needs to constructed and protected.

All of these options have a minimal effect of Regatta Lake filling rates and peak levels (refer **Table 6**).

Table 6: Peak levels and peak times for channel options

Option		Peak WL (mAHD)	Time of Peak
100yr Event	Base 2D	22.54	6:00pm 3/01/2000
	Straight	22.54	6:00pm 3/01/2000
	Narrow Curved	22.54	6:00pm 3/01/2000
	Wide Curved	22.54	6:00pm 3/01/2000
200yr Event	Base 2D	23.45	4:30pm 3/01/2000
	Straight	23.46	4:30pm 3/01/2000
	Narrow Curved	23.43	4:30pm 3/01/2000
	Wide Curved	23.48	4:30pm 3/01/2000

It should be noted that the resolution of the model would not be suitable to accurately determine the velocities at the edge of the crest and on the backslope as they represent average velocities over a 15m cell. These velocities would be dependent on the backslope treatment adopted.

A roughness value of 0.03 has been assumed for all options.

5.1 Option 1 – 50m Straight Channel

Option 1 consists of a 50m wide channel running at a constant grade to a 50m wide weir set at RL 16.5. At each side of the weir, a 1 in 6 batter slope runs up to the base v 13d terrain level; approximately 24mAHD.

Peak and average duration velocities for option 1 are shown in **Table 7** with the resultant protection required shown in **Table 8**. Chainages increase upstream, with chainage 0 representing the upstream lip of the weir crest. Note that the edge of the lake lies at Ch-20. It has been assumed that a reinforced slab would extend approximately 10m underwater at 1m below operating level to prevent scour, assist in energy dissipation and prevent scour should the lake level fall below operating levels.

Table 7: Option 1 Critical Velocities (m/s)

Chainage	-45	-30	-15	0	15	30
2hr Peak	2.75	4.75	4.75	3.50	3.00	2.75
5hr Mean	2.00	3.50	3.75	2.75	2.25	2.00
10hr Mean	1.25	2.25	2.25	1.75	1.50	1.25
30hr Mean	0.50	0.75	0.75	0.50	0.50	0.50

Table 8: Option 1 Protection Extents

Chainage	-45	-30	-15	0	15	30
2hr Peak		Good Grass	Good Grass			
5hr Mean	Good Grass	**Reinforced Grass**	**Reinforced Grass**	Good Grass	Good Grass	Good Grass
10hr Mean		Good Grass	Good Grass	Good Grass		
30hr Mean						

Note: Blank squares assume poor grass cover

Based on the above results, the 5hr average velocities govern the protection works.

5.2 Option 2 – Narrow bowl channel

This option consists of a narrow bowl. The starting width is 150m, and this width steadily reduces to 50m at the weir. At each side of the weir, a 1 in 6 batter slope runs up to the base v 13d terrain level; approximately 24mAHD.

Peak and average duration velocities for option 2 are shown in **Table 9** with the resultant protection required shown in **Table 10**. Chainages increase upstream, with chainage 0 representing the upstream lip of the weir crest. The weir crest has been assumed to be 10m wide. Note that the edge of the lake lies at Ch-20. It has been assumed that a reinforced slab would extend approximately 10m underwater at 1m below operating level to prevent scour, assist in energy dissipation and prevent scour should the lake level fall below operating levels.

Table 9: Option 2 Critical Velocities (m/s)

Chainage	**-45**	**-30**	**-15**	**0**	**15**	**30**
2hr Peak	3.25	5.25	4.75	3.75	3.00	2.25
5hr Mean	2.50	3.75	3.50	2.75	2.00	1.75
10hr Mean	1.50	2.25	2.25	1.75	1.25	1.00
30hr Mean	0.50	0.75	0.75	0.50	0.50	0.50

Table 10: Option 2 Protection Extents

Chainage	**-45**	**-30**	**-15**	**0**	**15**	**30**
2hr Peak		**Reinforced Grass**	Good Grass			
5hr Mean	Good Grass	**Reinforced Grass**	**Reinforced Grass**	Good Grass	Good Grass	
10hr Mean		Good Grass	Good Grass	Good Grass		
30hr Mean						

Note: Blank squares assume poor grass cover

Based on the above results, the 5hr average velocities govern the protection works.

5.3 Option 3 – Wide bowl channel

The final option investigated was a wide bowl. Similar to option 2, the initial width is 150m, but in this option, this width is maintained for the majority of the flow path, which ends in a 50m weir. At each side of the weir, a 1 in 6 batter slope runs up to the base v 13d terrain level; approximately 24mAHD.

Peak and average duration velocities for option 3 are shown in **Table 11** with the resultant protection required shown in **Table 12**. Chainages increase upstream, with chainage 0 representing the upstream lip of the weir crest. The weir crest has been assumed to be 10m wide. Note that the edge of the lake lies at Ch-20. It has been assumed that a reinforced slab would extend approximately 10m underwater at 1m below operating level to prevent scour, assist in energy dissipation and prevent scour should the lake level fall below operating levels.

Table 11: Option 3 Critical Velocities (m/s)

Chainage	**-45**	**-30**	**-15**	**0**	**15**	**30**
2hr Mean	3.25	5.25	4.75	3.75	3.00	2.25
5hr Mean	2.50	4.00	3.75	2.75	2.25	1.75
10hr Mean	1.50	2..5	2.25	1.75	1.50	1.00
30hr Mean	0.50	1.00	0.75	0.75	0.50	0.50

Table 12: Option 3 Protection Extents

Chainage	**-45**	**-30**	**-15**	**0**	**15**	**30**
2hr Mean		**Reinforced Grass**	Good Grass			
5hr Mean	Good Grass	**Reinforced Grass**	**Reinforced Grass**	Good Grass	Good Grass	
10hr Mean		Good Grass	Good Grass	Good Grass	Good Grass	
30hr Mean		Good Grass				

Note: Blank squares assume poor grass cover

Based on the above results, the 5hr average velocities govern the protection works.

6 Earthworks

It is noted that all options would require a similar level of protection based on the 15m grid results. As all weirs are the same length, the main differential is the earthworks. The straight weir option requires significantly less earthworks to construct, resulting in a lower construction cost.

7 Detailed Weir Model

Based on the cost saving associated with the straight channel, it was decided to further test the design in a detailed 2D model. The detailed model provides greater definition of the velocity profile over the river bank. 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 7**.

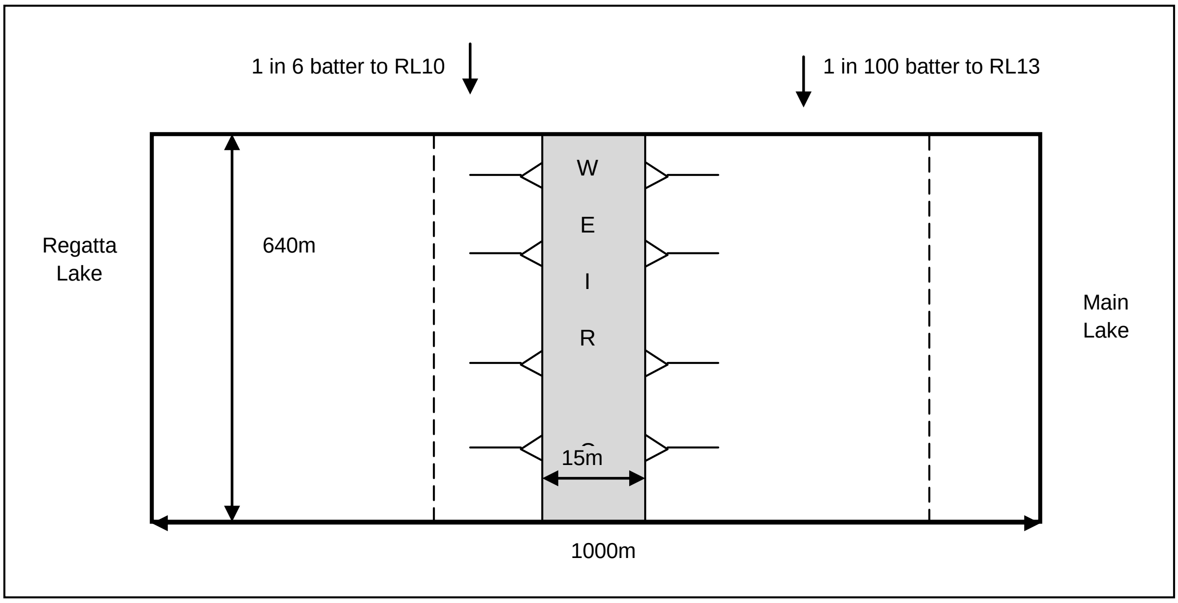


Figure 7: 2D Weir Model Layout

The model represents a generic cross section across the weir. The river boundaries are modelled as water level time series, taken from the full 2D model at points adjacent to the weir crest. The crest of the weir was set at RL16.5.

The velocities extracted from the model were analysed using the same method and critical values used to evaluate the previous options. The results are shown in **Table 13**, and the required protection measures in **Table 14**. The weir crest is from Ch0 to Ch15, with chainages increasing from Main Lake to Regatta Lake.

Table 13: Critical Velocities for the Straight Weir from the 100yr detailed 2D model

Chainage	**-25**	**-20**	**-15**	**-10**	**-5**	**0**	**5**	**10**	**15**
2hr Mean	2.50	4.75	6.25	6.25	5.75	5.00	4.50	4.00	4.00
5hr Mean	1.75	3.25	4.50	5.00	4.50	3.75	3.50	3.25	3.00
10hr Mean	1.25	2.00	2.75	3.00	2.75	2.50	2.25	2.25	2.00
30hr Mean	0.50	0.75	1.00	1.00	1.00	1.00	0.75	0.75	0.75

Table 14: Required protection for the straight weir from the 100yr detailed 2D model

Chainage	**-25**	**-20**	**-15**	**-10**	**-5**	**0**	**5**	**10**	**15**
2hr Mean		Good Grass	**Concrete**	**Concrete**	**Reinforced Grass**	Good Grass	Good Grass	Good Grass	Good Grass
5hr Mean		Good Grass	**Reinforced Grass**	**Concrete**	**Reinforced Grass**	**Reinforced Grass**	Good Grass	Good Grass	Good Grass
10hr Mean		Good Grass	Good Grass	Good Grass	Good Grass	Good Grass	Good Grass	Good Grass	Good Grass
30hr Mean									

Note: Blank squares assume poor grass cover

The detailed 2D model was also run for the 200yr event. The 200 year ARI is also larger than the proposed 100 year ARI climate change scenario (approximately 10% increase in flows). Therefore, if the weir protection is designed to the 200 year ARI it will also cover the proposed climate change effects on the 100 year ARI.

The results are shown in **Table 15**, and the required protection measures in **Table 16**. The weir crest is from Ch0 to Ch15, with chainages increasing from Main Lake to Regatta Lake.

Table 15: Critical Velocities for the straight weir from the 200yr detailed 2D model

Chainage	**-25**	**-20**	**-15**	**-10**	**-5**	**0**	**5**	**10**	**15**
2hr Mean	5.00	7.00	7.50	7.25	6.25	5.50	5.00	4.75	4.50
5hr Mean	2.50	4.75	6.50	6.25	5.75	5.00	4.50	4.25	4.00
10hr Mean	1.50	2.25	2.75	3.00	2.75	2.25	2.00	2.00	1.75
30hr Mean	0.75	1.00	1.25	1.50	1.25	1.25	1.25	1.00	1.00

Table 16: Required protection for the straight weir from the 200yr detailed model

Chainage	**-25**	**-20**	**-15**	**-10**	**-5**	**0**	**5**	**10**
2hr Mean	Good Grass	**Concrete**	**Concrete**	**Concrete**	**Concrete**	**Reinforced Grass**	**Reinforced Grass**	Good Grass
5hr Mean	Good Grass	**Concrete**	**Concrete**	**Concrete**	**Concrete**	**Concrete**	**Reinforced Grass**	**Reinforced Grass**
10hr Mean	Good Grass	Good Grass	Good Grass	Good Grass	Good Grass	Good Grass	Good Grass	Good Grass
30hr Mean								

Note: Blank squares assume poor grass cover

8 Weir Construction Options

Based on the velocities passing over the weir crest, the weir crest and the downstream slope require concrete protection. Preliminary designs have been prepared for 2 options. The first consists of an RCC face at a 1 in 1 grade running from the weir crest to the lake. The second option consists of a vertical wall instead. Both options included a 10m reinforced concrete weir crest, and a 10m reinforced concrete slab at 1m below operating level to prevent scour, assist in energy dissipation and prevent scour should the lake level fall below operating levels.

It is suggested that the vertical wall will prove cheaper to construct, and may be a more aesthetic option. A cross section of this option is included in **Appendix B**. This arrangement provides protection in both the 100 year and 200yr event.

9 Regatta Weir Recommendations

Based on the modelling conducted it is recommended that only one flowpath be connected to the Regatta Lake to reduce construction and protection costs. Of the options analysed, the Main Lake flowpath is considered the better option.

The curved channel options were successful in reducing velocities throughout the channel, which served to reduce the costs required to protect the channel bed. However, they require significantly more earthworks to construct. As the earthworks are likely to be a significant contributor to the overall cost, the curved options are likely to be significantly more expensive.

It is recommended that Option 1 be adopted in future designs. The simplicity of its design and its smaller footprint result in a greatly reduced cost compared to other options. Although it had higher channel velocities than the other options, the velocities were still within an acceptable range, and the velocity reductions offered by options 2 and 3 are not thought enough to warrant the increased construction cost.

Of the weir options investigated, it is suggested that the vertical wall option be adopted. However, this should be re-examined in the detailed design phase.

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 design of the Weir has been based on the 100 year and 200 year ARI design events. No other design events have been modelled. No sensitivity analysis has been undertaken but it is recommended that this be undertaken prior to the detailed design phase.
- 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

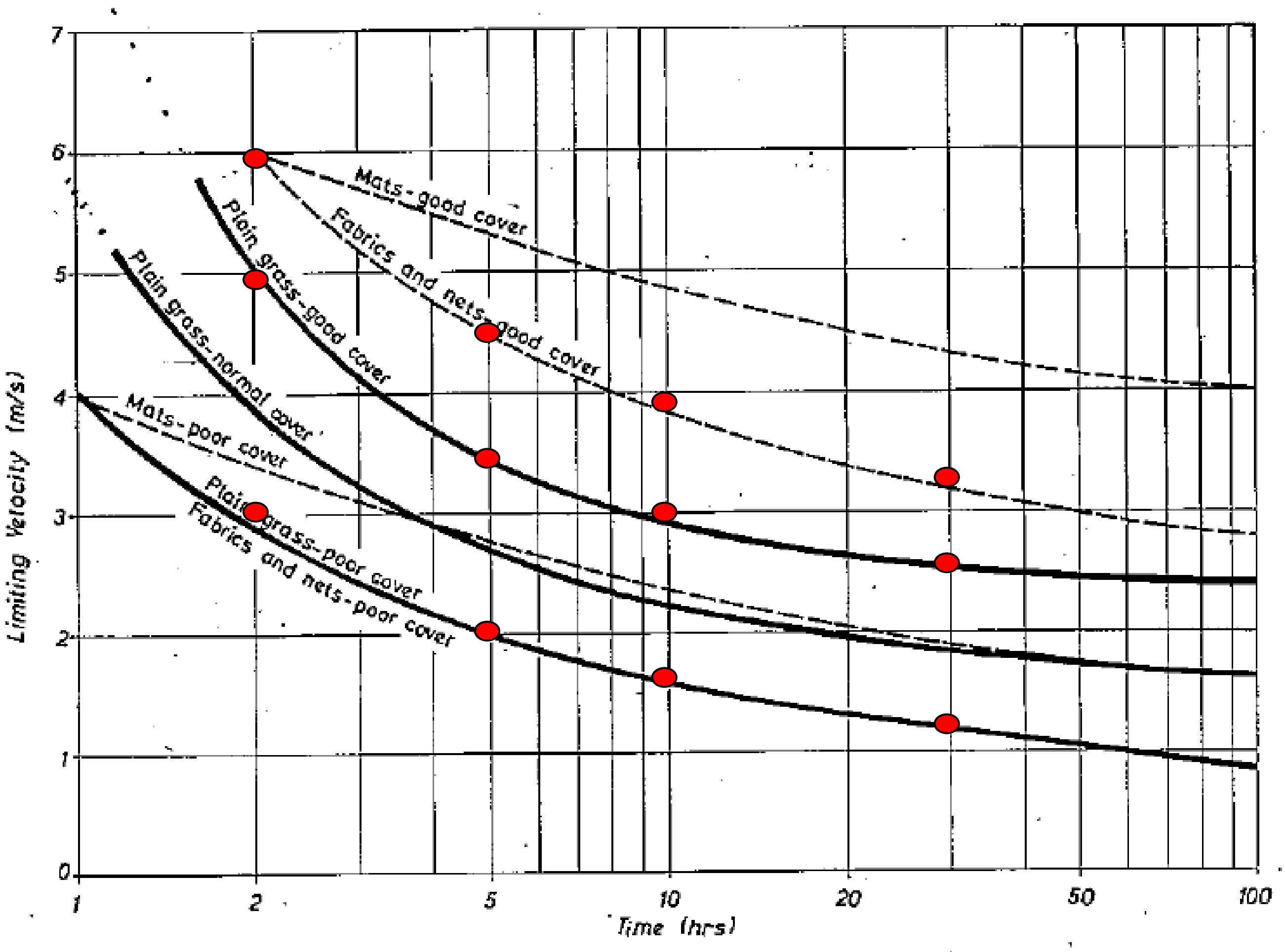
Cardno Lawson Treloar 1 (2009). *Penrith Lakes Flood Modelling: Model Calibration and Verification*, December, prepared for Penrith Lakes Development Corporation, Final.

Cardno Lawson Treloar 2 (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

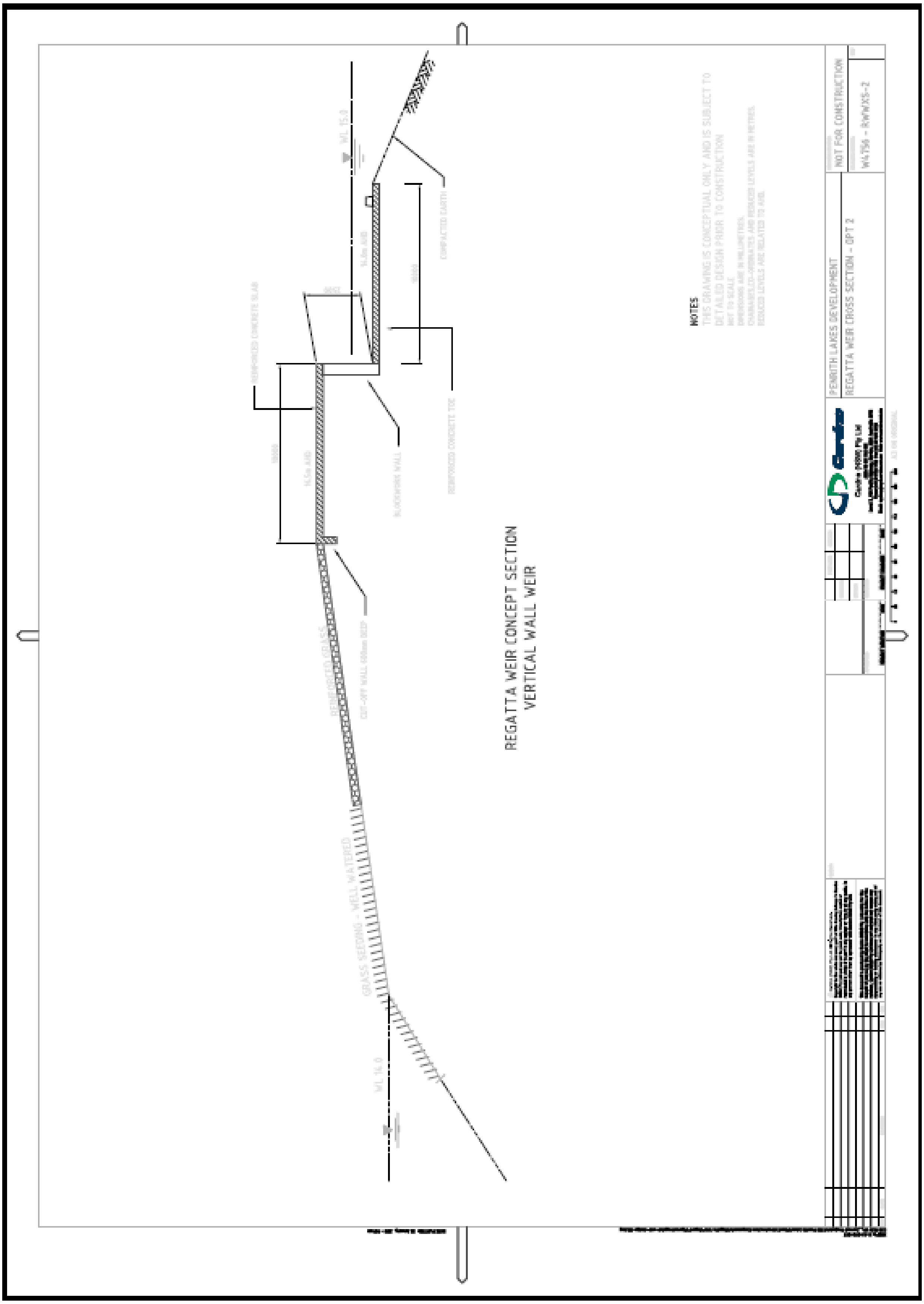
CIRIA Velocity Plot



Critical velocity points for protection works

Attachment B

Concept Sketches


REGATTA WEIR CONCEPT SECTION
VERTICAL WALL WEIR
NOT FOR CONSTRUCTION
PENRITH LAKES DEVELOPMENT
REGATTA WEIR CROSS SECTION - OPT 2