Cardno
Shaping the Future

Appendix A

Weir 6 Concept Design

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1 Introduction

The purpose of this appendix is to provide Penrith Lakes Development Corporation (PLDC) with advice on potential design options for Weir 6 of the Penrith Lakes Design Scheme (refer Figure 1). Cardno have undertaken the assessment of a number of configurations for Weir 6, and the results of this analysis are presented in this letter report. The analysis includes potential impacts on peak water levels, velocities across the weir, preliminary costings for some of the options and preliminary concept sketches for those options.

2 Current Design Scheme

The Penrith Lakes Design Scheme has undergone a number of changes in recent months, and we understand that further modifications are likely moving into the future. The preliminary assessment reported in this letter is based on the most recent design scheme that has been modelled (February, numerical design run ID: "pldc-des-081003-v9i-opt2"). The underlying terrain for this particular design is based on a design received from PLDC on 4 August 2008 (8468_JWP_Design v9_DTM_080728_Triangles.dwg).

Numerous modifications have been made to refine the hydraulic performance of the scheme, based on various discussions between PLDC and Cardno Lawson Treloar. These modifications include a number of design options which have been considered through the project. The most recent option has formed the basis for the analysis in this report. The key design features in the scheme used in this report include:

- Weir 1 (Main Weir) – Set at the 1 in 25 year ARI design level (21.6m AHD) and 600m wide.
- Weir 6 (between Main Lake and Wildlife Lake) – set at crest level 21m AHD and approximately 440 metres in width.
- Weir 6 Bund – a bund wall has been included which runs from the western edge of Weir 6 through to the river bank, with a crest level of 22.5m AHD. This was raised from 22m AHD from a previous design to exclude the 100 year ARI from overtopping this area.
- Rowing Weir (between Quarantine & Rowing Lake) – Crest level at 16m AHD and 100 metre in width.
- Weir 2 (between Quarantine & Main Lake – Crest level set at 16m AHD and 580 metres wide, with a gentle grade to main lake.
- Hunts Gully – has been maintained at existing surface levels.

- Smith Street – has been maintained at existing surface.
- Boundary Creek Bund Wall – A bund wall across Boundary Creek has been included to protect the Penrith CBD. The crest has been set at 27.7m AHD.

These design features are shown in **Figure 1**.

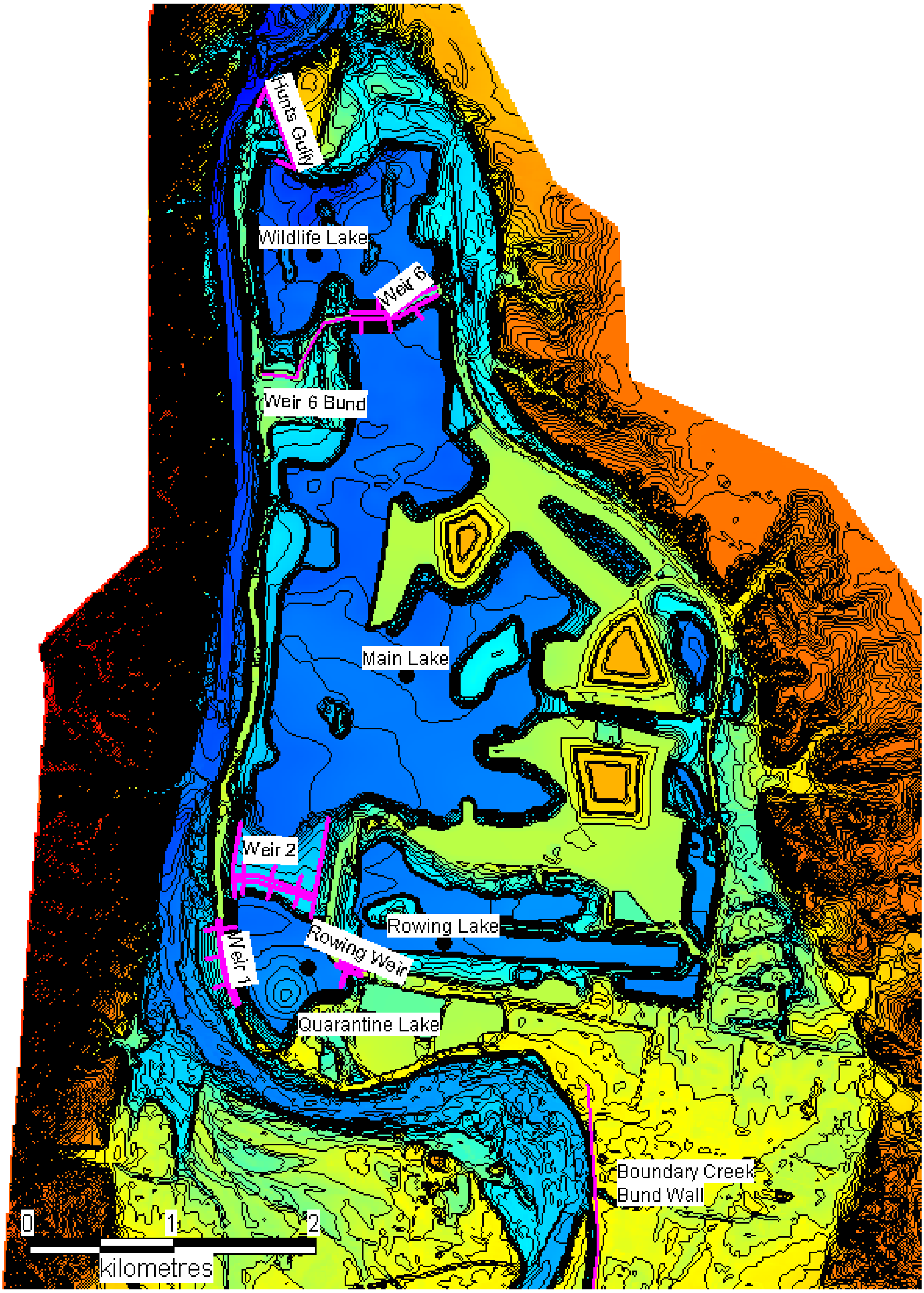

Figure 1 Current Penrith Lakes Scheme

3 Modifications to Weir 6 Bund

Based on above scheme, a bund was included between the western edge of Weir 6 and the river bank with a crest level of 22m AHD. The results of the modelling identified that this bund overtopped in the 100 year ARI design event, and that high velocities would occur across this entire area. To limit the total area of protection required, the bund crest was raised to 22.5m AHD, prevented overtopping in the 100 year ARI design flood. In order to compensate for the reduced capacity across this area, Weir 6 was extended by approximately 200 metres towards the east.

4 Backslope Test Model (Detailed Model)

A small 2D model was established to test some of the backslope treatments for Weir 6, and to provide greater resolution for the velocities across the weir. This 2D model utilised a 5 metre grid (compared with a 15 metre grid for the overall model). Boundaries for the model were defined from the coarser overall model and testing showed that the detailed model produced similar results to the overall model.

5 Weir 6 Design Options

A number of different design options were considered for Weir 6, based on the results of the detailed hydraulic modelling. These options are discussed below:

5.1 Option 1 – 2 Stage Weir

For option 1, a weir crest of 21m AHD was assumed across a width of 440 metres, with an additional 200 metres set at a level of 21.5m AHD. This primary purpose of this option is to limit the high velocity zone to a smaller area, and hence reduce the amount of protection works required. However, preliminary modelling suggested that this had the potential to increase peak water levels in the Main Lake by approximately 0.2 to 0.3 metres.

5.2 Option 2 – Flat Crested Weir with Slot

This option incorporated a 50 metre wide “slot” set at 20.5m AHD, while the rest of the weir remained at 21m AHD, to allow the Main Lake and the Wildlife Lake both drain down after the peak of the storm. With the lowering Wildlife Lake levels, the exposed backslope of Weir 6 increases. This can potentially result in a large area of the backslope requiring protection.

The purpose of the slot is to create an effective cut-off for the overtopping flow across the entire weir, thus allowing the final draining of the Main Lake to occur over a smaller section. This slot, however, would require significant protection as it would be exposed to high velocity flow for a period of greater than 24 hours.

Preliminary results incorporating this slot suggests that it has the potential to reduce the exposed backslope for the rest of the weir by approximately 1 to 1.5 metres. However, preliminary modelling indicates that when weir flow is shallow the velocity across the backslope of the weir is small enough to allow reinforced grass to be used as scour protection. The cost of constructing the slot is expected to be greater than providing reinforced grass and therefore Option 2 is not recommended.

5.3 Option 3 – Flat Crested Weir - 1 in 10 slope

This option incorporates a broad crested weir at 21m AHD, with a backslope of 1m in 10 (10%). This backslope was considered the maximum at which reinforced grass would be suitable.

Based on the results from the backslope test model, the velocities across the embankment. In this scenario, a 15 metre wide crest was adopted, based on the resolution of the numerical model. Alternatives crest widths could be utilised. Any weir crest width adopted should be confirmed with structural and geotechnical engineers, and should be verified with the numerical model.

Figure 2 shows the peak velocities across the weir, relative to the start of the weir crest (i.e. 15 metres represents the end of the weir crest).

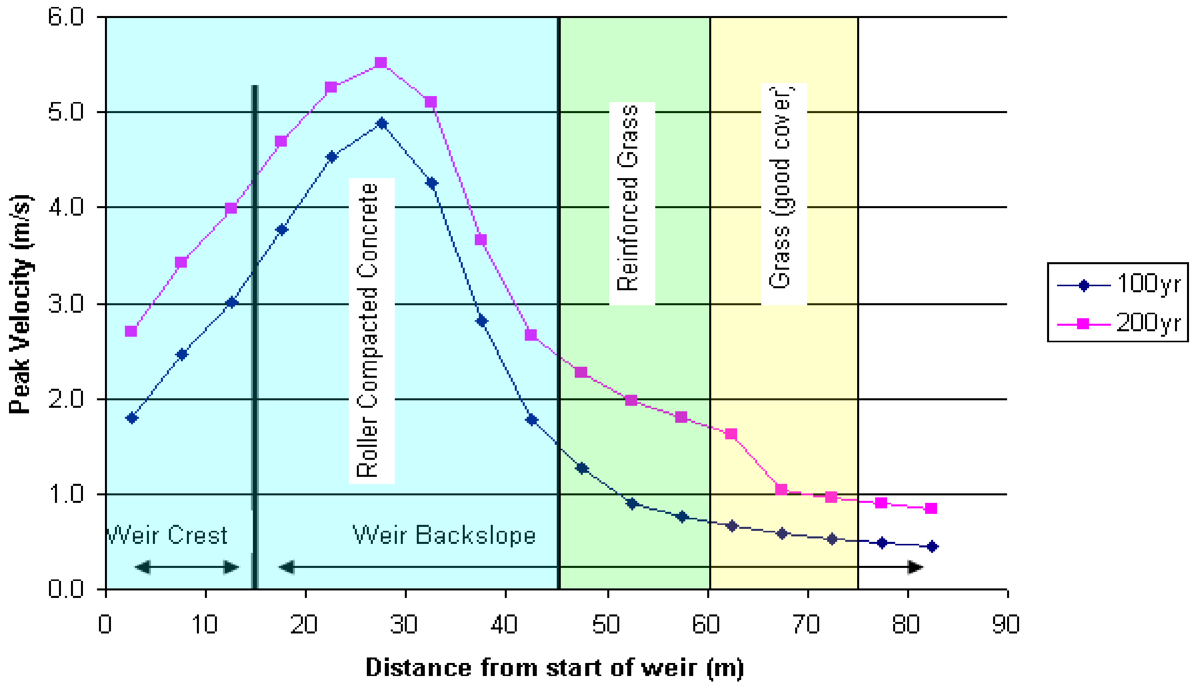

Figure 2 - Peak Velocity Results - Option 3

The peak velocities plotted in Figure 2 do not act for the entire period of overtopping, as the backslope becomes drowned out by the levels in the Wildlife Lake. However, high velocities would occur for a period of around 24 hours for the 100 year ARI design event at various locations along the backslope face as the water level in the Wildlife Lake changes. This is demonstrated in Figure 3.

For the purposes of the concept design, we have assessed 3 different treatments for the backslope of weir 6:

- Roller compacted concrete. Based on previous experience, we have assumed that roller compacted concrete would need to be approximately 1 metre thick. A detailed design may allow a refinement of this thickness.
- Reinforced grass. We have assumed that the maximum velocity that can be withstood for 24 hours is approximately 3m/s (based on testing reported by CIRIA, 1985). Note that this assumes that there is a reasonable grass cover.
- Plain grass, good cover (note that it is likely that this grass would need to be irrigated to maintain a good cover). Maximum velocity is limited to 2m/s (CIRIA, 1985).
- Poor grass covered slope, with a maximum velocity of 1m/s (CIRIA, 1985).

These treatments have been applied based on the results of the 200 year ARI design event.

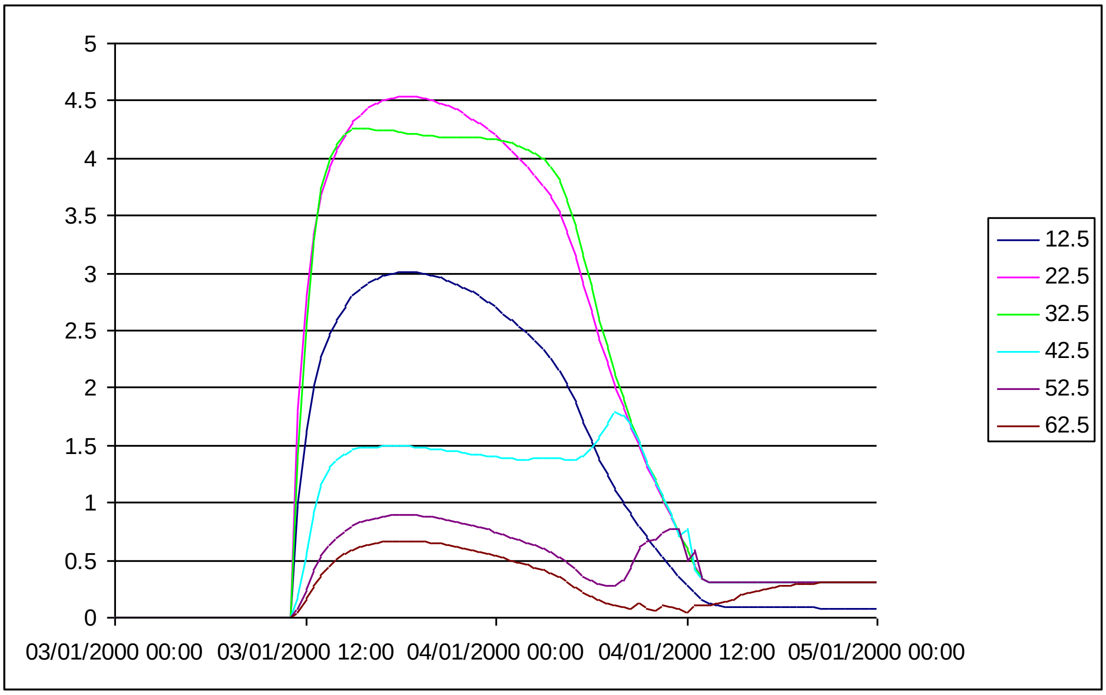

Figure 3 100 Year Velocity Time Series for Different Horizontal Distances – Option 3

Table 1 Recommended Treatment Types for Option 3

Treatment Type	Horizontal Distance (including weir crest) (metres)	Backslope Horizontal Distance (from end of weir crest) (m)	Vertical Distance below crest (metres)	Elevation (m AHD)
Roller Compacted Concrete	0 to 45	0 to 30	0 to 3	21 to 18
Reinforced Grass (<3m/s)	45 to 70	30 to 55	3 to 5.5	18 to 15.5
Grass (good cover) or Reinforced Grass (<2m/s)	70 to 85	55 to 70	5.5 to 7	15.5 to 14
Poor Grass (<1m/s)	>85	>70	>7	<15.5

Overtopping of the weir is expected to stop once the water level of the Wildlife Lake is approximately 5.5 to 6 metres (RL 15.5m AHD to 16m AHD) below the weir crest, and 55 to 60 metres away from the crest. Velocities above 1m/s are still experienced at the tail end of the flood for a distance of up to 70 metres horizontally from the weir crest. Beyond approximately 80 metres (allowing for a 10 metre safety margin) from the weir crest it would be possible to change (flatten or steepen) the weir backslope as well as provide vegetation (such as trees or park furniture) without significantly increasing the risk of scour in this area.

A concept sketch of this option is provided in Attachment A (Weir 6, option 3).

5.4 Option 4 – Broad Crested Weir- 1 in 20 slope

Option 4 is similar to Option 3, incorporating a 1 in 20 slope rather than a 1 in 10 slope. The intention of this option was to investigate the potential for a shallower backslope to reduce the backslope velocity. Modelling showed only minor changes to the peak velocities.

In general, the areas to be protected by the treatment measures described for Option 3 are about doubled for Option 4.

5.5 Option 5 – Broad Crest Weir with Drop Structure

Option 5 incorporates a vertical 2 metre drop, together with an energy dissipation structure close to the weir crest. The energy dissipation structure would be drowned out for a portion of the storm event, but would assist in the removal of some of the energy while the main lake is drawing down. A concept design of this option is provided in Attachment A (weir 6 option 5).

A simplified version of this weir was incorporated into the backslope testing model. As the resolution of the grid is 5 metres, a 15 metre crest width was adopted, followed by a 2 metre vertical drop, and then a 10 metre wide flat apron, representing the dissipation area. No energy dissipation structures were incorporated into the model, so it is expected that the velocities represent a worst case scenario.

The results of the modelling are presented in Figure 4. The vertical drop structure has the effect of reducing the velocities more dramatically with horizontal distance, when compared with Option 3.

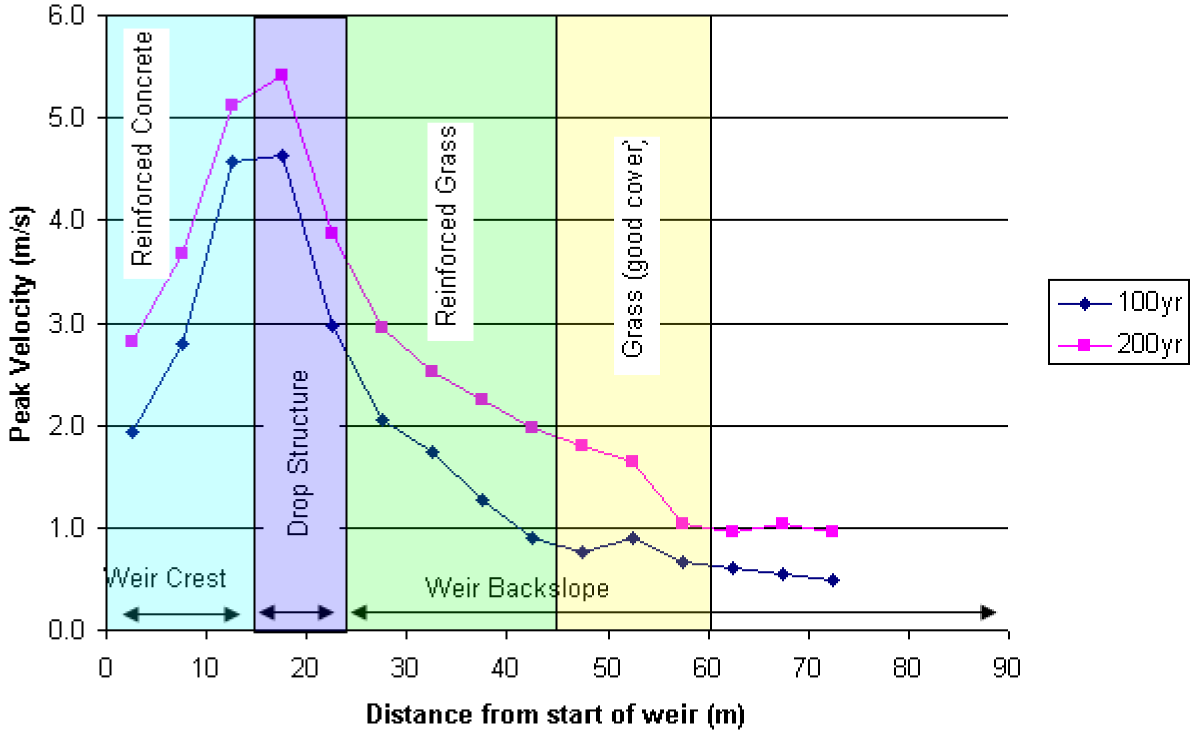

Figure 4 Peak Velocity Results - Option 4

Based on the results of this analysis, the type and extent of scour protection needed is shown in Table 2.

Table 2 Recommended Treatment Types for Option 4

Treatment Type	Horizontal Distance (including weir crest) (metres)	Backslope Horizontal Distance (from end of weir crest) (m)	Vertical Distance below crest (metres)	Elevation (m AHD)
Reinforced Concrete Drop Structure	0 to 23	0 to 8	0 to 2	21 to 19
Reinforced Grass (<3m/s)	23 to 60	8 to 45	2 to 5.7	19 to 15.3
Grass (good cover) or Reinforced Grass (<2m/s)	60 to 75	45 to 60	5.7 to 7.2	15.3 to 13.8
Poor Grass (<1m/s)	>75	>60	>6	<13.8

6 Weir 6 Costings

The concrete costs are likely to be the major factor in the relative cost differences. As such, Option 5 may be the cheapest option, as it requires substantially less concrete to construct. However, Option 5 would be more difficult to construct in terms of reinforcement and formwork, and therefore this might offset the additional cost of concrete for Option 3. Option 4 will be significantly more expensive than Option 3 due to the 1 in 20 slope, as opposed to the 1 in 10 slope used in Option 3.

It may also be possible to modify Option 3 to have a steeper slope (such as 1 in 2 slope). However, if this were the case, it would require a dissipative structure similar to Option 5.

7 Weir 6 Recommendations

Based on this assessment, it is recommended that either Option 5 would be the most economical for Weir 6. The key advantages of this option include:

- Significantly lower cost when compared with Option 4.
- A more stable hydraulic jump formation within the drop structure. For the majority of the storm, the hydraulic jump should be primarily limited to the drop structure. By comparison, the hydraulic jump in Option 3 and 4 would move up and down the slope with the changing backwater from the Wildlife Lake. The formation of the hydraulic jump in the drop structure also has the advantage of reducing the energy of the flow further down the backslope. Note that it may be possible, as discussed above, to have a steeper slope on Option 3 and to also incorporate a drop structure.
- A reduced high velocity zone. High velocities are generally limited to the drop structure, and reduced off quite rapidly after this.

Further consideration is needed regarding public safety issues, type of fencing required etc at the top of the weir drop.

8 Weir 6 Bund

Under the design scheme, a bund is proposed between the western end of Weir 6 and the river bank. The crest of the bund would be 22.5m AHD, which is above the 100 year ARI design level but is overtopped during a 200 year ARI design event.

The maximum overtopping height is approximately 0.8 metres in a 200 year ARI design event, although at this stage the bund would be drowned by the backwater from the Wildlife Lake. Overtopping of the bund occurs for a period of approximately 24 hours, with the maximum exposed backslope length of approximately 1.5 metres.

A simple 1D model was established to test the different back slope options for the bund. The results of this testing showed that for a 1(V) in 6(H) backslope the velocity would be less than 3m/s. Therefore, it is recommended that slopes of 1(V) in 6(H) be adopted as a minimum across the bund as this velocity is towards the upper limit for reinforced grass for this period of flooding. It is also noted that this slope is towards the upper limit for reinforced grass. However, given the low probability of the overtopping event, this should not be a significant issue. Gentler slopes would reduce the velocities of these flows and should be incorporated if possible.

9 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 Weir 6 and therefore different options for energy dissipation and scour protection.

10 References

Cardno Lawson Treloar (2008). *Penrith Lakes Flood Modelling: Model Calibration and Verification*, December, prepared for Penrith Lakes Development Corporation, Final.

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

Attachment A

Concept Sketches