Penrith Lakes Scheme

Flood Infrastructure Concept Design

Project W4756

Prepared for Penrith Lakes Development Corporation

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Executive Summary

Cardno has been engaged by Penrith Lakes Development Corporation (PLDC) to analyse the flood behaviour and flood impacts of the proposed Penrith Lakes Scheme. This includes the concept design of a number of key flood infrastructure components to the overall Penrith Lakes Scheme. This report comprises the details and results of the analysis.

The objectives of the analysis were:

- To remove or minimise the flood impacts to surrounding areas;
- To optimise weir and flowpath design; and,
- To provide preliminary information on the requirements for flood infrastructure.

Study Area

The Penrith Lakes Development Area is located north of Penrith CBD, adjacent to the Nepean River, in Western Sydney (**Figure 1.1**). The study area is approximately 7km long and covers an area of approximately 2000ha. The site is bordered by the Nepean River on the west and south, the Castlereagh escarpment in the east, and Smith St in the north (**Figure 1.2**).

Much of the Penrith Lakes Development Area is still an active quarry. However, in the process of quarrying, Penrith Lakes Development Corporation (PLDC) are rehabilitating the land into a number of parkland areas and lakes.

Proposed Lakes Scheme

The proposed Penrith Lakes Scheme comprises a number of lakes, as shown in the concept sketch in the figure below. The largest lake, referred to as Main Lake, is approximately 444 hectares in surface area, while the Wildlife Lake, in the north of the site, is approximately 110 hectares. There are also a number of smaller lakes within the scheme, including the existing Regatta Lake and a number of smaller lakes on the eastern side of the scheme which are collectively referred to as the Eastern Lakes in this report.

There are a number of key flood infrastructure in the scheme which control the inflow and outflow of floodwaters from the Nepean River, as well as the flows between the lakes themselves. This flood infrastructure allows for the controlled filling of the Lakes Scheme under a Nepean River flood and minimises any adverse impacts on flood levels on surrounding properties. The focus of this report is on the concept design of this infrastructure, including:

- Main Weir (Weir 1)
- Wildlife Lake weir
- Riverbank
- Weir 6
- Quarantine Flowpath
- Regatta Flowpath
- Eastern Lakes

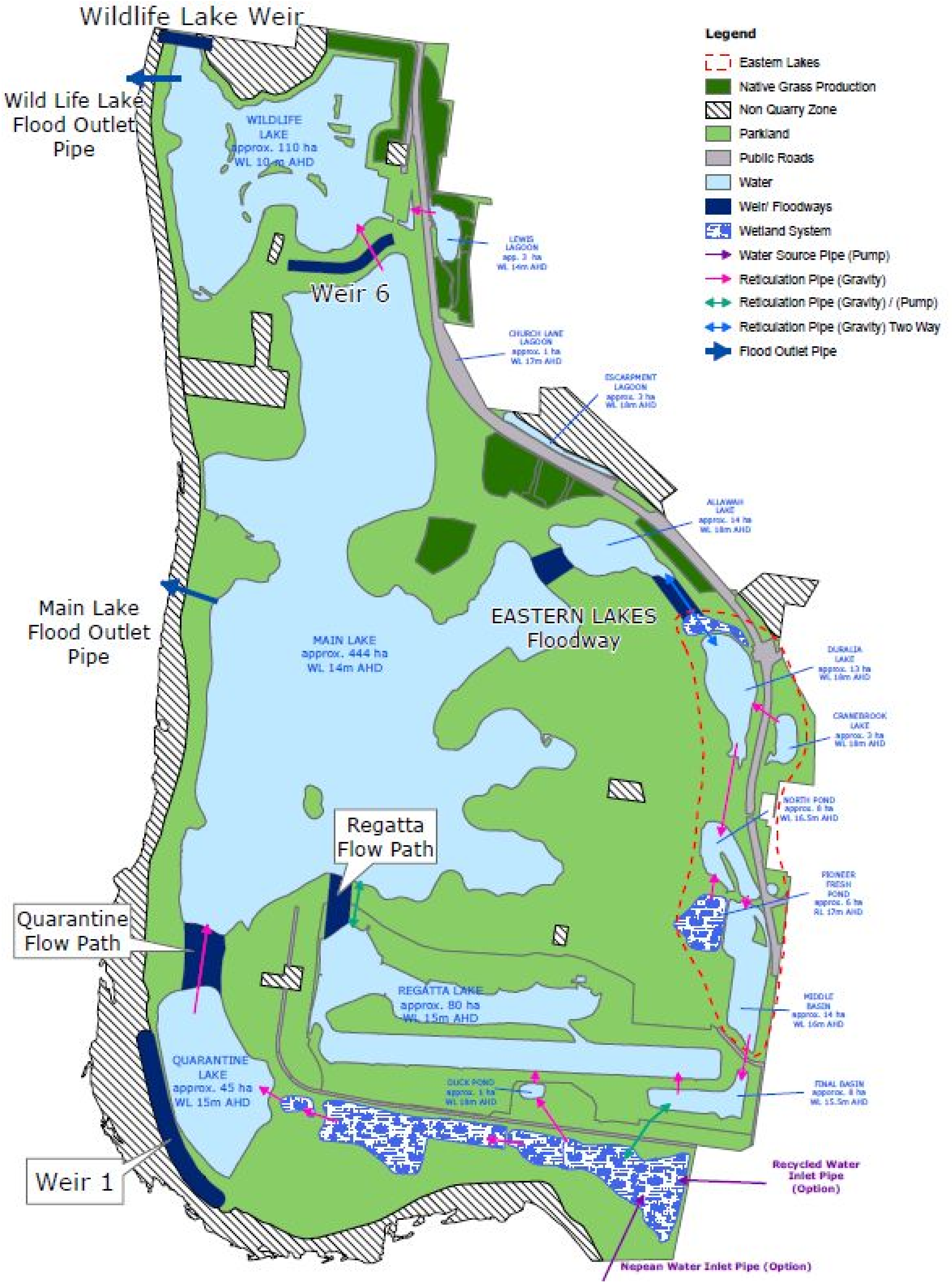

Figure. Concept Sketch of Penrith Lakes Scheme

Flooding Behaviour of Proposed Scheme

The following outlines the flood behaviour of the proposed scheme. It is broken down into four stages during a flood event. More details on this flood behaviour are provided in **Section 4**.

- **Stage 1** - During the early part of the flood event, the Wildlife Lake starts to fill through Wildlife Lake weir in the north. Overtopping of Wildlife Lake weir will occur in events greater than a 10 year ARI.
- **Stage 2** - In the second stage, Weir 1starts to overtop (only in events greater than 25 year ARI). This commences the filling of Quarantine Lake and Main Lake via the Quarantine Flowpath. As the Main Lake fills, the Regatta Lake will start to fill through the Regatta Flowpath. Meanwhile, Wildlife Lake is still filling through Wildlife Lake weir.
- **Stage 3** - Weir 6 represents the major control for the Main Lake. Once the Main Lake has filled to the crest level of Weir 6, it begins to overtop into the Wildlife Lake. Around this time, the overtopping of Weir 6 fills the Wildlife Lake such that it reverses the direction of flow through Wildlife Lake weir and water begins to flow from the lake into the Nepean River.
- **Stage 4** - As the flood through the Nepean River recedes, overtopping of Weir 1 stops. Following this, Weir 6 stops overtopping and finally flows through Wildlife Lake weir cease.

After the flood has receded, the Lakes are still elevated above their normal operating levels. Flood outlet pipes located in the Wildlife Lake and Main Lake allow the flood waters to drain to the Nepean River and allow the lakes to return to normal operating levels.

Flood Infrastructure Components

There are a number of key flood infrastructure components within the proposed Lakes Scheme. This report focuses on the concept design of these various components. The function of these components, and the concept design dimensions, are summarised in the following table.

Component	Description	Key Dimensions
Main Weir (Weir 1)	The Main Weir is the primary control for flood waters entering the Lakes Scheme from the Nepean River.	Weir Width: 600m Weir Crest Height: 21.6mAHD (25 year ARI)
Wildlife Lake weir	The Wildlife Lake weir serves two purposes. It conveys inflows from the Nepean during the early part of the flood, and outflows from the Lakes during the latter part of the flood.	Central Weir Width: 65m Central Weir Crest Height: 16.0mAHD (10 year ARI)
Riverbank	The Riverbank bund prevents the inflow of floodwaters into the Lakes Scheme until the lake levels are closer to the Nepean River levels, to protect the integrity of the riverbank.	Length ~ 5.7km Crest Height Ranges from: 23.9mAHD – 21.9mAHD
Weir 6	Weir 6 is the primary control (other than Weir 1) for flood waters between the Main Lake and the Wildlife Lake. It controls the water levels within the Main Lake, as well as Quarantine and Regatta Lakes.	Weir Width: 640m Weir Crest Height: 21mAHD

Component	Description	Key Dimensions
Quarantine Flowpath	This is a low level flowpath between the Quarantine Lake and the Main Lake to convey floodwaters into the Main Lake.	Base Width: 150m Crest Height: 16.5mAHD Flowpath Length: 310m
Regatta Flowpath	This is a low level flowpath between the Main Lake and Regatta Lake to convey floodwater into the Regatta Lake.	Weir Width: 50m Weir Crest Height: 16.5mAHD Flowpath Length: 225m
Eastern Lakes	The Eastern Lakes are a series of lakes to the east of the Main Lake. The majority of these lakes are disconnected from the Main Lake during a 100 year ARI flood by high ground levels although there is a connection through smaller existing culverts between the Regatta Lake and Final Basin.	Allawah – Duralia Connection Width: 370m Crest Height: 22.55mAHD Flowpath Length: 460m Duralia – North Pond Connection Width: 140m Crest Height: 19mAHD Flowpath Length: 470m

Flood Modelling Results

The concept design for the proposed Lakes Scheme was assessed for the 500 year, 200 year, 100 year, 50 year, 20 year and 10 year ARI events together with the PMF. The flood infrastructure, as addressed above, functions as intended under the design events. A detailed discussion of these results are provided in **Sections 7** to **9**. The following provides a summary of the results.

Impacts on Flood Levels as a Result of the Lakes Scheme

Annual Average Damage

A preliminary flood damages analysis was undertaken for the Emu Plains and Penrith Areas. This analysis, as shown in the table below, demonstrates that the proposed Penrith Lakes Scheme represents a significant benefit to the community as a whole, with an estimated $9.4M reduction in flood damages as a result of the proposed Lakes Scheme in present value terms. If a 100 year ARI event were to occur, then the estimated saving in damages is $56.3M. The number of properties which potentially have overfloor flooding significantly reduces as well, from 1027 properties in the 100 year ARI under the base case to 665 properties in the design case.

Estimated Number of Properties/ Buildings with Overfloor Flooding

Flood Event	Base Case	Proposed Design
10 year ARI	16	16
20 year ARI	25	25
50 year ARI	105	85
100 year ARI	1027	665
200 year ARI	2743	2422
500 year ARI	3505	3135

Preliminary Flood Damages Analysis

Flood Event	Base Case	Proposed Design
10 year ARI	$1.2M	$1.2M
20 year ARI	$1.8M	$1.8M
50 year ARI	$6.1M	$5.1M
100 year ARI	$117.7M	$61.4M
200 year ARI	$357.7M	$294.2M
500 year ARI	$505.0M	$466.2M
AAD*	$3.5M	$2.8M
Present Value (AAD)	$41.6M	$32.2M

* Annual Average Damage

Emu Plains and Penrith

The proposed lakes scheme results in significant reductions in peak water levels in both the 100 year ARI and the 200 year ARI within the Emu Plains and Penrith areas (refer figure below). Reductions in the order of 0.5 to 1 metre are observed in the 100 year ARI levels along the Nepean River. This results in a significant benefit to a large number of properties in this area

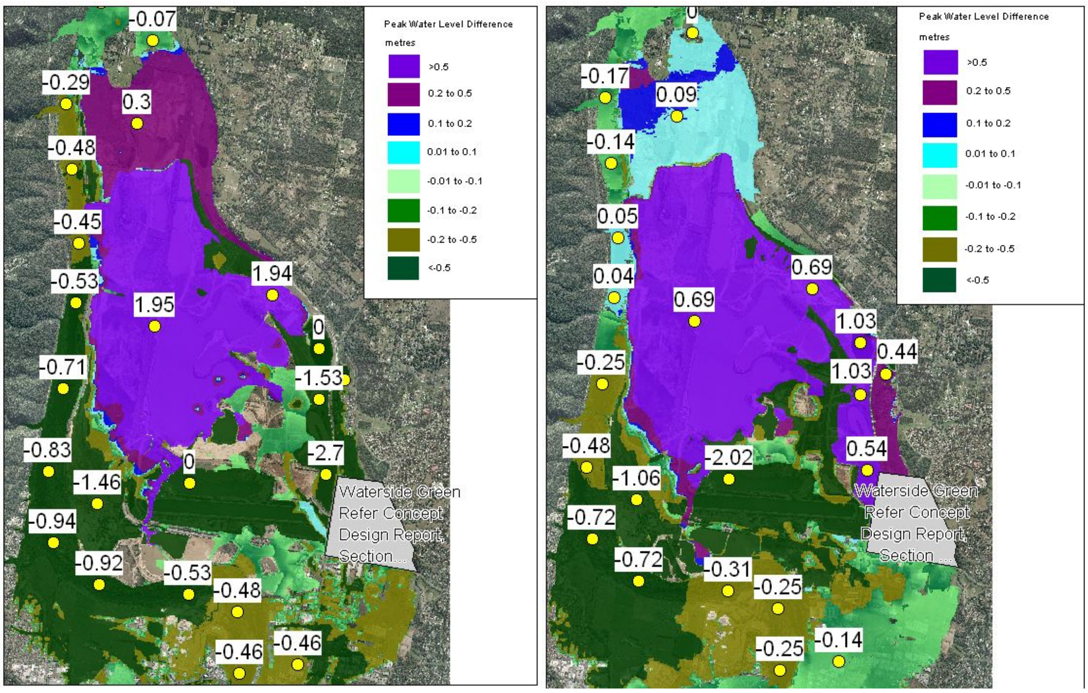

Figure. Change in Peak Water Level – 100 year ARI (left) and 200 year ARI (right)

Smith Street Area

The proposed Scheme results in increases in peak water levels within a natural floodway on the property to the north of Smith Street, by approximately 0.3 metres in a 100 year ARI event and approximately 0.1 metres in a 200 year ARI event.

The impacts in this area are on rural land, which is already impacted by flooding under the pre-quarry scenario. The following figures show the increases in peak water levels in this area. The locations showing peak water levels indicate existing structures (horse shelters) on the floodplain in this location, and show the increases in peak water levels. It is noted that in the majority of cases the increase of 0.3 metres in the 100 year ARI event affects structures where the pre-quarry flooding depth is in the order of 1 metre or greater.

As it is unlikely that development could occur in this area (due to it being an active floodway), even under pre-quarry conditions, it is considered that this impact is not significant.

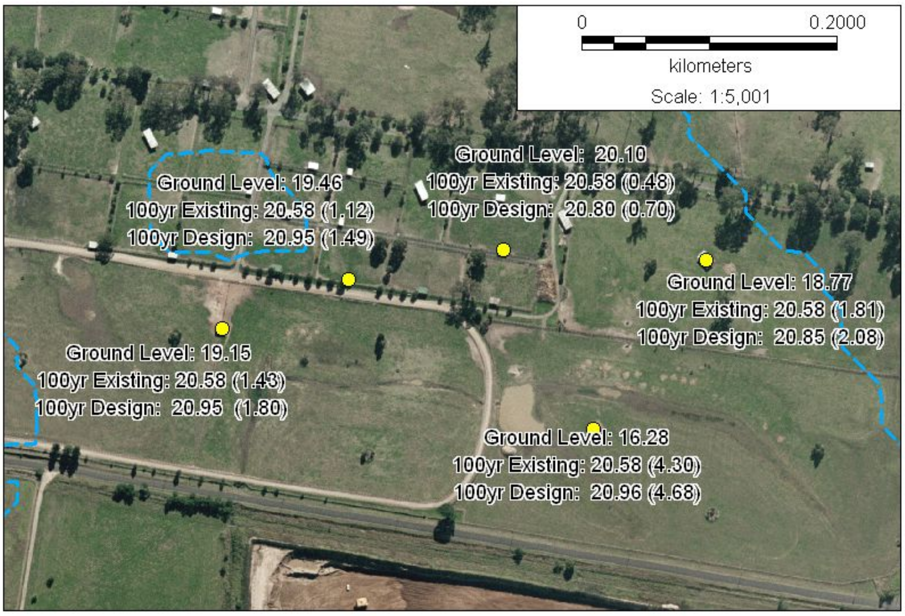

Figure. 100 year ARI Impacts in Smith Street Area (Peak Water Levels, with Depths in brackets)

Cranebrook Village Area

The Eastern Lakes area is primarily protected from flooding from the Main Lake during a 100 year ARI event. As such, the Penrith Lakes Scheme has a significant benefit to the Cranebrook Village area, as under the pre-quarry conditions this area would have experienced flood depths in the order of 0.5 to 1 metre in some locations (refer to figure below).

In a 200 year ARI event, a significant amount of water enters this area through the Penrith Industrial Area and Waterside Green. These flows then fill the Eastern Lakes prior to connecting to the Main Lake via a high level connection. While these high level connections protect the Cranebrook Village area in a 100 year ARI event, they also cause increases in peak water levels in a 200 year ARI event. These increases are in the order of 0.45 metres (refer to figure below).

A preliminary analysis of the flood damages in this area suggests that the savings in the 100 year ARI far outweigh any increase in the damages in the 200 year ARI.

Figure. 100 year ARI Impacts in Cranebrook Village Area (Peak Water Levels, with Depths in brackets)

Figure. 200 year ARI Impacts in Cranebrook Village Area (Peak Water Levels, with Depths in brackets)

Waterside Green

Waterside Green is a new development located to the east of the Penrith Lakes Scheme. This development was design based on a previous Lakes Scheme design. An assessment of the flood levels in this location for both the 100 year and 200 year ARIs show that the proposed Lakes Scheme would result in lower flood levels in this area compared to the design of Waterside Green.

Changes in Velocities

Along the Nepean River, minor changes in peak depth averaged velocities are observed, generally within ± 0.5 m/s (10%) in the 100 year ARI and less than 0.5 m/s in the 20 year ARI. Given that the depth averaged velocity along the Nepean River are in the order of 5 m/s in some locations in the 100 year ARI event, it is considered that these changes are relatively minor. Furthermore, as the changes are relatively minor in the 20 year ARI event, and would not occur at all in the 10 year ARI event, it is not expected that there would be significant geomorphological changes as a result of the proposed Lakes Scheme.

Increases in velocities are also observed in the natural flowpath to the north of the Wildlife Lake weir. At this location, increases in peak velocities of up to 1.4m/s are observed in the 100 year ARI and approximately 0.9 m/s in the 20 year ARI. It is noted that this increase in velocity occurs over a relatively short time frame, primarily while the Wildlife Lake is filling and the velocity is low enough that additional erosion of this area will not occur.

For the flowpath to the north of Smith Street, an increase in peak velocity is observed in the 100 year ARI, of up to 1 m/s. The resulting velocities at Smith Street in the 100 year ARI event are generally less than 2m/s. Given that this area has a good grass cover, it is unlikely that there would be significant erosion as a result of the Lakes Scheme. It should be noted that the proposed Lakes Scheme results in reductions in velocities in the 50 year ARI event of up to 0.4 m/s.

Climate Change Analysis

Changes to climate conditions are expected to have adverse impacts on sea levels and rainfall intensities. While the impact of sea level rise is not a major concern for Penrith Lakes, changes in design rainfall intensities will affect the peak flood levels of the overall lakes scheme.

A 5% increase in long duration rainfall intensities has been assumed for the 100 year ARI. This falls within the -7 to +10% predicted range for rainfall intensities for the Hawkesbury Nepean Catchment. This results in a 10% increase in peak flows during the 100 year ARI event. More details are provided in **Section 10**.

A comparison between the 100 year ARI event with climate change and the existing 100 year ARI event was undertaken.

In the Nepean River, increases in the order of 0.5 metres in the 100 year ARI flood levels are observed near the Penrith Weir and the Emu Plains area as a result of climate change. Further north, towards Hunts Gully, the levels in the Nepean River increase by 0.7 metres.

Within the Lakes Scheme itself, increases in the Main Lake are 0.34 metres. Wildlife Lake has larger increases of 0.73 metres.

Summary

In summary, the Penrith Lakes Scheme will result in significant benefits to the communities of Penrith and Emu Plains, with significant reductions in peak flood levels in those areas. The infrastructure outlined in this report has been sized so that it performs in events up to and including the PMF event.

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Glossary

Australian Height Datum (AHD)	A common national surface level datum approximately corresponding to mean sea level.
Average recurrence interval (ARI)	The long-term average number of years between the occurrence of a flood as big as or larger than the selected event. For example, floods with a discharge as great as or greater than the 20 year ARI flood event will occur on average once every 20 years. ARI is another way of expressing the likelihood of occurrence of a flood event.
Cadastre, cadastral base	Information in map or digital form showing the extent and usage of land, including streets, lot boundaries, water courses etc.
Catchment	The land area draining through the main stream, as well as tributary streams, to a particular site. It always relates to an area above a specific location.
Creek Rehabilitation	Rehabilitating the natural 'biophysical' (i.e. geomorphic and ecological) functions of the creek.
Creek Modification	Widening or altering the creek channel in an environmentally compatible manner (i.e. including weed removal and stabilisation with suitable native endemic vegetation) to allow for additional conveyance.
Design flood	A significant event to be considered in the design process; various works within the floodplain may have different design events, e.g. some roads may be designed to be overtopped in the 1 year ARI flood event.
Development	Is defined in Part 4 of the EP&A Act. Infill development: refers to the development of vacant blocks of land that are generally surrounded by developed properties and is permissible under the current zoning of the land. Conditions such as minimum floor levels may be imposed on infill development new development: refers to development of a completely different nature to that associated with the former land use. Eg, the urban subdivision of an area previously used for rural purposes. New developments involve re-zoning and typically require major extensions of existing urban services, such as roads, water supply, sewerage and electric power. Redevelopment: refers to rebuilding in an area. Eg, as urban areas age, it may become necessary to demolish and reconstruct buildings on a relatively large scale. Redevelopment generally does not require either re-zoning or major extensions to urban services.
Discharge	The rate of flow of water measured in terms of volume per unit time, for example, cubic metres per second (m3/s). Discharge is different from the speed or velocity of flow, which is a measure of how fast the water is moving for example, metres per second (m/s).

Flash flooding	Flooding which is sudden and unexpected. It is often caused by sudden local or nearby heavy rainfall. Often defined as flooding which peaks within six hours of the causative rain.
Flood	Relatively high stream flow which overtops the natural or artificial banks in any part of a stream, river, estuary, lake or dam, and/or local overland flooding associated with major drainage before entering a watercourse, and/or coastal inundation resulting from super-elevated sea levels and/or waves overtopping coastline defences excluding tsunami.
Flood fringe	The remaining area of flood-prone land after floodway and flood storage areas have been defined.
Flood hazard	A source of potential harm or a situation with a potential to cause loss. In relation to this manual the hazard is flooding which has the potential to cause damage to the community. Definitions of high and low provisional hazard categories are provided in Appendix L of the Floodplain Development Manual (NSW Government, 2005).
Flood-prone land	Land susceptible to inundation by the probable maximum flood (PMF) event, i.e. the maximum extent of flood liable land.
Floodplain	Area of land which is subject to inundation by floods up to the probable maximum flood event, i.e. flood prone land.
Floodplain risk management options	The measures that might be feasible for the management of a particular area of the floodplain. Preparation of a floodplain risk management plan requires a detailed evaluation of floodplain risk management options.
Flood planning area	The area of land below the FPL and thus subject to flood related development controls.
Flood planning levels	Are the combinations of flood levels (derived from significant historical flood events or floods of specific ARIs) and freeboards selected for floodplain risk management purposes, as determined in management studies and incorporated in management plans.
Flood Risk	Potential danger to personal safety and potential damage to property resulting from flooding. The degree of risk varies with circumstances across the full range of floods. Flood risk in this manual is divided into 3 types, existing, future and continuing risks. They are described below: ▪ Existing flood risk: the risk a community is exposed to as a result of its location on the floodplain. ▪ Future flood risk: the risk a community may be exposed to as a result of new development on the floodplain. ▪ Continuing flood risk: the risk a community is exposed to after floodplain risk management measures have been implemented. For a town protected by levees, the continuing flood risk is the consequences of the levees being overtopped. For an area without any floodplain risk management measures, the continuing flood risk is simply the existence of its flood exposure.

Flood storage areas	Those parts of the floodplain that are important for the temporary storage of floodwaters during the passage of a flood. The extent and behaviour of flood storage areas may change with flood severity, and loss of flood storage can increase the severity of flood impacts by reducing natural flood attenuation. Hence, it is necessary to investigate a range of flood sizes before defining flood storage areas.
Floodway areas	Those areas of the floodplain where a significant discharge of water occurs during floods. They are often aligned with naturally defined channels. Floodways are areas that, even if only partially blocked, would cause a significant redistribution of flood flow, or a significant increase in flood levels.
Freeboard	Provides reasonable certainty that the risk exposure selected in deciding on a particular flood chosen as the basis for the FPL is actually provided. It is a factor of safety typically used in relation to the setting of floor levels, levee crest levels, etc. (See Section K5). Freeboard is included in the flood planning level.
Geographical information systems (GIS)	A system of software and procedures designed to support the management, manipulation, analysis and display of spatially referenced data.
High hazard	Flood conditions that pose a possible danger to personal safety; evacuation by trucks difficult; able-bodied adults would have difficulty wading to safety; potential for significant structural damage to buildings.
Hydraulics	The term given to the study of water flow in a river, channel or pipe, in particular, the evaluation of flow parameters such as stage and velocity.
Hydrograph	A graph that shows how the discharge changes with time at any particular location.
Hydrology	The term given to the study of the rainfall and runoff process as it relates to the derivation of hydrographs for given floods.
Local overland flooding	Inundation by local runoff rather than overbank discharge from a stream, river, estuary, lake or dam.
Low hazard	Flood conditions such that should it be necessary, people and their possessions could be evacuated by trucks; able-bodied adults would have little difficulty wading to safety.
Mainstream flooding	Inundation of normally dry land occurring when water overflows the natural or artificial banks of a stream, river, estuary, lake or dam.
Major Drainage	Councils have discretion in determining whether urban drainage problems are associated with major or local drainage. For the purposes of this manual major drainage involves: ▪ the floodplains of original watercourses (which may now be piped, channelised or diverted), or sloping areas where overland flows develop along alternative paths once system capacity is exceeded; and/or

	▪ Water depths generally in excess of 0.3m (in the major system design storm as defined in the current version of Australian Rainfall and Runoff). These conditions may result in danger to personal safety and property damage to both premises and vehicles; and/or ▪ major overland flowpaths through developed areas outside of defined drainage reserves; and/or ▪ The potential to affect a number of buildings along the major flow path.
Management plan	A document including, as appropriate, both written and diagrammatic information describing how a particular area of land is to be used and managed to achieve defined objectives. With regard to flooding, the objective of the management plan is to minimise and mitigate the risk of flooding to the community. It may also include description and discussion of various issues, special features and values of the area, the specific management measures which are to apply and the means and timing by which the plan will be implemented.
Mathematical/computer models	The mathematical representation of the physical processes involved in runoff and stream flow. These models are often run on computers due to the complexity of the mathematical relationships. In this report, the models referred to are mainly involved with rainfall, runoff, pipe and overland stream flow.
NPER	National Professional Engineers Register. Maintained by the Institution of Engineers, Australia.
Peak discharge	The maximum discharge occurring during a flood event.
Probable maximum flood	The PMF is the largest flood that could conceivably occur at a particular location, usually estimated from probable maximum precipitation, and where applicable, snow melt, coupled with the worst flood producing catchment conditions. Generally, it is not physically or economically possible to provide complete protection against this event. The PMF defines the extent of flood prone land, that is, the floodplain. The extent, nature and potential consequences of flooding associated with a range of events rarer than the flood used for designing mitigation works and controlling development, up to and including the PMF event should be addressed in a floodplain risk management study.
Probable Maximum Precipitation	The PMP is the greatest depth of precipitation for a given duration meteorologically possible over a given size storm area at a particular location at a particular time of the year, with no allowance made for long-term climatic trends (World Meteorological Organisation, 1986). It is the primary input to PMF estimation.
Probability	A statistical measure of the expected frequency or occurrence of flooding.
Risk	Chance of something happening that will have an impact. It is measured in terms of consequences and likelihood. For this study, it is the likelihood of consequences arising from the interaction of floods, communities and the environment.

Runoff	The amount of rainfall that actually ends up as stream or pipe flow, also known as rainfall excess.
Stage	Equivalent to 'water level'. Both are measured with reference to a specified datum.
Stage hydrograph	A graph that shows how the water level changes with time. It must be referenced to a particular location and datum.
Stormwater flooding	Inundation by local runoff. Stormwater flooding can be caused by local runoff exceeding the capacity of an urban stormwater drainage system or by the backwater effects of mainstream flooding causing the urban stormwater drainage system to overflow.
Topography	A surface which defines the ground level of a chosen area.

Terminology in this Glossary has been derived or adapted from the NSW Government *Floodplain Development Manual*, 2005, where available.

Abbreviations

AAD	Average Annual Damage
AEP	Annual Exceedance Probability
AHD	Australian Height Datum
ARI	Average Recurrence Interval
AWE	Average Weekly Earnings
BoM	Bureau of Meteorology
CPI	Consumer Price Index
DCP	Development Control Plan
DECCW	Department of Environment, Climate Change and Water (formerly the Department of Environment and Climate Change)
DNR	Department of Natural Resources (now DECCW)
FPL	Flood Planning Level
FRMC	Floodplain Risk Management Committee
FRMP	Floodplain Risk Management Plan
FRMS	Floodplain Risk Management Study
GIS	Geographic Information System
GSDM	Generalised Short Duration Method
ha	hectare
IEAust	Institution of Engineers, Australia
IFD	Intensity Frequency Duration
km	kilometres
km^2	Square kilometres
LEP	Local Environment Plan
LGA	Local Government Area
m	metre
m^2	Square metres
m^3	Cubic metres
mAHD	Metres to Australian Height Datum

MHL	Manly Hydraulics Laboratory
MHWL	Mean High Water Level
mm	millimetre
m/s	metres per second
MSL	Mean Sea Level
NSW	New South Wales
PMF	Probable Maximum Flood
PMP	Probable Maximum Precipitation
RAFTS	RAFTS proprietary software package
RTA	Roads and Traffic Authority
SEPP	State Environmental Planning Policy
SES	State Emergency Service

1 Introduction

1.1 Study Area Description

The Penrith Lakes Development Area is located north of Penrith CBD, adjacent to the Nepean River, in Western Sydney (**Figure 1.1**). The study area is approximately 7km long and covers an area of approximately 19km^2. The site is bordered by the Nepean River on the west and south, the Castlereagh escarpment in the east, and Smith St in the north (**Figure 1.2**).

Much of the Penrith Lakes Development Area is still an active quarry. However, upon completion of the quarrying, it is proposed by the Penrith Lakes Development Corporation (PLDC) to redevelop the land into a number of large lakes. A concept sketch of the proposed Lakes Scheme is provided in **Figure 1.3**.

1.2 Study Objectives

Cardno has been engaged by Penrith Lakes Development Corporation (PLDC) to analyse the flood behaviour and flood impacts of the completed Penrith Lakes Scheme. This includes the concept design of a number of key flood infrastructure components to the overall Penrith Lakes Scheme. This report comprises the details and results of the analysis.

The objectives of the analysis were:

- To remove or minimise impacts to surrounding areas;
- To optimise weir and flowpath design; and,
- To provide preliminary information on the protection requirements for flow structures.

2 Available Data

2.1 Previous Studies

Until early 2008 the assessment of flooding of the Penrith Lakes Scheme was undertaken by the University of NSW Water Research Laboratory (WRL) utilising a large physical model of the proposed Penrith Lakes Development. This model was constructed, operated and maintained on-site at Penrith Lakes. In May 2008, Cardno was commissioned by the Penrith Lakes Development Corporation (PLDC) to construct a numerical model of the Penrith Lakes Scheme to allow the rapid of refinements to the hydraulic operation of the proposed lakes scheme. This numerical model underwent extensive calibration and verification from 2008 to 2010, and is detailed in *Penrith Lakes Flood Model : Calibration and Verification* (Cardno, 2010A).

The calibrated and verified numerical model has since been utilised to undertake hydraulic assessments of various potential design improvements for the Penrith Lakes Scheme as a whole. This work is currently in progress.

A number of studies have been undertaken prior to the creation of a numerical model by Cardno on the flood behaviour within the Nepean River. These studies are reviewed in detail in *Penrith Lakes Flood Model : Calibration and Verification* (Cardno, 2010A), and include:

- Public Works Department New South Wales (1978). Hawkesbury River March 1978 Flood Report, PWD 79009.
- University of New South Wales Water Research Laboratory (1985a). Penrith Lakes Scheme Flood Protection – Nepean River Flood Profiles, June, prepared by R J Cox & W L Pierson, Technical Report 85/06.
- University of New South Wales Water Research Laboratory (1985b). Penrith Lakes Flood Protection Preliminary Design, December, prepared by RJ Cox, R Nittim & W L Pierson, Technical Report 85/14.
- University of New South Wales Water Research Laboratory (1992). Penrith Lakes Scheme Flood Protection Physical Model Studies, June, prepared by RJ Cox & GM Witheridge, Technical Report 92/03.
- University of New South Wales Water Research Laboratory (2008a). Penrith Lakes Scheme Flood Protection Model – Recalibration of River Flood Profiles, September 2007 re-issued April 2008, prepared by D J Anderson, D S Rayner & B M Miller, Technical Report 2007/18.
- University of New South Wales Water Research Laboratory (2008b). Physical Model Investigations and Flood Studies for 2007, April, prepared by Brett Miller for Matthew Zollinger (PLDC), ref: WRL Letter Report 22/04/2008 07030.07 DSR:DJA
- Worley Parsons (2008). Nepean River RMA-2 Model, Draft Rev C, prepared for Penrith City Council.

2.2 Available Survey Data

2.2.1 Aerial Survey

Aerial laser scanning (ALS) data was supplied by Penrith City Council on 19 April 2008. Typical accuracies of ALS data are +/- 0.15m on hard surfaces to one standard deviation.

This data is available for the entire Penrith LGA. The following tiles were utilised for the study:

- 2806260
- 2806264
- 2826260
- 2826264
- 2826268
- 2846272
- 2846276
- 2866260
- 2866264
- 2866268
- 2866272
- 2866276
- 2886276

The ALS data was flown in 2003, and is therefore representative of the catchment conditions at that time.

2.2.2 Physical Model Laser Scanning

Two sets of laser scanning of the physical model were available:

- Early 2007 scan, supplied by WRL on 29 April 2008 (0.5m CONTOURS at 500 with HT ADJ.dwg)
- 2005 scan, supplied by WRL on 11 June 2008 (Contours-PriorTo2005Modifications.dwg)

The laser scanning, based on the data set provided by WRL (29 April 2008) is accurate to +/- 3mm in the physical model, which equates to +/- 0.21m at a real world scale. Further details are available in the *Penrith Lakes Flood Model : Calibration and Verification* (Cardno, 2010A).

2.2.3 Pre-quarry Aerial Survey

A terrain model of the Penrith Lakes Scheme was provided by PLDC on 11 June 2008. This terrain model was derived from photogrammetry that was undertaken prior to the majority of the quarry works. For the purposes of this report, it is referred to as the pre-quarry condition.

2.2.4 Cross Section Data

Cross section data of the Nepean River was supplied by WRL on 29 April 2008, derived from Patterson Britton & Partners (now Worley Parsons) survey and WRL Figures. Further details are available in the *Calibration and Verification Report* (Cardno, 2009a).

2.2.5 Additional Survey and Design Details

Additional survey and terrain information was provided at a number of locations:

- Andrews Road Culverts – details of the existing culverts under Andrews Road, to the east of Castlereagh Road, provided by PLDC on 17 June 2008 (Drawing Title : Swale Drain Survey in Industrial Park, dated 21 June 2007, filename: 070621_cn_andrewsRd.pdf).
- Proposed Upgrade to Andrews Road and Castlereagh Roads. Proposed amplification works along Andrews Road to ensure that an evacuation route is available above the 500

year ARI. Details, including the sizes and location of the existing culverts and the proposed design culvert provided by J Wyndham Prince on 30 July 2008 (filename : 8233 Andrews Road Summary.pdf).

- Waterside Green Development- design terrain details were provided for the Waterside Green development by PLDC on 20 June 2008 (filename : 080607_8361 JWP Design V6 DTM Triangles_Water Side Green Only.dwg).

2.3 Aerial Photography

Two sets of aerial photographs were available for the study:

- May 2008 Aerial Photography, supplied by PLDC on 23 June 2008.
- 2003 Aerial Photography, supplied by Penrith City Council on 19 April 2008.

2.4 Design Terrain

A design terrain, representative of the proposed lake system, was provided by PLDC on 30 October 2009 (*091030_Two Lakes V13d_triangles.dwg*). The proposed design is discussed in more detail in **Section 5.4**.

2.5 RUBICON Model Results

Results from the RUBICON modelling undertaken in 2005 were provided by WRL on 29 April 2008. These results were originally provided to WRL by WMAwater. These results included both water level and discharge hydrographs for cross sections located in the study area. These results included:

- 1978, 1986 and 1990 historical flood events (*Historical_Timeseries.xls*)
- 100 yr ARI, 200 yr ARI, 500 yr ARI and 1000 yr ARI design flood events (Design_Timeseries.xls).

Additional discharge and water level time series were provided by WMAwater to PLDC on 5 May 2008. These results included:

- 10 yr ARI, 20 yr ARI and 50 yr ARI design floods; and the
- 1 day and 3 day PMF floods.

3 Background

3.1 Previous Lake Designs

Previous concept lake designs were undertaken by WRL utilising a physical model of the Nepean and the Lakes Scheme.

The previous scheme incorporated five main lakes, including the existing Regatta Lake. A series of smaller lakes, referred to as the Cranebrook Lakes and in this report the Eastern Lakes, were located on the eastern portion of the Penrith Lakes Scheme, adjacent to Cranebrook Road.

Numerous weir configurations and designs were undertaken by WRL. **Table 3.1** shows the weir dimensions from the 2006 Version 4 scheme assessed by WRL. The location of the weirs and the scheme design is shown in **Figure 3.1**. This design was utilised for the verification of the numerical model, and is discussed in detail in the report *Penrith Lakes Flood Model : Calibration and Verification* (Cardno, 2010A). It is noted that there were also subsequent design modifications by WRL which are detailed in their reports (refer **Section 2.1)**. However, the 2006 Version 4 scheme is generally representative of more recent designs and is the scheme with the most results and surface information available.

The 2006 Version 4 scheme was generally in line with the proposed scheme in the Penrith Lakes Deed. A comparison on the weir lengths, as stated in the Deed, and the 2006 Version 4 scheme are provided in **Table 3.1**.

Table 3.1 Weir Dimensions for 2006 Version 4 Model Runs

Weir No	Length (m)		Zw – D/S	Zw – U/S	ZB – D/S	ZB – U/S	WB – D/S	WB – U/S	End Slope	End Slope
	WRL	Deed								
0	200	300*	25.4	25.4	N/A	N/A	N/A	N/A	N/A	N/A
1	130		20.9	21.1	24.5	25.00	15.00	15	40.00	12.00
3	470	500	20.405	20.65	24	24.20	10.00	25	8.50	6.00
5	300	700	20	20.1	23	23.30	15.00	50	17.50	10.00
7	270	500	10.8	10.8	22	22.30	20.00	20	10.00	10.00
2	1200	500	23.75	23.75	24.5	24.50	N/A	N/A	N/A	N/A
4	420	500	21.4	21.4	23	23.00	25.00	65	N/A	N/A
6	440	500	21	21	22	22.00	30.00	35	N/A	N/A
8	500	500	21	21	22	22.00	8.00	8	N/A	N/A

Zw – Elevation of Weir Crest (m AHD)
ZB – Elevation of Bank (m AHD)
WB – width across
EndSlope – Slope from Weir crest to top of bank
U/S – Upstream
D/S – Downstream
* Only one weir is included in the Deed, which approximately correlates with Weir 0 and 1 in WRL 2006 Version 4

3.2 Overview of Proposed Lakes Scheme

An overview of the proposed lakes scheme is provided in **Figure 3.2.** The most significant change in the lakes layout is the combination of the two central lakes in previous designs to form a single large lake. This large lake, referred to as the Main Lake, is approximately 3.7 kilometres long and up to 2 kilometres wide.

3.2.1 Lake Details

A summary of the lake areas and proposed operational water levels for the larger lakes in the scheme is shown in **Table 3.2.**

Table 3.2 Primary Lake Details

Lake	Area (ha)	Operational Water Level (m AHD)
Main Lake	444	14
Wildlife Lake	110	10
Quarantine Lake	45	15
Regatta Lake	80	15

A series of smaller lakes to the east of the Main and Regatta Lakes is collectively referred to as the Eastern Lakes in this report. Details on these lakes is provided in **Table 3.3.**

Table 3.3 Eastern Lakes Details

Lake	Area (ha)	Operational Water Level (m AHD)
Lewis Lagoon	3	14
Allawah Lake	14	18
Duralia Lake	13	18
Cranebrook Lake	3	18
North Pond	8	16.5
Pioneer Fresh Pond	6	17
Middle Basin	14	16
Final Basin	8	15.5

3.2.2 Comparison of Weirs

The previous lake designs, such as the 2006 Version 4 WRL design (refer **Section 3.1**), resulted in a significant number of long weirs. The proposed lakes scheme reduces both the number and overall length of the weirs. A summary of the total weir lengths from both the 1987 Deed of Agreement and the 2006 Version 4 WRL design are provided in **Table 3.4**. The proposed scheme represents a significant reduction in the overall disturbance of the riverbank.

Table 3.4 Weir Lengths - Previous Lake Schemes

Scheme	Total Weir Length (m)	Riverbank Weir Length (m)	Total Number of Weirs
Deed	4000	2000	8
2006 Version 4 (WRL)	3930	1370	9
Proposed Scheme	1600*	640	5

* does not include the high level flowpaths to the Eastern Lakes

3.2.3 Flood Infrastructure Components

There are a number of key flooding infrastructure components within the proposed Lakes Scheme. These key infrastructure components are identified in **Figure 3.2**. A summary of these key infrastructure components and their function is given in **Table 3.5**.

Table 3.5 Summary of Flood Infrastructure Components

Component	Description
Main Weir (Weir 1)	The Main Weir is the primary control for flood waters entering the Lakes Scheme from the Nepean River and subsequently the Main Lake.
Wildlife Lake weir	Wildlife Lake weir serves two purposes. It conveys inflows from the Nepean during the early part of the flood, and outflows from the Lakes during the latter part of the flood.
Riverbank	The Riverbank bund prevents the inflow of floodwaters into the Lakes Scheme until the lake levels are closer to the Nepean River levels, to protect the integrity of the riverbank.
Weir 6	Weir 6 is the primary control (other than Weir 1) for flood waters between the Main Lake and the Wildlife Lake. It controls the water levels within the Main Lake, as well as Quarantine and Regatta Lakes.
Quarantine Flowpath	This is a low level flowpath between the Quarantine Lake and the Main Lake to convey floodwaters into the Main Lake.
Regatta Flowpath	This is a low level flowpath between the Main Lake and Regatta Lake to convey floodwater into the Regatta Lake.
Eastern Lakes	The Eastern Lakes are a series of lakes to the east of the Main Lake. The majority of these lakes are disconnected from the Main Lake during a 100 year ARI flood by high ground levels although there is a connection through smaller existing culverts between the Regatta Lake and Final Basin.

Greater details of the various flood components of the proposed scheme are provided in **Section 6**.

4 Overview of Flooding Behaviour

The following provides a summary of the flooding behaviour of the proposed Lakes Scheme.

4.1 Stage 1 – Filling through Wildlife Lake weir

During the early part of the flood event, the Wildlife Lake starts to fill through Wildlife Lake weir in the north (**Figure 4.1**). The crest level of Wildlife Lake weir is approximately 16m AHD, while the operating level of the Wildlife Lake is approximately 10m AHD. Overtopping will occur in events greater than a 10 year ARI.

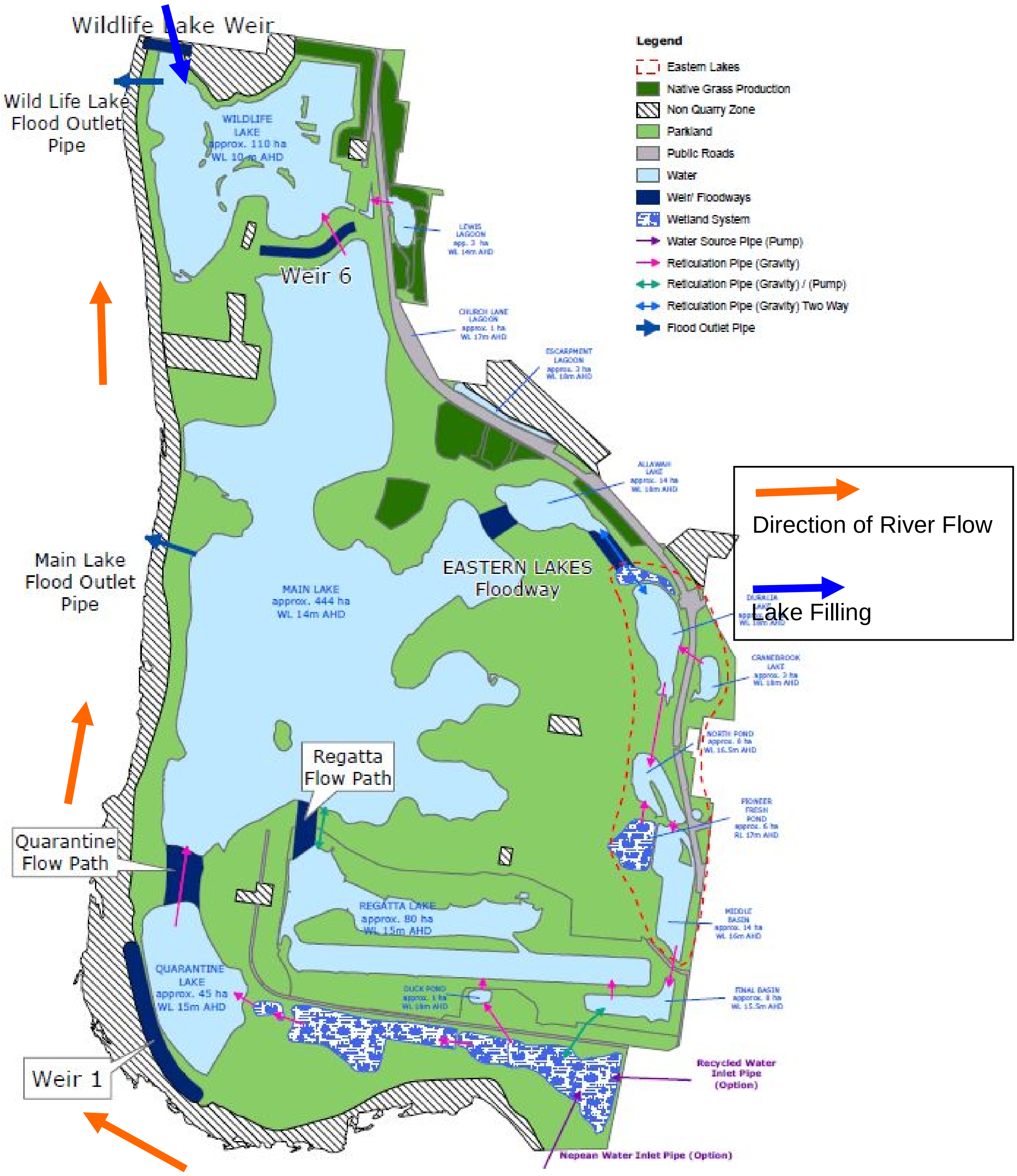

Figure 4.1 Stage 1 - Flooding Behaviour

4.2 Stage 2 – Filling through Wildlife Lake weir & Across Weir 1

In the second stage, Weir 1, at a level of 21.6m AHD, starts to overtop (only in events greater than 25 year ARI). This commences the filling of Quarantine Lake and Main Lake via the Quarantine Flowpath. Meanwhile, Wildlife Lake is still filling through Wildlife Lake weir (**Figure 4.2**).

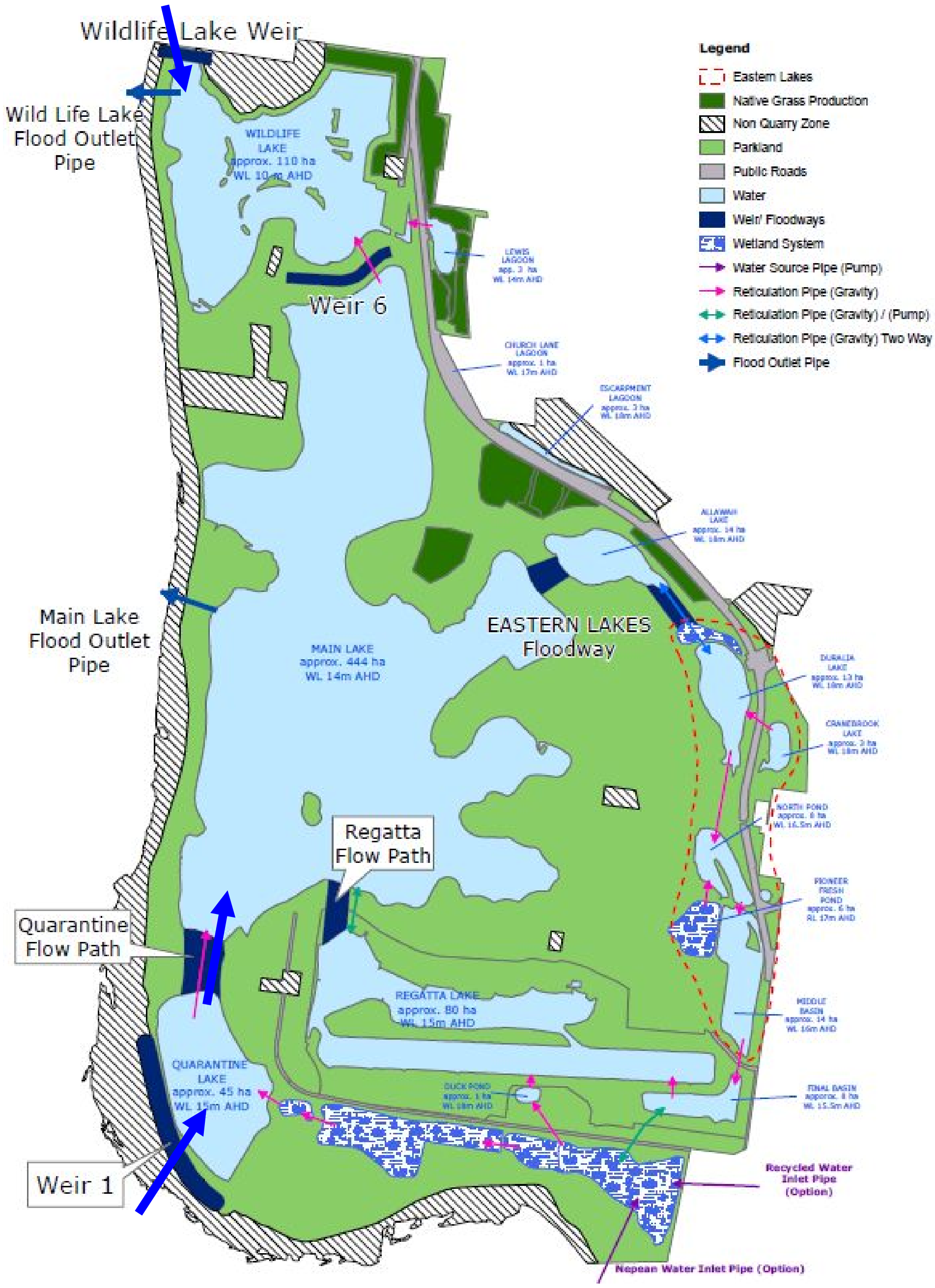

Figure 4.2 Stage 2 - Flooding Behaviour

4.3 Stage 3 – Overtopping of Weir 6

Weir 6, at a level of 21m AHD, represents the major control for the Main Lake. Once the Main Lake has filled from 14m AHD (operating level) to 21m AHD, it begins to overtop into the Wildlife Lake. Around this time, the overtopping of Weir 6 fills the Wildlife Lake such that it reverses the direction of flow through Wildlife Lake weir (**Figure 4.3**).

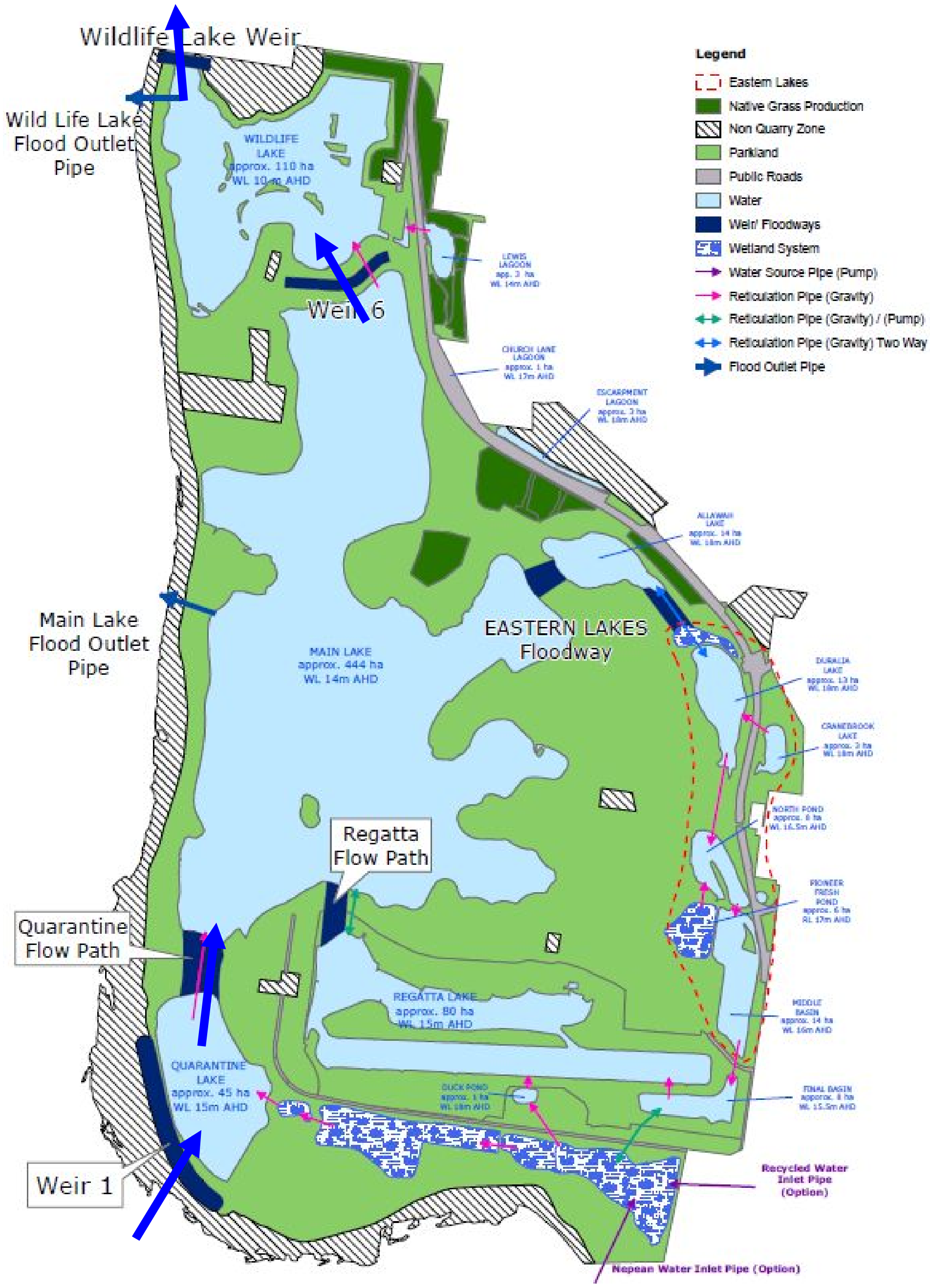

Figure 4.3 Stage 3 - Flooding Behaviour

4.4 Stage 4 – Post Flood

As the flood through the Nepean River recedes, overtopping of Weir 1 stops. Following this, Weir 6 stops overtopping and finally flows across the Wildlife Lake Weir cease.

After the flood has receded, however, the lakes are elevated above their normal operating levels. For the Main Lake, the post-flood level is 21m AHD (the crest level of Weir 6). For the Wildlife Lake, the post-flood level is 16m AHD (the crest level of Wildlife Lake weir).

The objective of the flood drainage is therefore to draw-down the post-flood levels within the lakes back to normal operating conditions. For the Main Lake, this represents a draw down of approximately 7 metres of water, while for the Wildlife Lake this represents a draw down of approximately 6 metres of water.

The concept design of these pipes is the subject of the report *Penrith Lakes Scheme : Concept Flood Drainage Design* (Cardno, 2010B).

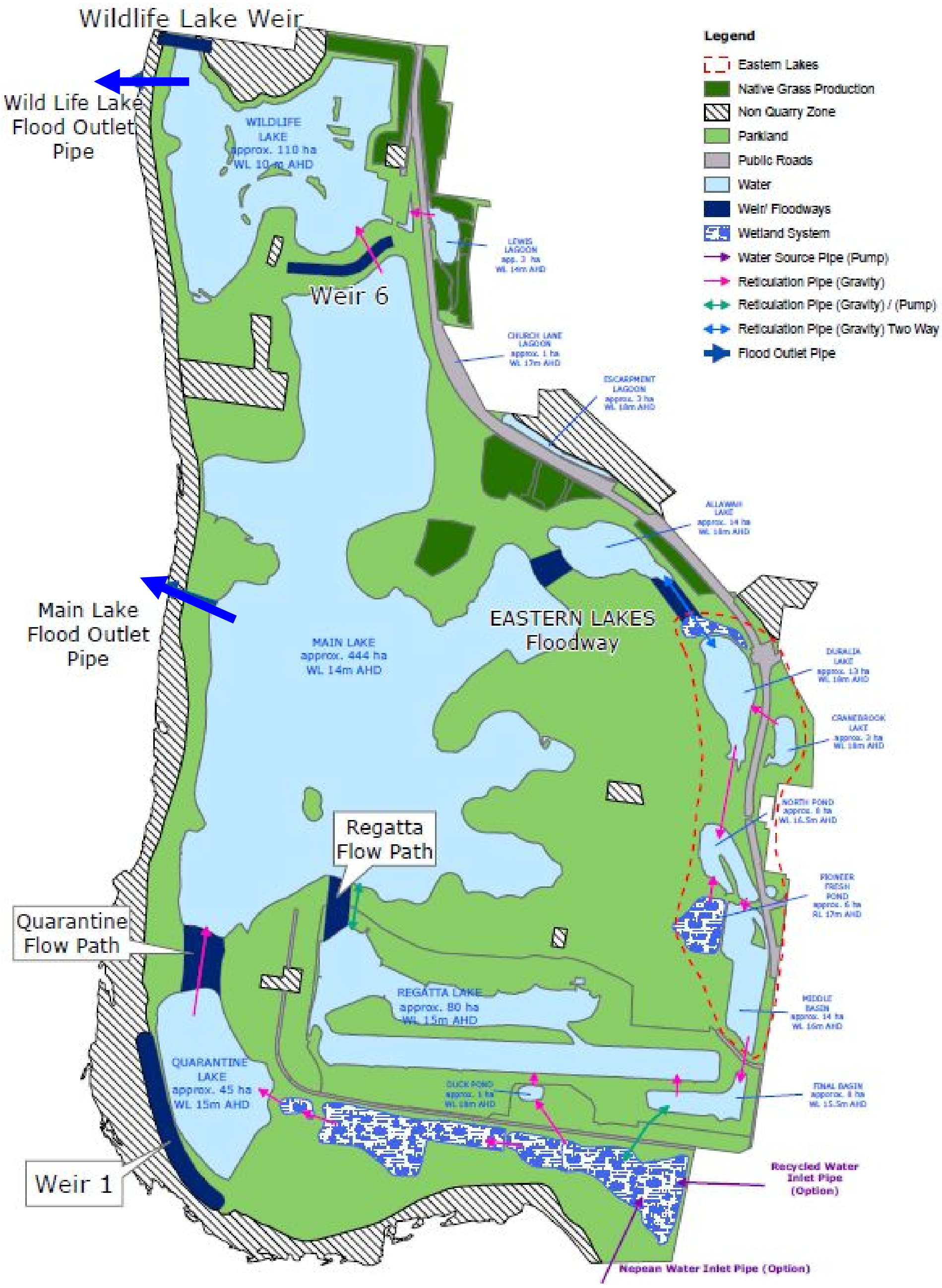

Figure 4.4. Stage 4 – Flooding Behaviour

5 Modelling Scenarios

A two-dimensional (2D) numerical model was established for the study area. The details of the establishment, calibration and verification of this model are provided in Cardno (2009).

Two key modelling scenarios have been undertaken for this report:

- Pre-quarry Scenario (Base Case) – a representative scenario of the conditions of the Penrith Lakes area prior to quarrying.
- Deed Scenario – representative of the scheme as detailed in the Penrith Lakes Deed of Agreement.
- Preliminary Design Scenario - based on terrain 13d (**Section 2.4**).
- Final Concept Design Scenario – based on the preliminary design scenario with modifications to the various flood infrastructure elements.

A description of the terrain components of these models is provided in the following sections.

5.1 Pre-Quarry Scenario (Base Case)

The Pre-Quarry Scenario represents the Lakes Scheme prior to the quarry works being undertaken. The model terrain was based on the terrain established for the calibration and verification of the numerical model, and is detailed in the report *Penrith Lakes Flood Model : Calibration and Verification* (Cardno, 2010A). The following modifications were undertaken:

- Areas within the Penrith Lakes Scheme were based on the pre-quarry aerial photogrammetry (refer **Section 2.2.3**).
- Waterside Green was incorporated into the terrain utilising the information discussed in **Section 2.2.5**.
- The proposed culverts along Andrews Road and Castlereagh Road, as discussed in **Section 2.2.5**.
- Areas outside of the Scheme and Waterside Green were defined based on the 2003 ALS data (**Section 2.2.1**).

This scenario represents the Penrith study area if the quarry works had never been undertaken. Following discussions with DECCW and Penrith City Council, this scenario has been utilised as the benchmark scenario to assess potential impacts of the development.

5.2 Deed Scenario

The deed scenario represents the weirs and lake scheme proposed by the 1987 Deed of Agreement. The components of this are discussed in more detail in **Section 3**.

It is noted that the Deed does not specify the elevations of the proposed weirs. The model terrain was therefore based on the calibration and verification terrain (detailed in Cardno (2009)). This terrain represents one of the more recent WRL lake scheme options (**Section 3**). Modifications were undertaken to the model to represent the weir lengths detailed in the Deed (**Section 3.1**).

5.3 Preliminary Design Scenario

The preliminary design scenario is based on design terrain 13d, supplied by PLDC (refer **Section 2.4**). This scenario represents the starting point for the majority of the concept design discussed within this report. It forms a benchmark scenario for alterations to the various flood infrastructure components of the design, as discussed in **Section 6**.

The two exceptions to this are the Main Weir and Weir 6. Both of these weirs were assessed in previous design iterations, primarily within 2008 and 2009. The lengths and heights of these weirs were not altered in this report. A detailed description of the process in determining the heights and lengths for these weirs is provided in **Section 6**.

The terrain external to the Penrith Lakes Scheme is the same as that adopted for the Pre-quarry Scenario.

Some modifications were undertaken to the roughness mapping from Cardno (2010A) to reflect the proposed development, with the new roughness mapping shown in **Figure 5.1.**

5.4 Final Concept Design Scenario

The final concept design represents the Penrith Lakes Scheme following the outcomes of this assessment. While based on the Preliminary Design Scenario, the changes to the flood infrastructure components included in the final concept scheme is detailed in **Section 6**.

6 Flood Infrastructure Components

The concept design of each of the flood infrastructure components identified in **Section 3.2.3** was undertaken. This involved a number of iterations for each option, to optimise both the flood performance together with the overall cost and function. This process is detailed in the following sections.

6.1 Main Weir (Weir 1)

The Main Weir (Weir 1) is the primary control for floodwaters from the Nepean River from discharging into the Quarantine Lake and subsequently the Main Lake during a large flood event.

This weir underwent a concept design process in 2008 and 2009. The key constraint set by PLDC was the prevention of floodwaters from the Nepean River entering the Lakes (other than the Wildlife Lake) in events less than the 25 year ARI event. It is understood that this criterion was adopted to protect water quality in both the Main Lake as well as the Regatta Lake. The estimated 25 year ARI flood level at this location results in a weir crest level of 21.6 m AHD.

The length of the weir has been optimised to:

- Prevent impacts on flood levels in areas surrounding the Penrith Lakes Scheme;
- Provide sufficient filling of the Lakes Scheme, particularly in the 200 year ARI event when the Riverbank starts to overtop to reduce the difference in water levels under overtopping;
- Minimise the overall weir length to reduce environmental impacts and to reduce weir construction costs.

The proposed length of the weir is 600 metres.

During a 100 year ARI flood, up to 2000m^3/s discharges across the weir into the Lakes Scheme. Significant flow velocities will occur across the weir as the crest of the weir is at 21.6m AHD and the operating water level of the Quarantine Lake is at 15m AHD. It is therefore similar to a large spillway or dam. It is expected that this entire weir would need to be constructed from roller compacted concrete or equivalent materials.

It should also be noted that as the level of this weir is higher than Weir 6, the direction of flow is always from the Nepean River into the Lakes. There is never a reversal of flow from the Lakes into the Nepean River across this weir.

It is possible to alter to some degree the width of the Main Weir. Testing was undertaken on reducing the width of this weir by approximately 100 metres (from the northern end). This resulted in reductions in peak water levels within the Main Lake of approximately 0.1 metres and increases in flood levels in the Nepean River near the weir in the order of 0.06 metres. The final sizing of this weir can be determined during detailed design.

While the peak water levels in both the Nepean River and the Lakes do not change significantly, the rate of filling of the lakes does change (refer **Figure 6.1**). For example, at the location shown in **Figure 6.1**, a slower filling rate results in a 0.4 metre difference between the two scenarios over the same period in time. At this point, the shorter weir takes

45 minutes longer to fill than the base design. This potentially has implications for protection works for the Riverbank, as well as for the Regatta Flowpath and the Quarantine Flowpath.

Therefore, it is recommended that should any changes to this weir be undertaken, that the impacts on these other structures also be considered.

The location of the Main Weir is shown in **Figure 6.2**.

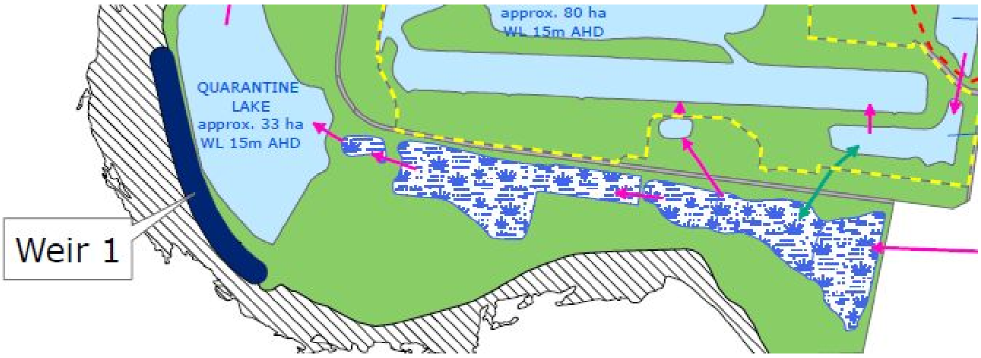

Figure 6.2. Location of Weir 1

6.2 Weir 6

Weir 6 forms the primary hydraulic control for flows between the Main Lake and the Wildlife Lake. Modifications to this weir have a number of implications for:

- Flood storage within the Main Lake, Quarantine Lake, Regatta Lake and to a lesser extent the Eastern Lakes.
- The quantity of flow entering the Wildlife Lake. This affects both the levels within the Wildlife Lake, and more importantly the potential impacts on downstream properties;
- The water level within the Main Lake, which in turn affects any potential development proposed for the scheme.

The majority of the optimisation of this weir was undertaken in 2009, and is detailed in **Appendix A**. The optimisation was primarily undertaken based on the design terrain v9, although this terrain is not significantly different to the current terrain from a flooding perspective.

The following weir dimensions were adopted, based on **Appendix A**:

- Weir Length – 640 metres
- Crest Level – 21m AHD

In addition to the primary weir, a bund is proposed on the western abutment from the weir through to the riverbank. This bund is set at 22.5m AHD, and is designed to exclude overflows through this area in a 100 yr ARI event.

As included in the preliminary design, Weir 6 also incorporates a bund on the eastern abutment to prevent flows from overtopping this area onto Castlereagh Road. This bund is set at 23m AHD.

It is noted that there is some flexibility in the width of this weir, which could be refined in the detailed design phase. The width primarily depends on the acceptable peak flood level within the Penrith Lakes Scheme. Preliminary weir calculations (as detailed in **Appendix A**) were undertaken to estimate the approximate increases in peak water level within the Lakes Scheme in a 100 year ARI event (refer **Table 6.1**).

It is important to note, however, that higher peak flood levels within the Main Lake do have the potential to influence both the behaviour of the Riverbank as well as the filling within some of the Eastern Lakes. Therefore, should Weir 6 be modified then it is recommended that these other components be also reviewed.

Table 6.1 Estimated Changes in 100 year ARI Main Lake Peak Level for Changes in Weir 6

Width of Weir (m)	Estimated Change over Proposed Weir	100 year ARI Peak Water Level (m AHD)
640	0.00	22.63
540	0.20	22.83
440	0.45	23.08

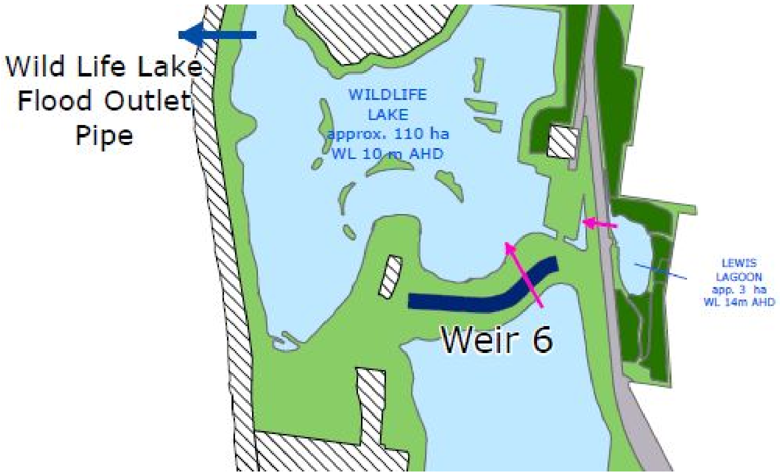

Figure 6.3. Location of Weir 6

6.3 Wildlife Lake weir

Hunts Gully is the natural flow path that connects the Nepean River and Wildlife Lake. It connects to the Wildlife Lake north-western boundary. During flood events, this flowpath experiences significant flow in both directions – initially from the river to the Wildlife Lake as levels in the river rise, and secondly from the Wildlife Lake to the river as the river levels start to fall and the lakes begin to empty. The Wildlife Lake Weir is proposed to provide a controlled inflow for water from Hunts Gully into the Wildlife Lake.

The Wildlife Lake Weir was analysed to determine a weir design which would minimise peak velocities and associated scour protection and construction costs. This particular flowpath had an additional design constraint as it lies near to the site boundary, and the design was undertaken such that there were no works required outside of the PLDC boundary.

The concept design, as discussed in **Appendix B**, incorporates a 65m weir with a crest level of 16mAHD (which is between the 10 year ARI level and the 20 year ARI level). This will therefore prevent flood events of 10 year ARI or less from entering the Wildlife Lake.

The abutments ramp up to 18.5mAHD at a grade of 1(V) in 6 (H). The crest level of the abutment is 18.5mAHD. This level then extends until it intersects with the ground surface of the design base case (refer **Appendix B**).

The central section of the weir crest at 16mAHD is designed to carry the initial high velocity flows in order to minimise the protection works required. The additional area added by the abutments at 18.5mAHD represents an elevation at which point the differences in the water levels between the Wildlife Lake and Hunts Gully is relatively small when overtopping occurs, resulting in lower velocities across this area.

Other scenarios were tested, but they failed to meet the design criteria (by requiring construction off-site), did not perform as satisfactorily as the selected design, or were significantly more expensive. Additional details on this investigation are available in **Appendix B**.

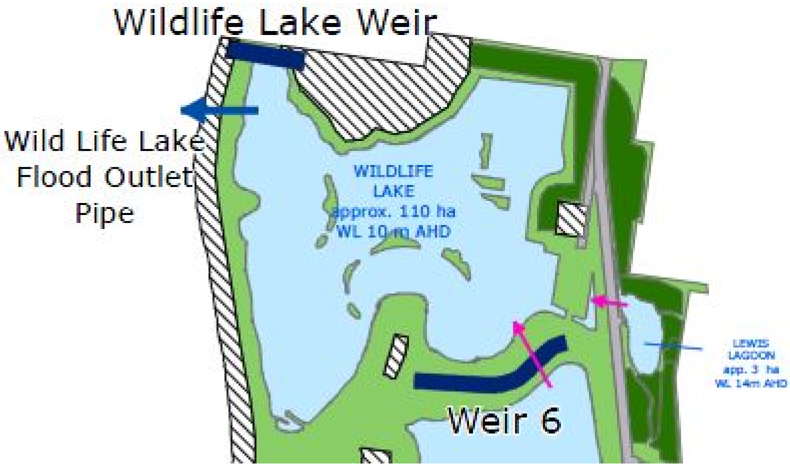

Figure 6.4. Location of Wildlife Lake weir

6.4 Quarantine Flowpath

The Quarantine flowpath connects the Quarantine Lake to Main Lake. The Quarantine Lake fills in flood events when water levels in the Nepean River exceed 21.6mAHD (i.e. the crest level of the Main Weir). Once water levels in Quarantine Lake reach 16.5mAHD water flows into Main Lake via this flowpath. This connection experiences high velocity flows during the initial stages of filling of the Main Lake. When the water levels in the Main Lake rise above 16.5 m AHD and begin to drown out this flowpath, the velocities reduce and the potential to erode the ground surface reduces.

Initial velocities over the weir are capable of eroding natural surfaces. This necessitates the construction of protection works in areas of high velocities. The analysis of this issue was focused on designing a flowpath and weir structure which will minimise the peak velocities and in turn will reduce the extents of protection works and overall costs.

The design proposed for this connection is a 150m wide weir located adjacent to Main Lake constructed of Roller Compacted Concrete (RCC) over a 15m length (in the direction of flow) at the weir crest. A zone of reinforced grass is also required and extends upstream 150 m towards Quarantine Lake (refer **Appendix C**). Detailed design may change these sizes slightly.

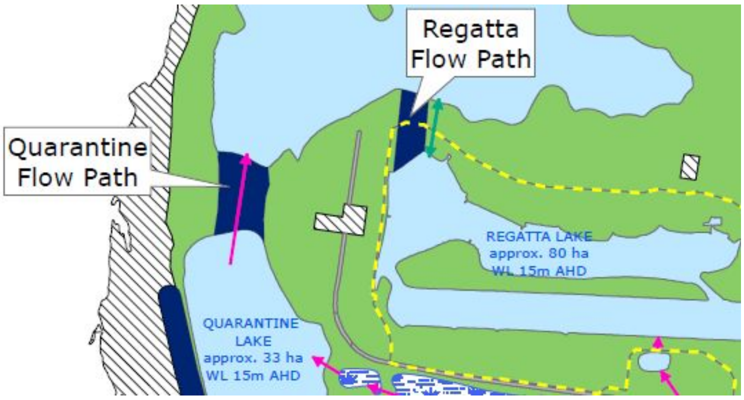

Figure 6.5. Location of Quarantine Flowpath

6.5 Regatta Flowpath

The Regatta flowpath connects the Main Lake and Regatta Lake. In flood events, water levels rise in Main Lake until these waters can spill into Regatta Lake ie. when the lake level exceeds the weir crest level of 16.5mAHD.

Similar to the Quarantine flowpath, this flowpath also experiences significant flows and velocities. The velocities are highest during the initial stages of the filling, until the water levels in the Regatta Lake begin to equilibrate with the water levels in the Main Lake. As a result the Regatta Flowpath will require either armouring or other forms of scour protection. This component was analysed in detail in order to minimise the works required to construct and protect the flowpath. Details are provided in **Appendix D**.

The option selected for this flowpath comprises a 50m wide flowpath connecting the lakes, with a weir structure located adjacent to Regatta Lake. The proposed weir structure is a 50m wide, 1.5m high blockwork wall, with a 10m length (in the flow direction) of reinforced concrete on the weir crest, and a dissipater structure at the base of the wall (refer **Appendix D**). A 25m length of reinforced grass is required upstream of the weir structure to transition the flow onto the weir.

Other options provided slightly lower peak velocities, but their design required significantly more earthworks which made them comparatively more expensive. The saving in the extents of protection was not enough to outweigh the increase in construction costs.

The preferred option was chosen as it represents the best balance between overall cost, velocity reduction, and minimisation of protection extents. Further information on this option is attached in **Appendix D**. Detailed design may change these sizes slightly.

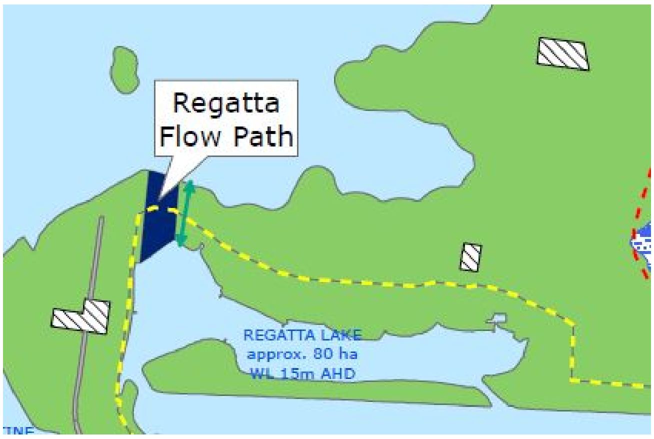

Figure 6.5. Location of Regatta Flowpath

6.6 Eastern Lakes

The Eastern Lakes comprise Allawah Lake, Duralia Lake, North Pond and the Final Basin. These lakes are located directly east of Main Lake (refer **Appendix E**).

Under the Preliminary Design Scenario, residential properties to the east of the PLDC site in Cranebrook Village are now protected in a 100 year ARI event as a result of the Lakes Scheme whereas previously they were inundated. However, residents in Cranebrook Village would experience adverse flooding conditions in a 200 year ARI event as a result of the Penrith Lakes scheme.

This impact in a 200 yr ARI event is primarily driven by flows which break out from the Nepean River upstream of the site and flow through the Penrith Industrial Area and Waterside Green. In a 100 year ARI event, these flows are relatively minor and the high level connections from the Eastern Lakes effectively protect the Cranebrook Village from inundation. However, in a 200 year ARI event, the flows through Waterside Green are significantly larger and the high level connections result in an increase in peak water levels within the Cranebrook Village.

An investigation into the eastern lakes was undertaken to reduce the impact in the 200 year ARI event. The proposed layout for this area is discussed in detail in **Appendix E**. It incorporates a high level connection between Allawah Lake and Duralia Lake that is set above the 100 year ARI flood level. This connection is approximately 370 metres wide and set at RL 22.55m AHD.

A wide connection is also provided between Duralia and the North Pond, to facilitate the transfer of water from North Pond and the Cranebrook Village area through to Duralia Lake. At this stage, this connection is 150 metres wide and set at RL 19m AHD. However, it is noted that some changes to this flowpath may be possible without adversely affecting the overall outcome for residents living in Cranebrook Village.

6.7 River Bank

The Nepean River forms the southern and western boundaries to the PLDC site. The river bank experiences overtopping in the Preliminary Design in sections during the 100 year ARI event and along most of its length in the 200 yr ARI event, and is completely overtopped in the 500 yr ARI event.

The aim of this investigation was to determine the overtopping velocities along the bank in order to design, if required, appropriate protection works. Similar to the consideration discussed above, the design aims to minimise the costs associated with protection works and construction by reducing peak velocities to acceptable levels.

The recommended design for the river bank is detailed in **Appendix F**. It involves raising the river bank to a level sufficient to reduce the velocities in the 200 year ARI event such that well maintained grass provides adequate protection (i.e. reduce velocities below 2m/s). To provide protection in the 500 year ARI event, it is noted that some reinforcement of the grass would be required along the riverbank.

It is noted that well maintained grass assumes that the area would be irrigated and that a good grass cover maintained. If this is not possible, then reinforcement matting that is capable of withstanding velocities between 1 - 2m/s with poor grass cover would be recommended.

Further information on this investigation is included in **Appendix F**.

7 Flood Model Results

The preliminary design scenario was updated to incorporate the recommended flood infrastructure components, as discussed in **Section 6**. This final design scenario was assessed for the 500 year, 200 year, 100 year, 50 year, 20 year and 10 year ARI events together with the PMF.

The results of the Final Design Scenario are summarised in the following figures:

- Peak Water Levels and Depths – **Figures 7.1** to **7.7**;
- Peak Velocities – **Figures 7.8** to **7.14**.

Water level time series have also been prepared for the 100 year and 200 year ARI events at two key locations:

- River levels at the Main Weir (Weir 1) and water levels in the Main Lake are provided in **Figures 7.15** and **7.16**;
- Flood levels in Hunts Gully and the Wildlife Lake are provided in **Figures 7.17** and **7.18.**

These figures are provided at the end of the report.

Table 7.1 provides a summary of the peak water levels within the proposed lakes scheme.

Table 7.1 Summary of Peak Water Levels in Lakes Scheme

Flood Event (ARI)	Peak Water Level (m AHD)						
	Quarantine Lake	Main Lake	Regatta Lake	North Pond	Duralia Lake	Allawah Lake	Wildlife Lake
PMF	29.70	29.61	29.70	29.69	29.64	29.61	29.46
500 year	24.59	24.51	24.59	24.74	24.65	24.51	24.17
200 year	23.53	23.43	23.44	23.92	23.85	23.43	22.66
100 year	22.67	22.63	22.63	19.52	19.52	22.63	20.96
50 year	18.53	18.49	18.45	16.47	18*	18*	18.91
20 year	15*	14*	15*	16*	18*	18*	16.01
10 year	15*	14*	15*	16*	18*	18*	10*

*denotes operating water level

Table 7.2 provides a summary of the peak flows at key locations. It should be noted that for events larger than the 100 year ARI, overtopping occurs along the river bank and in other locations (such as through the Eastern Lakes).

Table 7.2 Summary of Peak Flows in the Model

Flood Event (ARI)	Peak Flow (m^3/s)				
	M4	Main Weir (Weir 1)	Wildlife Lake weir*		Smith Street
			Into Lakes	Into River	
PMF	35,890	5,272	554	13,928	12,906
500 year	19,645	4,988	580	5,179	4,337
200 year	16,436	4,280	565	2,840	2,518
100 year	13,478	2,256	510	1,395	810
50 year	11,015	639	414	145	29
20 year	8,573	0	218	0	0
10 year	6,004	0	0	0	0

** Wildlife Lake weir flows in two directions, from the River into the Lakes and from the Lakes into the River.*

8 Provisional Flood Hazard

8.1 General

Flood hazard can be defined as the risk to life and limb caused by a flood. The hazard caused by a flood varies both in time and place across the floodplain.

The *Floodplain Development Manual* (NSW Government, 2005) describes various factors to be considered in determining the degree of hazard. These factors are:

- Size of the flood
- Depth and velocity of floodwaters
- Effective warning time
- Flood awareness
- Rate of rise of floodwaters
- Duration of flooding
- Evacuation problems
- Access.

Hazard categorisation based on all the above factors is often referred to as 'true hazard'. The scope of the present study calls for determination of 'provisional' flood hazards only. The provisional flood hazard is generally considered in conjunction with the above listed factors as part of the Floodplain Risk Management Study (the next stage of the Floodplain Risk Management process after the Flood Study) to provide a comprehensive analysis of the overall flood hazard.

8.2 Provisional Flood Hazard

Provisional flood hazard is determined through a relationship developed between the depth and velocity of floodwaters (Figure L2, NSW Government, 2005). The Floodplain Development Manual (2005) defines two categories for provisional hazard - High and Low.

The model results were processed using an in-house developed program, which utilises the model results of flood level and velocity to determine hazard. Provisional flood hazard was prepared for all the design events. The provisional hazard is based on the envelope of the hazard at each location for each ARI.

The provision flood hazard is shown in **Figures 8.1** to **8.7** at the end of this report.

9 Discussion of Results

9.1 General

A general description of the flooding behaviour in the Nepean River is provided in Cardno (2009).

A description of the flood behaviour for the proposed Lakes Scheme is provided in **Section 4**. This describes the flooding behaviour in a 100 year ARI event, where the inflows to the Lake Scheme are primarily controlled through the Main Weir and Wildlife Lake weir.

In events larger than a 100 year ARI event, the Nepean River starts to overtop sections of the river bank. In the 500 year ARI event, the flood levels in the Nepean River nearly equalise with the flood levels in the Main Lake. As discussed in **Section 6.7**, the river bank has been modified to ensure that it is adequately protected up to the 500 year ARI event.

For the 200 year ARI and above, flood water enters the Scheme via the Eastern Lakes. This water originates from flows that backflow up Boundary Creek from the Nepean River (upstream of the site) and flow through the Penrith Industrial Area and Waterside Green.

9.2 Future Modifications to the Design

Each of the flood infrastructure components was optimised based on the preliminary design scenario. The combining of all of the flood infrastructure components into a single final concept design scenario resulted to some changes in estimated flood levels, particularly in the Main Lake. The previous 100 year ARI level in the Main Lake for the preliminary design scenario was 22.54m AHD, while the new level is 22.63m AHD. This is not a significant difference, but it does have a minor impact on the design of some of the flood infrastructure components.

It is recommended that the following infrastructure components be reviewed during the detail design phase:

- Weir 6 – Western Bund. The western bund was set at 22.5m AHD, and is intended to prevent the 100 year ARI event from overtopping this area. While some overtopping may not be a significant issue, it may be worth investigating raising this bund to 22.65m AHD to prevent this overtopping.
- Eastern Lakes – the high level connection between Allawah and Duralia Lake was set at 22.55m AHD and was designed to exclude the 100 year ARI. Some overtopping of this area occurs in the 100 year ARI, but it does not adversely affect the Cranebrook Village area (refer **Section 9.3.3**). Should total exclusion of the 100 year ARI be required, then this connection would need to be raised to 22.65m AHD.
- River bank – a section in the north of the Main Lake would need to be raised above 22.65m AHD to exclude the 100 year ARI event. Only a very small flow overtops this area and it would not have an impact on the overall scheme.

9.3 Comparison with Base Case

A comparison between the proposed design scenario and the base case scenario (Pre-Quarry) was undertaken for the 100 year ARI and 200 year ARI events. This is used as representative of the changes in flood behaviour as a result of the proposed lakes scheme (where the external catchment is assumed to be represented by the 2003 ALS data and Waterside Green is as per the design).

Figures 9.1 and **Figure 9.2** show the differences in peak water level in the 100 year ARI and 200 year ARI events respectively.

A preliminary flood damages assessment was undertaken for the Emu Plains and Penrith area. As no floor level survey was undertaken, the estimates were based on ground levels from the ALS data and assuming that floor levels were 0.3 metres above ground. Residential property locations were assumed to be in the centre of the cadastral block, while commercial and industrial properties were outlined based on aerial photograph.

The residential damage curves from DECCW (DIPNR, 2004) were utilised for the estimates. The damages for the industrial and commercial properties were based on in-house developed curves utilising information from FLDamage and surveys undertaken in similar catchments. Floor areas for commercial and industrial properties were estimated from aerial photos, and these properties were assumed conservatively to be of a low value.

The estimated damages were undertaken for events up to the 500 year ARI event. No external damages were assumed in this analysis. The estimates from the analysis are provided in **Table 9.1**. An estimate of the number of properties with overfloor flooding is provided in **Table 9.2**.

The analysis demonstrates an approximate $9.4M reduction in flood damages as a result of the proposed Lakes Scheme in present value terms. If a 100 year ARI event were to occur, then the estimated saving in damages is $56.3M. This represents a significant reduction in damages in this event. Furthermore, the number of properties which potentially have overfloor flooding significantly reduces, from 1027 properties in the 100 year ARI under the base case to 665 properties in the design case.

It should be noted that this estimate could be refined with the floor level data of the flood affected properties. However, this was not available at the time of this analysis.

Table 9.1 Preliminary Flood Damages Analysis

Flood Event	Base Case	Proposed Design
10 year ARI	$1.2M	$1.2M
20 year ARI	$1.8M	$1.8M
50 year ARI	$6.1M	$5.1M
100 year ARI	$117.7M	$61.4M
200 year ARI	$357.7M	$294.2M
500 year ARI	$505.0M	$466.2M
AAD*	$3.4M	$2.6M
Present Value (AAD)	$41.6M	$32.2M

* Annual Average Damage

Table 9.2 Number of Properties/ Buildings with Overfloor Flooding

Flood Event	Base Case	Proposed Design
10 year ARI	16	16
20 year ARI	25	25
50 year ARI	105	85
100 year ARI	1027	665
200 year ARI	2743	2422
500 year ARI	3505	3135

The following sections discuss in detail the changes in peak water levels as a result of the proposed Lakes Scheme.

9.3.1 Emu Plains and Penrith

The proposed lakes scheme results in significant reductions in peak water levels in both the 100 year ARI and the 200 year ARI within the Emu Plains and Penrith areas (see **Figures 9.1** and **9.2**). This is due to the additional storage provided by the Penrith Lakes Scheme.

Reductions in the order of 0.5 to 1 metre are observed in the 100 year ARI levels along the Nepean River. This results in a significant benefit to a large number of properties in this area.

9.3.2 Smith Street Area

In both the 100 year ARI and the 200 year ARI events, this area acts as a secondary flowpath to the Wildlife Lake Weir. Floodwaters from the Nepean backflow into this area prior to the Wildlife Lake spilling flows through this area. Flows of up to 810 m3/s flow through this area in a 100 year ARI event.

The proposed Scheme results in increases in peak water levels on the property to the north of Smith Street, by approximately 0.3 metres in a 100 year ARI event and approximately 0.1 metres in a 200 year ARI event.

The impacts in this area are on rural land, which is already impacted by flooding under the pre-quarry scenario. **Figures 9.3** and **9.4** provide a comparison of the peak water levels for both the pre-quarry and the proposed lakes scheme for both the 100 year and 200 year ARI events. The locations showing peak water levels indicate existing structures (horse shelters) on the floodplain in this location, and show the increases in peak water levels. It is noted that in the majority of cases the increase of 0.3 metres in the 100 year ARI event affects structures where the pre-quarry flooding depth is in the order of 1 metre or greater.

As it is unlikely that development could occur in this area (due to it being an active floodway), even under pre-quarry conditions, it is considered that this impact is not significant.

9.3.3 Cranebrook Village Area

The Eastern Lakes area is primarily protected from flooding from the Main Lake in a 100 year ARI event. As such, the Cranebrook Village area is not impacted by the 100 year ARI event under the Lakes Scheme. This is a significant benefit to the area, as under the pre-quarry conditions this area would have experienced flood depths in the order of 0.5 to 1 metre in some locations (refer **Figure 9.5**).

In a 200 year ARI event, a significant amount of water enters this area through the Penrith Industrial Area and Waterside Green. These flows then fill the Eastern Lakes prior to connecting to the Main Lake via a high level connection. While these high level connections protect the Cranebrook Village area in a 100 year ARI event, they also cause increases in peak water levels in a 200 year ARI event. These increases are in the order of 0.45 metres (refer **Figure 9.6**).

Alternative options were considered for lowering the high level connections to the Eastern Lakes (refer **Appendix D**). However, in these cases properties would be affected in the 100 year ARI event.

As such, it is considered reasonable that the benefits of these properties not being flooded in events up to the 100 year ARI as a result of the Lakes Scheme far outweighs the additional costs of additional flood damages in the 200 year ARI event. This is demonstrated in **Table 9.3**. This analysis was conducted in the same manner as **Section 9.3**, and shows that the annualised flood damages (AAD) in the Cranebrook Village area decrease under the proposed Lakes Scheme. This demonstrates that the reduced flood damages in the 100 year ARI ($1.0M) outweigh the increase in flood damages in the 200 year ($1.0M), as it is a less frequent event.

Table 9.3 Preliminary Flood Damages - Cranebrook Village Area

Flood Event	Base Case	Proposed Design
100 year ARI	$1.0M	$0M
200 year ARI	$3.7M	$4.7M
500 year ARI	$5.9M	$6.1M
AAD*	$31,000	$28,000
Present Value (AAD)	$385,000	$345,000

9.3.4 Waterside Green

Waterside Green is located on the eastern side of the Lakes Scheme, a short distance south of the Cranebrook Village area. This new development was designed based on peak flood levels that were provided by PLDC and WRL during an earlier Lakes Scheme design. It is therefore important to ensure that the flood levels from the most recent design are either the same or lower than those utilised for the design of Waterside Green.

The peak flood levels from the Waterside Green design were extracted from the report *Lakeside Village, Penrith : Hawkesbury-Nepean Flooding* (Patterson Britton & Partners, 2004). The levels were extracted for Lake 5 within Waterside Green, as this represents the most downstream lake where levels are reported. These levels were compared to the flood levels determined in this report from the current Lakes Scheme concept design (**Table 9.4**).

It is noted that the current lake scheme results in lower peak flood levels for both the 100 year ARI and 200 year ARI within the Waterside Green development. Therefore, there are no adverse impacts to this area.

Table 9.4 Waterside Green Peak Flood Levels at Lake 5 (m AHD)

Flood Event	Patterson Britton (2004)	Current Lake Scheme
100 year ARI	22.50	21.98
200 year ARI	24.15	24.03

9.3.5 Changes in Velocities

The changes to the peak water levels within the Nepean River may also result in a change in the peak velocities. It is important to assess these changes in velocity as they have the potential for geomorphological implications for the Nepean River over the Base Case scenario, including increased sediment transport and changes to river geometry.

Figures 9.7 to **9.9** provide the changes to peak depth averaged velocity for the 20 year, 50 year and 100 year ARI events. It is noted that the weirs within the Lakes Scheme are not activated in the 10 year ARI event and more frequent events, and therefore there would be no changes in peak velocities for these events.

Along the Nepean River, minor changes in peak depth averaged velocities are observed, generally within ± 0.5 m/s (10%) in the 100 year ARI and less than 0.5 m/s in the 20 year ARI. Given that the depth averaged velocity along the Nepean River are in the order of 5 m/s in some locations in the 100 year ARI event, it is considered that these changes are relatively minor. Furthermore, as the changes are relatively minor in the 20 year ARI event, and would not occur at all in the 10 year ARI event, it is not expected that there would be significant geomorphological changes as a result of the proposed Lakes Scheme.

Increases in velocities are also observed in the natural flowpath to the north of the Wildlife Lake weir. At this location, increases in peak velocities of up to 1.4m/s are observed in the 100 year ARI and approximately 0.9 m/s in the 20 year ARI. It is noted that this increase in velocity occurs over a relatively short time frame, primarily while the Wildlife Lake is filling and the velocity is low enough that additional erosion of this area is not likely.

For the flowpath to the north of Smith Street, an increase in peak velocity is observed in the 100 year ARI, of up to 1 m/s. The resulting velocities at Smith Street in the 100 year ARI event are generally less than 2m/s. Given that this area has a good grass cover, it is unlikely that there would be significant erosion as a result of the Lakes Scheme. It should be noted that the proposed Lakes Scheme results in reductions in velocities in the 50 year ARI event of up to 0.4 m/s.

9.4 Comparison with 1987 Deed

A comparison between the 1987 Deed Scenario (as defined in **Section 3.1** and **5.2**) and the proposed development scenario are provided in **Figures 9.10** to **9.11** for the 100 year ARI and 200 year ARI events. With the exception of an area north of Smith Street and a small section of the Nepean River between the Main Weir and Wildlife Lake weir, the proposed scheme results in lower peak water levels on properties outside of the scheme compared with the 1987 Deed Scenario. Peak water levels in the 100 year ARI are around 0.3 metres lower in some areas.

A comparison was also made between the Deed Scenario and the base case scenario (pre-quarry). The results for the 100 year and 200 year ARI events are shown in **Figures 9.12** and **9.13** respectively.

Along the Nepean River, the Deed Scenario generally results in reductions in peak water levels compared with the base case, although in the Emu Plains area and near the Penrith Weir, these reductions are not as large as the proposed design.

In the area of the Eastern Lakes, the model shows impacts within the Cranebrook Village in both the 100 year ARI (0.36 metres) and the 200 year ARI (1.13 metres). This compares with the proposed design where no impacts are observed during the 100 year ARI event, and an impact of approximately 0.45 metres during the 200 year ARI.

It is concluded that the proposed design represents a significant improvement on the Deed Scenario.

9.5 Emergency Evacuation

This report does not focus on evacuation issues for the potential Penrith Lakes Development.

10 Climate Change Analysis

Changes to climate conditions are expected to have adverse impacts on sea levels and rainfall intensities. While the impact of sea level rise is not a major concern for Penrith Lakes, changes in design rainfall intensities will affect the peak flood levels of the overall lakes scheme.

A review of the potential impacts of climate change on Penrith Lakes was addressed in advice provided by WRL in 2008 which is attached in **Appendix F**. A summary of this is provided here.

There are only limited studies describing the relationship between climate change an increases in extreme rainfall intensities in Australia, including:

- *Climate Change in the Hawkesbury Nepean Catchment* (CSIRO, 2007); and,
- *Climate Change in New South Wales. Part 2. Projected Changes in Climate Extremes* (Hennessy et. al., 2004).

These studies generally predict that by 2070 the 40 year 1 day rainfall intensity may change by -7% to +10%. For the 40 year 3 day rainfall (which is equivalent to the critical duration at Penrith Lakes), the reports do not explicitly state the differences but note that they are similar to the 1 day estimates with the exception to Spring, where decreases in rainfall intensities are observed.

The estimated changes to rainfall intensities from these reports suggests a median increase of 1.5%. For the purposes of this assessment, however, a conservative 5% increase in long duration rainfall intensities has been assumed for the 100 year ARI. This is consistent with the advice provided by DECCW, which is also provided in **Appendix G**.

Preliminary analysis of 5% rainfall increases by WRL suggested that this would result in a 10% increase in peak flows within the study area. However, more detailed modelling undertaken by WMAwater on behalf of DECCW (also provided in **Appendix G**) suggests that a 5% increase in 100 year ARI rainfalls will result in a 6% increase in peak flows in the study area. As this was based on the hydrological models developed for the area, this is considered a better estimated.

For the purposes of this assessment, a conservative estimate of a 10% increase in flows has been adopted. However, this could be reviewed downward based on the WMAwater analysis in future assessments.

A comparison between the 100 year ARI event with climate change and the existing 100 year ARI event was undertaken. The results of this analysis are shown in **Figure 10.1**.

In the Nepean River, increases in the order of 0.5 metres in the 100 year ARI flood levels are observed near the Penrith Weir and the Emu Plains area as a result of climate change. Further north, near the Wildlife Lake Weir, the levels in the Nepean River increase by 0.7 metres.

Within the Lakes Scheme itself, increases in the Main Lake are 0.34 metres, due to the additional overtopping flows across the Main Weir. The Wildlife Lake has larger increases of 0.73 metres, due to the increased flows through Wildlife Lake weir and increased overtopping flows across Weir 6.

Increases in the Eastern Lakes area of around 3.84 metres are observed. This is a result of the overtopping of the high level connections between the Main Lake and the Eastern Lakes, as well as the additional flows through Waterside Green. The large increase is a result of the minimal 100 year ARI inundation under existing conditions.

11 Sensitivity Analysis

11.1 Model Roughness

To test the sensitivity of the flood behaviour to roughness, two scenarios were tested The first scenario was a global increase of roughness values of 20% while the second scenario was a global decrease in roughness values of 20%. **Figures 11.1** and **Figure 11.2** show the results of this analysis.

An increase in roughness values of 20% results in increases in peak water levels of around 0.5 to 0.6 metres in the bend of the Nepean River near the Penrith Weir. This creates additional overtopping flow through the industrial area and Waterside Green.

In the section of the Nepean River between Emu Plains and Hunts Gully, increases in the order of 0.3 to 0.4 metres are observed. These increases have the effect of increasing the flows entering the Lake Scheme through both the Main Weir and Wildlife Lake weir.

Increases in the Eastern Lakes area of around 3.86 metres are observed. This is a result of additional flows through Waterside Green, as well as some overtopping of the high level connections between the Main Lake and the Eastern Lakes. The large increase is a result of the minimal inundation under the base lakes scheme.

Increases in the Main Lake are of the order of 0.27 metres while in the Wildlife Lake the increases are in the order of 0.45 metres.

A lowering of model roughness of 20% results in larger decreases in flood levels thatn the increases due to an increase in roughness. Decreases in the order of 0.7 to 0.8 metres are observed in the Nepean River at the bend near the Penrith Weir. The area between Emu Plains and Wildlife Lake weir result in decreases in the order of 0.6 metres.

The decrease in water levels at the Penrith Weir reduce the overtopping flows through the industrial area and Waterside Green, which in turn results in decreases in flood levels of the order of 1.86 metres in the Eastern Lakes.

The reduction in peak water levels within the Nepean River also reduces the overall water overtopping the weirs in the Penrith Lakes Scheme. Reductions in peak water levels in the Main Lake are 0.6 metres while the reductions of 0.8 metres are observed in the Wildlife Lake.

11.2 Model Inflows

To test the sensitivity of the model to changes in inflows, two inflow scenarios were tested. The first scenario was an increase in flows of 20%, while the second scenario was a decrease in flows of 20%. The results of this analysis are shown in **Figures 11.3** and **11.4**.

The model is more sensitive to an increase in inflows of 20% than an increase in roughness of 20%. It is worth noting that an increase in 100 yr ARI inflows of 20% is roughly equivalent to the 200 year ARI flow. This is reflected in the increases in the levels seen by a 20% increase in inflows, which are roughly equivalent to the difference in peak water levels between the 100 year ARI and the 200 year ARI events.

Increases in peak water levels within the Nepean River are of the order of 0.8 metres in the bend of the Nepean River near the Penrith Weir. Further north, towards Hunts Gully, the increases are larger, of the order of 1.4 metres.

Increases in peak water levels within the Lakes Scheme are 0.72 metres in the Main Lake and 1.56 metres in the Wildlife Lake.

The model is more sensitive to a reduction in inflows of 20% than a reduction in roughness of 20%. A 20% reduction in inflows is also roughly equivalent to a 50 year ARI event.

A 20% reduction in model inflows results in reductions in peak water levels along the Nepean River of the order of 1.2 metres near the Penrith Weir and 1.5 metres near Hunts Gully.

Within the Lakes Scheme, the decreases are more significant as a result of the reduction of overtopping flows across the weirs. The Main Lake has a reduction of the order of 5 metres while the Wildlife Lake has a reduction of approximately 2.1 metres.

11.3 Model Boundary

The sensitivity of the model to the boundary conditions was tested by varying the expected discharge at a given water level in the Q-H relationship by +/- 20%. The results of this analysis are provided in **Figures 11.5** and **11.6**.

An increase in the discharge of 20% within the Q-H relationship results in a reduction in peak water levels throughout the scheme, due to the increased hydraulic efficiency of the model boundary.

Within the Nepean River, the reductions are larger near Hunts Gully and are of the order of 0.5 metres, while at the Penrith Weir the reductions are of the order of 0.07 metres. A reduction in the impact of the downstream boundary of peak water levels is observed for the Nepean River once it reaches the Emu Plains area.

Within the Lakes Scheme itself, reductions of 0.14 metres are observed in the Main Lake due to the reduced overtopping of the Main Weir. The Wildlife Lake, which is connected to the Nepean River through Wildlife Lake weir, is lower by 0.4 metres.

A decrease in the discharge of 20% within the Q-H relationship results in an increase in peak water levels throughout the scheme.

Within the Nepean River, the increases are largest closer to the model boundary. At Wildlife Lake weir, the increase in peak water level is approximately 1 metre while at the Penrith Weir the increase is lower at 0.15 metres.

Within the Lakes Scheme itself, increases of 0.22 metres are observed within the Main Lake, due to the increased overtopping of the Main Weir. The Wildlife Lake increases by 0.83 metres.

In general, the model is more sensitive to a 20% decrease in the Q-H relationship than a 20% increase.

11.4 Summary

In general, the Lakes Scheme is the most sensitive to changes in the peak inflows to the model. It is more sensitive to reductions to the inflows to the model than increases to the inflows.

Changes to the model boundary tend to have the most significant effect on flood levels in Hunts Gully and the Wildlife Lake. The effect of the model boundary is less significant within the Nepean River at Emu Plains, and hence the impact on the Main Weir and the Main Lake are less significant.

The model is also quite sensitive to reductions in model roughness although it is not as sensitive to increases roughness.

A summary of the sensitivity results is provided in **Table 11.1**.

Table 11.1 Summary of Sensitivity Results (change in metres)

Location	Roughness		Inflows		Boundary	
	+20%	-20%	+20%	-20%	+20%	-20%
Main Lake	0.27	-0.6	0.72	-5.0	-0.14	0.22
Wildlife Lake	0.45	-0.8	1.56	-2.1	-0.4	0.83
Nepean River – near Emu Plains	0.5 – 0.6	-0.7 to -0.8	0.8	-1.2	-0.07	0.15

+ve values represent an increase in peak water levels, -ve values represent a decrease

It should also be noted that this sensitivity analysis demonstrates the potential changes in peak water level as a result of different assumptions in the modelling. However, the infrastructure has been designed for a full range of flood events, and this sensitivity analysis does not impact on the performance of that infrastructure.

12 Conclusions

A detailed 2D hydraulic model has been established for the Penrith Lakes study area, which was calibrated and verified with details provided in the report *Penrith Lakes Flood Model : Calibration and Verification* Cardno (2010A). The calibration and validation process has been undertaken with extensive consultation with:

- Water Research Laboratory (Brett Miller, Doug Anderson)
- Penrith City Council (Craig Ross, David Yee, Ratnam Thilliyar, Elias Ishak)
- Worley Parsons (David McConnell)
- Department of Environment, Climate Change and Water (David Avery)

This process was undertaken from April 2008 through to March 2010.

This model was then utilised to assess and optimise a number of flood infrastructure components which are proposed within the scheme, including:

- Main Weir (Weir 1)
- Wildlife Lake weir
- Weir 6 (Main Lake to Wildlife Lake)
- Quarantine Flowpath
- Regatta Flowpath
- Eastern Lakes
- River bank works.

Each of these optimised components was then incorporated into a Final Concept Design Scheme. This concept design was analysed for the 10 year, 20 year, 50 year, 100 year, 200 year and 500 year ARI events, as well as the Probable Maximum Flood (PMF). The results of this analysis have shown that the proposed Lakes Scheme flood infrastructure functions as intended.

The Lakes Scheme results in significant reductions in peak water levels through the Emu Plains and Penrith areas. A flood damages analysis demonstrates that the Lakes Scheme results in a saving of approximately $9.4M in present value terms for the communities of Penrith and Emu Plains. There are some minor increases in peak water levels in the 100 year ARI near Smith Street, however these impacts are in existing floodways and are not considered significant.

In the Cranebrook Village area, a reduction in flooding is observed in the 100 year ARI event. However, an increase is observed within the 200 year ARI event. An assessment of this demonstrates that the benefits in the 100 year outweigh the costs in the 200 year.

An analysis was also undertaken of the potential impacts of climate change. This analysis suggests that the Main Lake levels could increase by 0.34 metres during a 100 year ARI. It is noted that climate change does not affect the performance of the infrastructure within the Lakes Scheme.

In summary, the Penrith Lakes Scheme will result in significant benefits to the communities of Penrith and Emu Plains, with significant reductions in peak flood levels in those areas. The infrastructure outlined in this report has been sized so that it performs in events up to and including the PMF event.

13 References

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