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MURRAY FUTURES
Riverine Recovery

Riverine Recovery

Weir Pool Hydraulic Modelling

TECHNICAL NOTE

WATER FOR GOOD

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1. Background

1.1 Context

The *Murray Futures* Program is funded by the Australian Government and provides a significant opportunity for South Australia to sustain, support, and reinvigorate communities and industries within the Murray-Darling Basin in South Australia. The *Riverine Recovery Project (RRP)*, a component of *Murray Futures*, aims to improve the way wetlands, floodplains and backwaters are managed from Wellington to the South Australian border. The RRP funding consists of $78 million from the Australian Government and $8.7 million from the South Australian Government. The *Riverine Recovery Project* will improve efficiency of environmental water use by reducing evaporative losses and boost the ecological health for floodplains and wetlands.

This Technical Note describes the numerical hydraulic modelling carried out as part of the *Riverine Recovery Project* (RRP) under the Enhanced River Operations and Weir Pool Management project element. This project element is one of several being undertaken by the Science, Monitoring and Knowledge Branch (SMK) of the South Australian Department of Environment, Water and Natural Resources (DEWNR) as part of Phase 1 of the RRP.

Variation in water levels in the lower River Murray has been significantly reduced due to river regulation, including extractions and the construction of dams in the upper catchment and weirs in the lower Murray. The weirs are operated to hold water levels constant for low to medium river flows to facilitate irrigation and navigation. Consequences of regulation and stabilised water levels include the permanent inundation of previously ephemeral wetlands and reduced inundation of higher floodplain areas, leading to ecological impacts such as the re-distribution of species in channel and floodplain habitats (Walker 2006, cited in Lloyd Environmental 2010).

Variation of the operating levels of weir pools has been proposed to improve ecosystem health and resilience by restoring some aspects of seasonal variation and ephemeral wetting and drying of wetlands. As such, this Technical Note seeks to provide hydrological information relating to various weir pool manipulation scenarios, with a view to informing subsequent stakeholder engagement, policy directions, and operational decision-making.

1.2 Objectives

The primary objective of this Technical Note is to summarise the hydraulic modelling that has been undertaken to contribute to the RRP project element output: “Undertake investigations to assess inundation extent to be derived from improved river flow management (including weir pool raising and lowering)”.

More specifically, the hydraulic modelling outputs include:

- Mapping of inundated areas and how these change with raising weir pool levels
- Calculation of corresponding water volume changes
- Prediction of water levels (backwater curves).

This Technical Note details the hydraulic modelling methodology, calibration, and outputs. As part of the RRP Enhanced River Operations and Weir Pool Management project element, SMK has also undertaken studies into the ecological response (DEWNR 2012b) and salinity risks of weir pool manipulation (DFW 2012). Outputs from the hydraulic modelling were processed into ESRI ArcGIS® layers, which have been used to inform those studies. This Technical Note does not include inundation maps because the deliverables of this project element were ESRI ArcGIS® layers to be used in other studies, while maps in publishable format were not required.

2. Method

Despite the use of the term "weir pool" to describe the reach of river between one weir and the next, the Murray remains a river, with a very low but non-zero water level gradient driving its flow. This means that hydraulic calculations are needed to determine water levels on the river, both for current weir operating conditions and for the proposed weir level manipulations. The same applies to flows through wetlands and their connecting channels; gradients and velocities are exceptionally low, but hydraulic calculations are still needed to determine water levels and the changes in water level profile with different levels of flow. A one-dimensional modelling approach would have been suitable to calculate the flow in the main channel and connecting channels, but because this study requires the representation of flow in adjacent wetlands, a two-dimensional modelling approach was deemed most appropriate.

The hydraulic modelling was carried out using the two-dimensional, numerical, hydraulic model MIKE 21. Existing numerical models that had previously been developed for other purposes, such as flood level prediction, were used as the basis for model development in this project. MIKE 21 is based on a computational grid that covers the area of interest and the model calculates flow, flow velocity, and water level for each cell of the grid. Input information includes the land surface elevation, surface roughness, initial water level, and eddy viscosity for each grid cell. MIKE 21 resolves the flow equations on the cell-based grid to compute water level variation and flow in response to inflows and to the various forces acting on a body of water. The program can be applied to rivers (as in this study), lakes, estuaries, and coastal areas.

The models used in this project were a combination of:

1. existing models developed by Water Technology Pty Ltd
2. in-house models previously developed for flood mapping and modified to fit the purpose of this study
3. models constructed for this project.

It is computationally too demanding to use a single model for the entire river length, if it is to be investigated at a reasonable level of resolution. Consequently, the river has been divided into several reaches with a separate model for each reach. The dividing points between models were chosen to align with water level gauges. Calibration of The models were calibrated using the water level gauges at the upstream and downstream boundaries of each model, as well as other intermediate gauges. The weirs on the River Murray are conventionally called locks because locks have been constructed at the weirs to provide for boat passage. When referring to specific weirs in this report, the conventional naming system of locks is used. The coverage of the models was from Lock 1 to upstream of Chowilla, just past the South Australian state border with New South Wales and Victoria, thus including the six weir pools and 375 km of river length. See Figure 1 for a map of the River Murray in South Australia and the locations mentioned in this report. The extents of the seven models used were:

- Lock 1 to Morgan
- Morgan to Lock 2
- Lock 2 to Overland Corner
- Overland Corner to Lyrup
- Lyrup to Lock 5
- Lock 5 to Lock 6
- Lock 6 to Upstream of Chowilla.

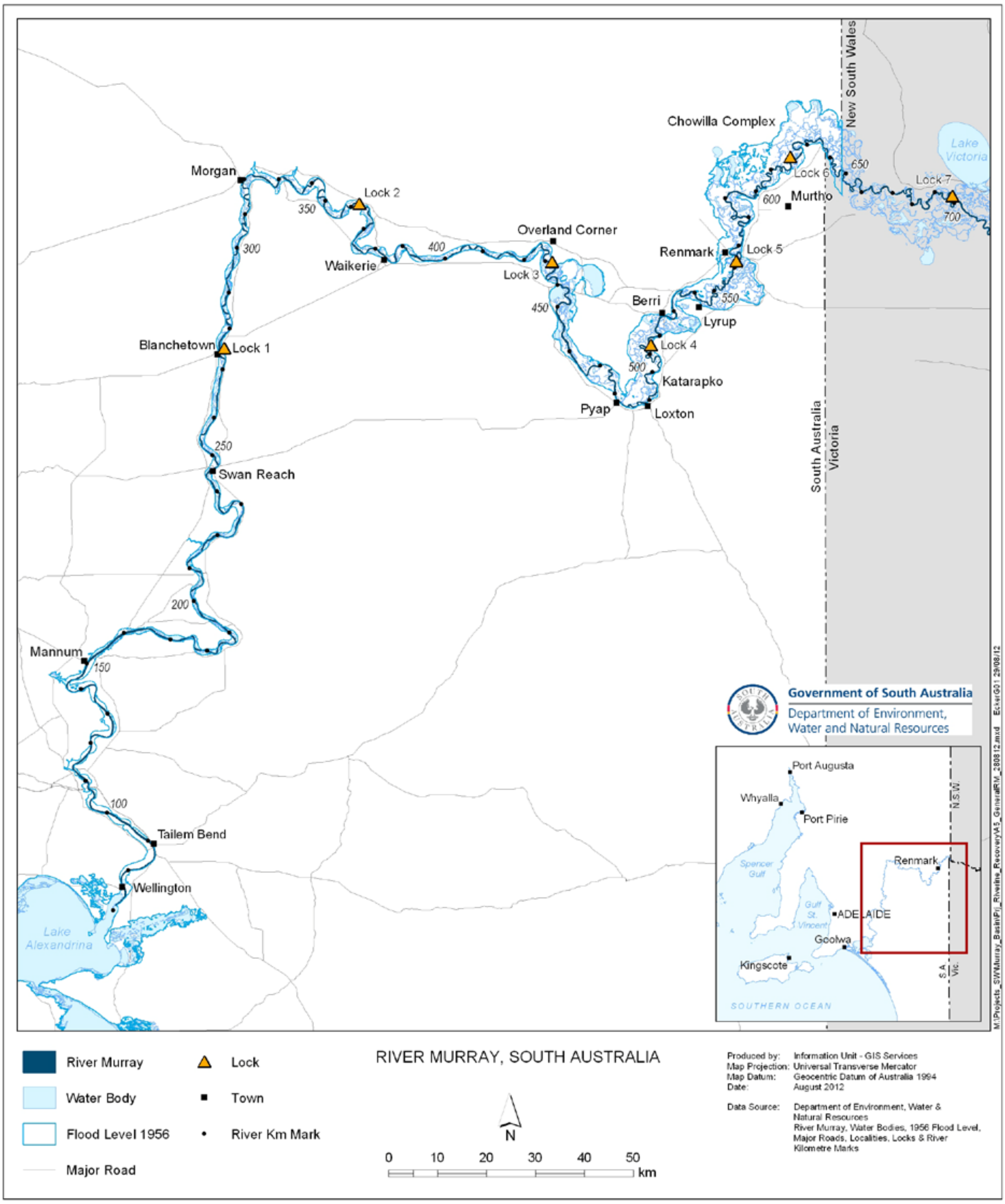


Figure 1: Map of the River Murray in South Australia with locations used in this study.

Some of the models include hydraulic structures, such as weirs and culverts, which have been modelled using the one-dimensional model MIKE 11. The one-dimensional model MIKE 11 and two-dimensional model MIKE 21 are then coupled using MIKE FLOOD, an umbrella program that governs the flow of water between the two models. The model of Weir Pool 6 (Water Technology Pty Ltd 2009) differs from the others used in this study, in that the Murray main channel and most of the anabranch channels are included in the MIKE 11 model rather than the MIKE 21 model.

The two-dimensional model requires specification of the flow resistance, which has been provided as an array of Manning's n values. Manning's equation is a commonly used equation governing open channel flow and textbook values for Manning's n are widely available. Manning's n is an empirical parameter for the resistance of the channel bed against flow and ranges of n values are generally given for a certain flow situation. Following conventional practice, these Manning's n values have been modified along with eddy viscosity to calibrate the model (described below), i.e. to match modelled water levels and flows with gauged values.

The models were run with steady-state (constant) boundary conditions at the upstream and downstream ends of the model. The desired flow rate for the model scenario was used as the upstream boundary condition. The Lyrup to Lock 5 model had an upstream water-level boundary in addition to the flow boundary, which was necessary to simulate the diversion to the Pike River anabranch system upstream of Lock 5. Each model run was continued until changes in water level and flow were negligible, to establish close to steady-state conditions. Typically, the computational time required for the models to reach steady-state conditions was about one day for each model run.

2.1 Elevation Data

The surface elevation data used in all models were extracted from the 2008 River Murray Digital Elevation Model (DEM). The DEM, collated by CSIRO as part of the 2008 Imagery Baseline Data Program, is a product of several smaller 'River Murray' DEMs, stitched together using ESRI ArcGIS® methods. The smaller DEMs include the Chowilla Floodplain, the Chowilla to Pyap Floodplain (Katarapko), the Pyap to Lock 1 Floodplain, the Lock 1 to Wellington Floodplain (with channel bathymetry included), the Lower Lakes and Coorong region, and the South East region within South Australia. The horizontal resolution of these DEMs ranges from 2 m to 50 m, with the final stitched DEM having a horizontal resolution of 2 m and a vertical accuracy of +/- 0.15 m. To generate the bathymetric input data for the hydraulic models, the 2 m River Murray DEM was resampled to a 15 m grid to match the horizontal resolution of the computational grid of the hydrological models. The vertical accuracy of the resampled elevation values would represent an average of the original higher resolution elevation values.

2.2 Weir Pools 1–5

The Existing Models

The models used in this project were adapted from existing MIKE 21 and MIKE FLOOD models that had previously been developed to model flood flow conditions. All of these models used a 15 m bathymetric grid, extracted from the DEM, as described above, with intensive depths in the main channel obtained in the 1980s. Those models already in MIKE FLOOD included a few structures on minor channels. However, the weirs were not included in these models because the weirs have a negligible impact on water levels during flood flows. These models have been run with a computational time step of two seconds. Such a short time step is needed for numerical stability of the two-dimensional model.

Adaption of the Models

Two of the original models have been divided into smaller models:

1. the original model from Morgan to Overland Corner was split at Lock 2 to create two individual models
2. the original model from Lyrup to Murtho was split at Lock 5, with the Lyrup to Lock 5 portion modified and a new model was created from Lock 5 to Lock 6.

The existing Lyrup to Murtho model did not extend upstream of Murtho and a new section of the model needed to be created from Murtho to Lock 6, as part of the Lock 5 to Lock 6 model.

The main reason to partition the original models was for easier specification of the boundary conditions, as the chosen weir pool level then becomes the downstream water level boundary. Secondly, the smaller models also made for improved overall model run times. The Overland Corner to Lyrup model was converted from a MIKE 21 to a MIKE FLOOD model with the inclusion of Locks 3 and 4 as MIKE 11 structures.

Model Bathymetry

The elevation data used to generate the bathymetric input for the models was collected using LiDAR (Light Detection and Ranging), which is a laser-based method. The pulse of light emitted by the laser cannot penetrate water unless the water is exceptionally optically clear. Therefore, the land surface elevation data collected using LiDAR returns pool water level for any water bodies. This means that bathymetry data are erroneous for the wetlands submerged at weir pool level. Furthermore, many of the channels that connect wetlands to each other and to the river are too narrow to be properly represented by the 15 m bathymetry grid. These shortcomings have not mattered for the models' original purpose of flood flow analysis, but the present purpose requires a detailed representation of the changes in connectivity and area of inundation of wetlands.

Bathymetric information was available for some anabranches, particularly within the Katarapko and Pike wetland regions. However, for the majority of minor channels connecting wetlands to the main river channel, realistic bathymetric data were not represented in the DEM. Instead, elevations for these channels were shown in the DEM as equal to or greater than the level of the weir pool. In order to model the connectivity of these wetlands to the main channel for weir-raising scenarios and in the absence of any bathymetry measured on-ground, it was necessary to manually alter elevations within the DEM to create channels inundated under standard weir-operating conditions. The wetlands and minor channels were first identified from close inspection of the original DEM and (particularly) aerial photographs to determine their connectivity to the river. Connecting channels were generally given an elevation of slightly less than standard pool level. In some cases, due to dense vegetation in the aerial photography or uncertainty around the presence of banks of structures, assumptions had to be made regarding the presence and controlling sill height of connecting channels. For the wetlands that were inundated at the time the LiDAR data was collected, the bed levels were estimated using depths of surrounding wetlands which were not inundated. Using the land surface elevation around the wetland, a best estimate of the wetland bed level was made.

The connecting channels, as modelled in this approach, are no less than 15 m wide (grid size) but are shallow. There is no way of assessing how realistic their hydraulic properties are without on-site observations and surveys. The method is considered valid for this model purpose because as long as the connectivity in the model is correct, the modelled water levels are likely to be sufficiently accurate for the purpose of this study. Flow rates and (particularly) velocities will be less accurately modelled. The major caveat of this approach is the difficulty in determining whether the channels are connected or not. In its current form, the model is not suitable for determining wetland filling rates or flows through small channels.

Hydraulic Structures

There are numerous hydraulic structures on the minor channels throughout the Murray valley, such as a number of weirs, but also many culverts installed for various purposes. However, most of these structures have not been included in the present models. This has in part been a pragmatic decision in response to the available timeframe, the particular objective of the present modelling, lack of influence on the extent of inundation, and for many locations the lack of firm information on invert levels. Where there are controlled structures, it has been assumed that these will be open in the case of a weir raising event.

However, this approach also has its merits in terms of the information the models provide. In considering the additional areas that can be flooded with a weir raising, the models in their present form generally provide an upper envelope. Hydraulic structures that are in place before and during a weir raising may in some cases decrease the effectiveness of the weir raising. In particular, culverts and weirs that keep reaches of a minor channel at elevated water levels effectively isolate those reaches from the effects of raising the weir downstream.

Those hydraulic structures that have been included are:

- A weir on Katarapko Creek that limits flow into the stream from the Murray main channel. This weir has been represented as raised bed levels within the MIKE 21 model.
- Several weirs within the Pike River system keep water levels higher than the adjacent Murray main channel. These are also represented as raised bed levels within the MIKE 21 model.
- Two culverts immediately upstream of Lock 5, on the true left bank. These limit flows in the two channels that supply the Pike River system.

The weirs

The weirs at Locks 1–6 have been added to the MIKE 11 model setup as a control structure . These control structures have been specified to keep the pool level constant over a wide range of flows, as is done in practice.

Boundary Conditions

For the model to calculate the inundated area for a specific scenario, based on the flow rate and the level of the weir, boundaries need to be specified at the upstream and downstream extents of the model area. For example, the water flowing from upstream into the model area needs to be defined as an upstream boundary condition and the flow rate at this point needs to be specified. Generally, the models have only one inflow point upstream, except for the Lock 5 to Lock 6 model, where two flow-boundaries were specified to represent the main River Murray at Lock 6 and Chowilla Creek. Flow gaugings from Lock 5 and 6 and Chowilla Creek were used to determine the flow split for each flow rate.

For most models, the downstream boundary is coincident with the location of a weir, the level of which is specified in the model scenarios. Where the downstream model boundary occurs at a location between weirs, the water level boundary has been set equal to the level simulated at the most upstream chainage of the model section located downstream. For example, for the model of the river section from Lock 2–Morgan, the downstream boundary is located at Morgan between Lock 1 and 2. The boundary condition at Morgan is set to the water level simulated at the upper chainage of the model for the river section Morgan–Lock 1, which is located downstream of Morgan.

Calibration

Calibration is the conventional practice in numerical hydraulic modelling of varying one or more of the hydraulic parameters (usually channel roughness), so that modelled and measured water levels and flows match. The complete dataset of archived water level and flow-rate data have been accessed from DEWNR's Hydstra database to identify occasions when the flow rate equalled (or was close to) the modelled flows of 10 GL/d, 20 GL/d, etc. The events were sorted to give more weighting to those approaching steady-state conditions. Favouring those events closest to steady state was intended to reduce calibration uncertainty by excluding variations in observed water levels resulting from variable travel times and hydraulic fluctuations, such as those caused by wind and weir adjustments. Gauge locations used for calibration are shown in Table 1 with the difference between the highest and lowest water level used for calibration at each location for each flow rate. The scatter of the individual gaugings is notable and it follows that any calibration cannot be precise.

Table 1: Gauge locations, chainage, and range between highest and lowest observed water level for each flow rate used for calibration

Gauge Location	River Chainage (km)	Difference between highest and lowest water level (m) used for calibration for a specific flow rate				
		10 GL/d	20 GL/d	30 GL/d	40 GL/d	50 GL/d
Lock 1 upstream	274.2	0.03				
Morgan	321.7	0.06				
Cadell	332.8	0.03				
Lock 2 downstream	362.1	0.06				
Lock 2 upstream	362.1	0.11				
Waikerie	383.0	0.01				
Overland Corner	417.5	0.13				
Lock 3 downstream	431.4	0.03				
Lock 3 upstream	431.4	0.11	0.21	0.13	0.23	0.19
Loveday	446.9	0.15	0.15	0.10	0.03	0.19
Loxton	493.9	0.19	0.23	0.28	0.55	0.49
Bookpurnong	504.5	0.47	0.15	0.77	0.51	0.24
Lock 4 downstream	516.2	0.26	0.32	0.87	0.72	0.40
Lock 4 upstream	516.2	0.36	0.17			
Berri	525.7	0.34	0.19			
Lyrup	537.7	0.34	0.23			
Lock 5 downstream	562.4	0.32	0.39			
Lock 5 upstream	562.4	0.12	0.20	0.18	0.20	0.13
Renmark	567.9	0.12	0.19	0.17	0.27	0.23
Lock 6 downstream	619.8	0.36	0.56	0.12	1.04	0.19
Lock 6 upstream	619.8	0.81	0.86			

Model water levels have been matched to the gauged levels by adjusting the flow resistance from the bed (expressed in the models as M, which is the reciprocal of the Manning's n). Calibration model runs were carried out for all of the flow rates to be modelled for each weir pool. That is a flow of 10 GL/d and 20 GL/d for weir pool 1, 2, and 4, flows of 10 GL/d, 20 GL/d, 30 GL/d, and 50 GL/d for weir pool 3, and flows of 10 GL/d, 30 GL/d, 40 GL/d, and 50 GL/d for weir pool 5. The intent of the calibration is to determine a single flow resistance map which achieves the best match to recorded water levels for all flow rates. The calibration focused on changing the roughness of the main channel, while the roughness values for the floodplain were then scaled proportionally. Table 2 provides a summary of the Manning's n values used in the models.

Table 2: Manning's n values used for each model

Modelled river section	Main channel or floodplain	Manning's n value for roughness (-)	Manning's n value for majority of model grid cells on floodplain
Lock 1– Morgan	Main channel	0.015	
	Floodplain	0.028–0.083	0.03
Morgan–Lock 2	Main channel	0.017	
	Floodplain	0.028–0.083	0.05
Lock 2–Overland Corner	Main channel	0.02	
	Floodplain	0.028–0.083	0.05
Overland Corner–Lyrup	Main channel	0.015	
	Floodplain	0.025–0.07	0.05
Lyrup–Lock 5	Main channel	0.02	
	Floodplain	0.029–0.07	0.03
Lock 5– Lock 6	Main channel	0.025	
	Floodplain	0.025–0.077	0.077

In Figures 2 to 6, the individual water level gaugings for a particular flow are plotted along with a longitudinal water level profile for each river section, extracted from the two-dimensional model output. These graphs show the variation in gauged levels for a given flow, where these observations are located along the river, and where the modelled water levels fall within the range of observations. The figures show that it was not possible to achieve a perfect match between observed and modelled water levels for all gauging locations along the river for all of the flow rates, but for most locations the modelled water levels lie within the range of observed values.

The largest deviation between modelled and gauged water levels occurred at Weir pool 3 for the higher flow rates (30 GL/d and 50 GL/d). It is considered that irrespective of the level of the weir, the error in the flow resistance values equally affects the modelled water levels at a given flow rate. As this project focuses on the calculated additional area of inundation from weir pool raisings and assuming the error in flow resistance affects the scenario with and without weir raising equally, the impact on the calculated additional area is minor.

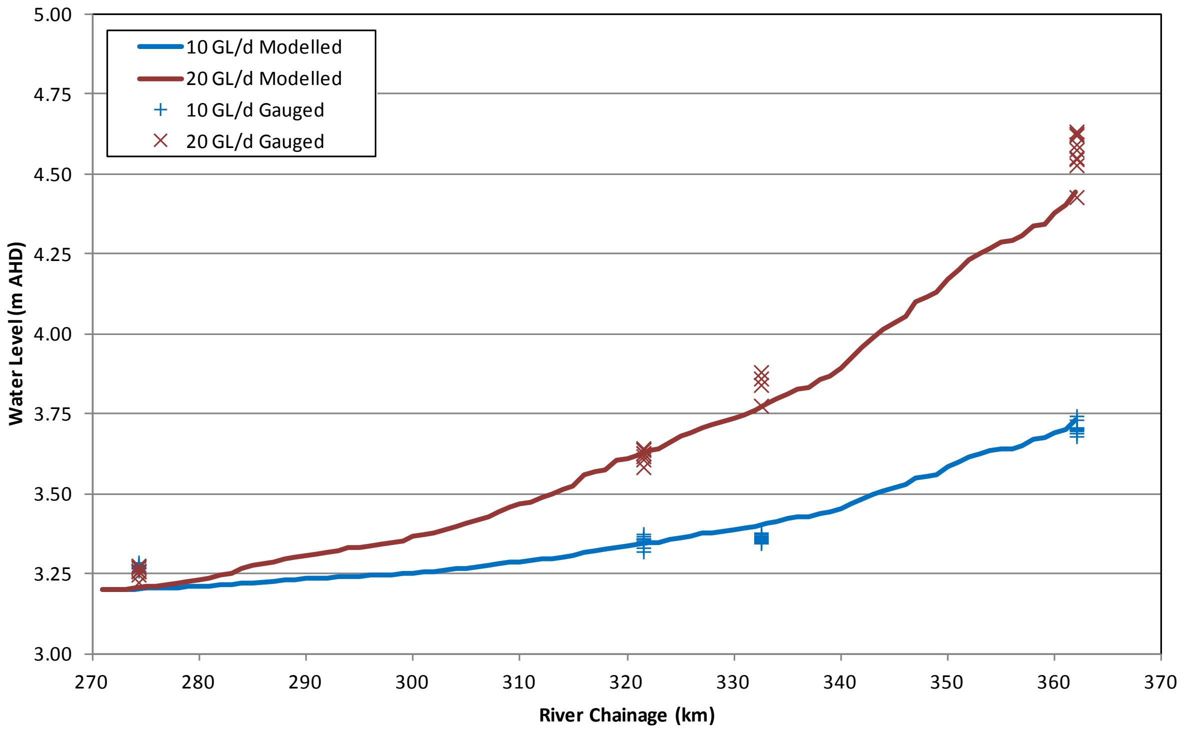


Figure 2: Calibration results of MIKE FLOOD model for Weir Pool 1

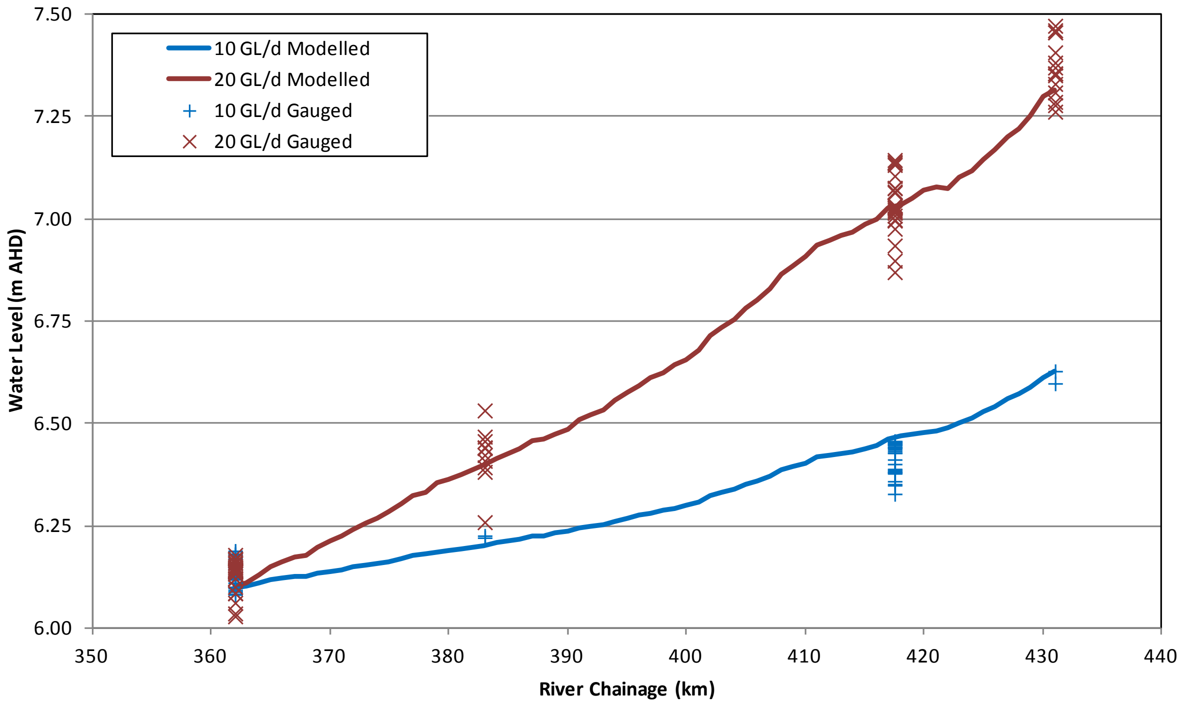
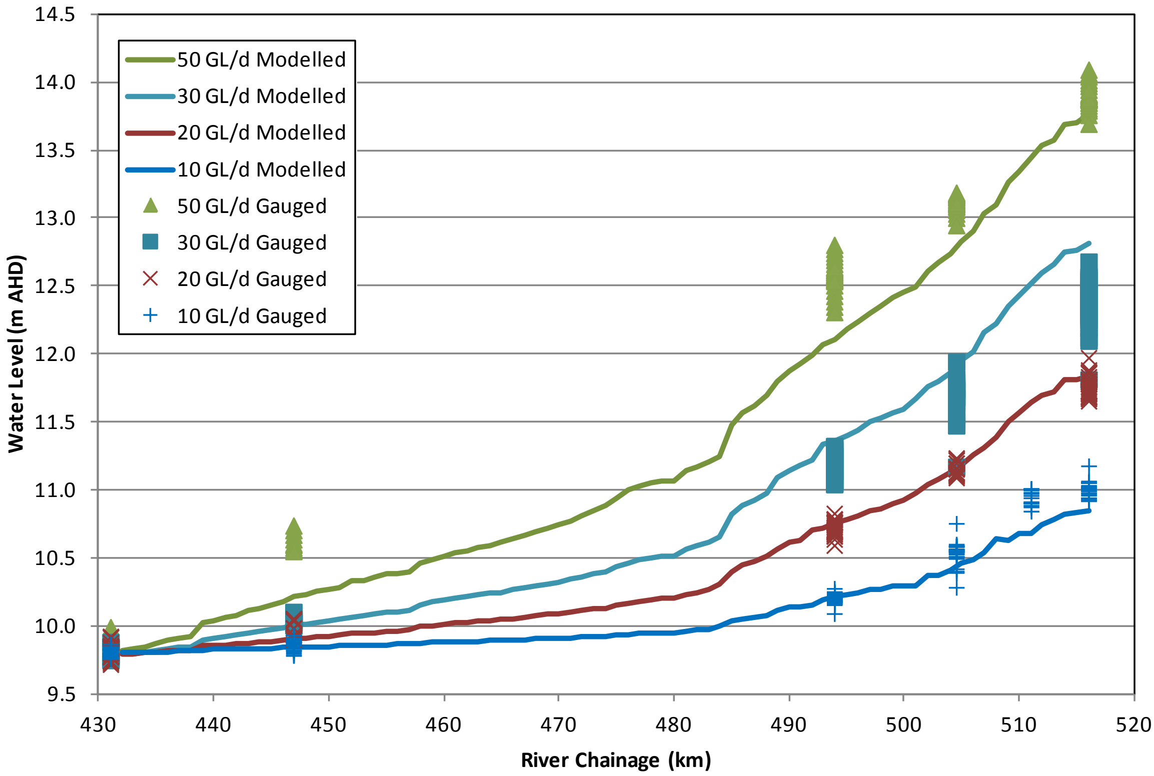


Figure 3: Calibration results of MIKE FLOOD model for Weir Pool 2



Note: 50 GL/d modelled levels are less than gauged values due to water levels at Lock 3 being held higher than 9.8 m AHD during the calibration events. The effect is greatest at the lower end of the reach, closest to the weir.

Figure 4: Calibration results of MIKE FLOOD model for Weir Pool 3

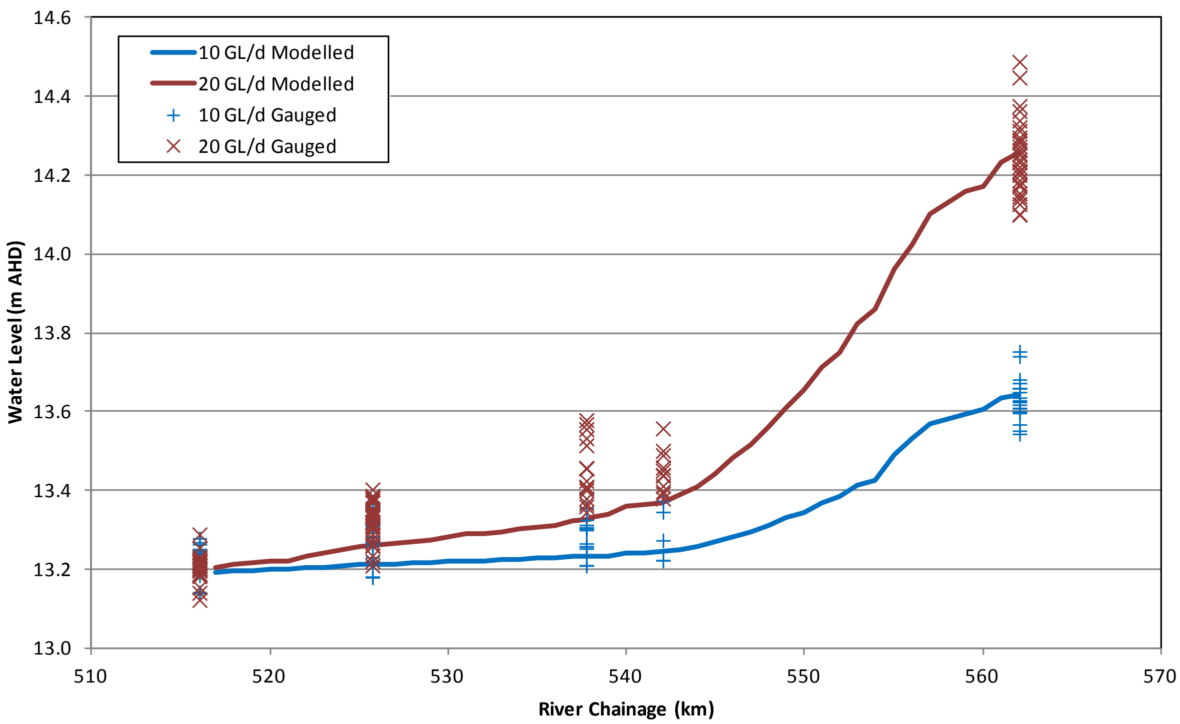


Figure 5: Calibration results of MIKE FLOOD model for Weir Pool 4

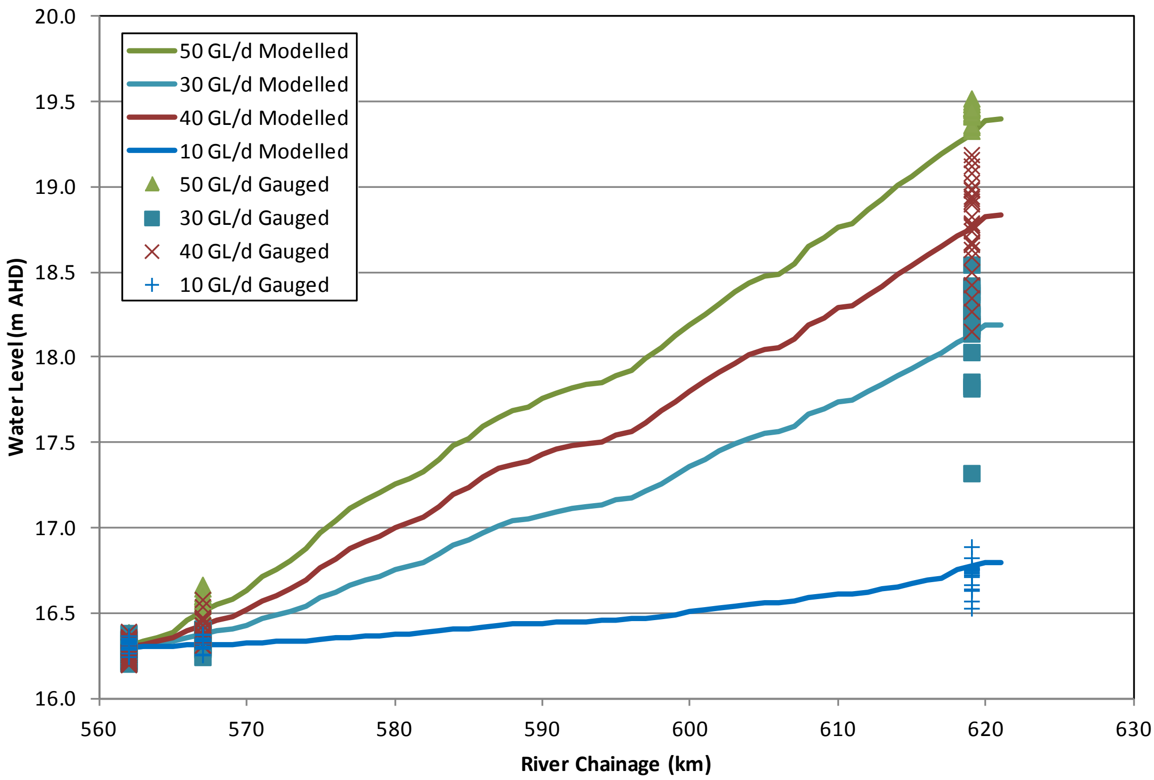


Figure 6: Calibration results of MIKE FLOOD model for Weir Pool 5

2.3 Weir Pool 6

The Existing Model

The model used for Weir Pool 6 in this project was the result of a previous project executed by Water Technology Pty Ltd of Melbourne. In 2009, Water Technology adapted and improved the original model, which had been developed by DHI (DHI, 2006). The Water Technology model was calibrated against historic flood events in 1992, 1996, and 2000, with peak flows between 38 GL/d and 68 GL/d (Water Technology, 2009). Prior to the calibration of the Water Technology model to these flood events, the underlying one dimensional channel network had been calibrated over a three-year simulation period from January 2005 to December 2007 inclusive, which included periods with low flow. The model in its present state should therefore be valid for both low and moderate flows.

The model differs in two crucial ways from those used for Weir Pools 1–5:

- All the significant channels have been represented within the one-dimensional MIKE 11 model that forms part of the MIKE Flood model. In this case, the MIKE 11 model computes water levels and flows accurately stand-alone, with the MIKE 21 model needed only to show the resulting inundation of the floodplains.
- The MIKE 21 two-dimensional model uses a coarser bathymetric grid of 30 m that computes floodplain water levels and flows.

Adaption of the Model

The model obtained from Water Technology included a few structures on minor channels, as well as the weir at Lock 6 and the new Chowilla regulator. The Chowilla regulator has been removed from the model setup because the regulator is assumed open for the purposes of this study to assess the inundation due to weir pool manipulation. For the present modelling, all regulator culverts have been assumed open. A few minor structures modelled by Water Technology have not been removed for the present modelling because they are not likely to have a large impact on the modelled inundated area.

On inspection, it was found that no connecting channels needed to be added to the Water Technology model. However, some minor changes were made to the bathymetry of some wetland areas to ensure correct connectivity with the channel system.

Calibration

The model calibration carried out by Water Technology has been to match modelled and gauged anabranch flows. Water Technology's report (Water Technology, 2009) presents this calibration for three high-flow events which also include the lower flows relevant to the present study. For the model's present use, calibration of water levels is more relevant. Water Technology's report indicates that the model has also been calibrated to gauged water levels, but this part of their calibration is not presented in their report. Due to this lack of information, it has not been possible to evaluate the model's performance with regards to water level computation for weir pool 6.

The only gauged water level site on this section of the River Murray is close to Lock 7, within New South Wales. Figure 7 shows data from this site compared to the modelled longitudinal water surface profiles. The modelled water levels are below the observed levels at Lock 7, which indicates that the modelled flow resistance needs to be increased for the modelled water levels to match the gauged levels. The 10 GL/d flow was remodelled with Manning's n increased from 0.03 to 0.035 and this profile is also plotted in Figure 7. The graph indicates that even a somewhat higher flow resistance of about 0.04 would be compatible with the gauged data

However, there is no information to indicate whether such an increased resistance should be applied to the lower-gradient reaches on the South Australian side of the border. Given that the resulting flow resistance is comparable with that found in calibrating the models of the other weir pools, it appears appropriate to retain the resistance values used by Water Technology, in the knowledge that modelled water levels near Lock 7 will not be reliable. Based on the difference in modelled water levels using Manning's n values of 0.03 and 0.035 (Figure 7) it can be estimated that downstream of chainage 665 km, the resulting uncertainty in water levels is in the order of 0.15 m.

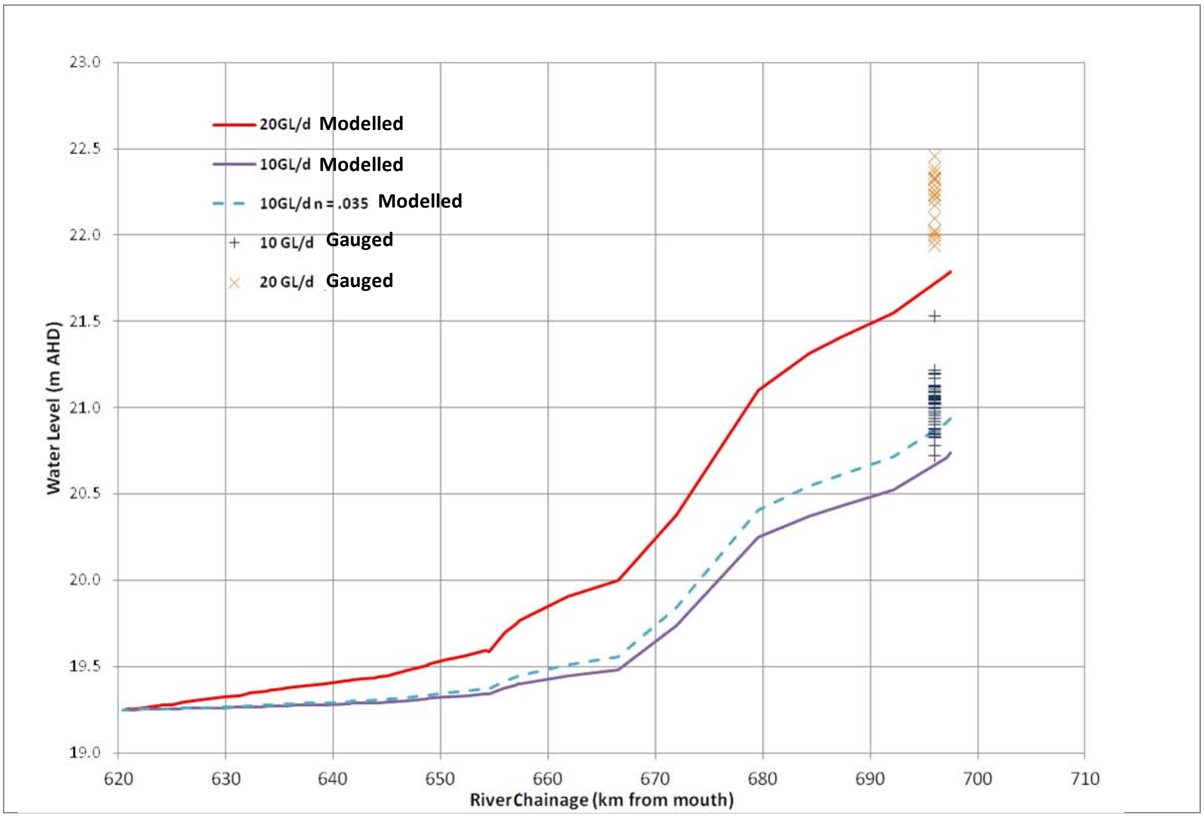


Figure 7: Water level results for calibrating MIKE FLOOD model for Weir Pool 6

Gauged water level data from the anabranches in the Chowilla region are also of little help in calibrating the model. Inspection of the available water level data from site A4261091 on Chowilla Creek shows, for a given flow, a scatter in measured water levels of 0.5 m. This is too much scatter for more than a generalised confirmation that the model results appear reasonable.

2.4 Post-processing

Conversion of Flooded Extent to a ESRI ArcGIS® Shape File

Inundation extents at 15 m resolution were the main output from the hydraulic models. The water surface elevation output of the MIKE 21 simulations were converted from the MIKE specific format (DFS2) to GIS shape files to map the inundation extent in ESRI ArcGIS®. GIS polygons were generated from the inundated area information in the Mike21 model output files. Across the six weir pools, surface areas for each scenario were extracted from the attribute table of the GIS polygons.

The initial water levels assumed in the numerical modelling result in 'false positives', where isolated wetlands are shown as full but in reality they would dry out. These have been manually edited from the shape file of inundation extent created from the model output.

Computation of Volumes

The inundation volumes were calculated for each flow scenario with the weir not raised (the base case) and for the weir raising scenarios using water surface elevation and bathymetric data exported from the MIKE 21 modelling package. Both the water surface elevation and bathymetric datasets (exported as DFS2 files) were then imported into the GIS environment and converted to geodatabase raster files with a pixel resolution of 15 m. Weir Pool 6 raster files have a resolution of 30 m, equal to the resolution of the model's computational grid.

Using the Spatial Analyst functionality in ESRI ArcGIS, the bathymetric raster was subtracted from the water surface elevation raster, creating a new raster with values identifying the change in depth between the two grids. The sum of the change of depth (this figure can be found in the classification statistics of the raster), multiplied by the area of a pixel (either 225 m² for 15 m or 900 m² for 30 m pixel), provided the total volume of the raster for a scenario. This process was repeated for each base case and weir raising scenario across all six weir pools.

3. Scenarios Modelled

Weir pool manipulations were carried out for each of the models. The scenarios undertaken were based on the priorities set during the Weir Pools Workshop held on 5 March 2012 at Flinders University City Campus in Adelaide. Workshop participants were representatives of the ecology, surface water, groundwater, policy, river operations, and major hazards groups within DEWNR (at that time the Department for Water and the Department of Environment and Natural Resources) and the Department of Planning, Transport, and Infrastructure, members of the South Australian Murray-Darling Basin Natural Resources Management Board, SA Water staff members, and the Environmental Protection Agency. The schedule of scenarios to be tested was decided on during this workshop and selection criteria taken into account were structural limitations of the weirs identified in Lloyd Environmental (2010) and safe operating conditions of the weirs. Within these constraints, the workshop selected raising intervals as shown in Table 3.

3.1 Weir Raisings

43 scenarios consisting of 29 weir raising scenarios and 14 base cases (no weir raising) were identified as preferred by the workshop (Table 3). The program scope was to deliver up to 30 scenarios, inclusive of base cases, so it was necessary to prioritize the scenarios to be modeled. The prioritization is indicated in Table 3, with priority A as the highest priority and priority C the lowest. This study has completed all A and B priority scenarios and 4 out of 12 priority C scenarios.

3.2 Weir Lowerings

It was decided during the workshop that for scenarios of weir pool lowering, the provision of longitudinal water surface profiles would be the only required output. This is due to the lack of bathymetric data below pool level, which limits the models applicability to provide meaningful results of the reduced area of wetland inundation due to weir pool lowering. The scenarios to be modelled were weir lowerings of 20 cm at Locks 1, 2, 5 and 6, for just the one flow rate of 10 GL/d. Lowering scenarios for weir pools 1, 2, and 5 were modelled the same way as the weir raisings and the profile was extracted from the two-dimensional output data.

Table 3: Scenarios for modelling of raisings of weir pools

Weir Pool	Height to increase (cm)	Flow rate				
		10 GL/d	20 GL/d	30 GL/d	40 GL/d	50 GL/d
1	Base case	A	A			
	+25cm	C				
	+50cm	B	B			
	+106cm	A	A			
2	Base case	B	C			
	+35cm	C	C			
	+70cm	B				
3	Base case	B		B		A
	+30cm	C		C		A
	+59cm	B		B		
4	Base case	A	B			
	+25cm	C				
	+60cm	A	B			
	+114cm	B	B			
5	Base case	A		B	A	A
	+35cm	C		C*	C*	C
	+50cm	A		B	A	A
6	Base case	A	A			
	+50cm	C	C			
	+62cm	A	A			

Legend

(grey) Not operationally safe/feasible
(black) Not to be modelled
A Priority A
B Priority B (Items marked 1 are the highest priority of the priority B scenarios
C Priority C
C* Only one of these is necessary to model

4. Results

4.1 Inundation Areas and Volumes (weir raisings only)

The main output from the modelling is the set of GIS shape files defining the inundated areas for different scenarios. For practical reasons these maps are not presented in this report.

Table provides the inundation areas as determined from the edited shape files and also presents the additional areas flooded by the raisings. Individual model runs with weir raising scenarios showed increases in flooded areas varying from 154 ha to 1956 ha.

Table 4: Modelled Inundation areas and volumes for weir pool raising scenarios

Weir Pool	Flow (GL/day)	Weir raising (cm)	Area inundated (ha)	Additional area inundated[1] (ha)	Relative increase in inundated area[1] (%)	Additional volume[1] (GL)
1	10	0	2328			
		50	2853	525	23	12.3
		106	3504	1176	51	29.4
	20	0	2461			
		25	2726	265	11	6.0
		50	2984	523	21	12.2
		106	3578	1117	45	29.1
2	10	0	1938			
		35	2096	158	8	5.3
		70	2278	340	18	11.2
	20	0	2060			
		35	2215	155	8	5.0
3	10	0	5590			
		59	7145	1556	28	34.3
	30	0	6355			
		59	8204	1849	29	36.4
	50	0	7659			
		30	8871	1212	16	21.5
4	10	0	2473			
		60	3275	803	32	12.2
		114	4331	1859	75	29.0
	20	0	2622			
		60	3507	885	34	13.0
		114	4578	1956	75	30.3
5	10	0	2434			
		50	3351	917	38	13.5
	30	0	3191			
		50	4217	1026	32	11.0
	40	0	4082			
		50	5111	1029	25	11.3
	50	0	5330			
		50	6153	822	15	10.0
6	10	0	1700			
		62	2182	482	28	6.1
	20	0	1805			
		62	2418	613	34	8.1

[1] Refers to additional inundated area and volume compared with no weir pool raising (0 cm).

4.2 Backwater Curves (weir raisings and lowerings)

A backwater curve is the upstream longitudinal profile of the water surface in an open channel, when the water surface is not parallel to the channel bed owing to the depth of water having been increased by an obstruction such as a dam or weir. Figures 8–13 show the modelled backwater curves for the various weir level scenarios for each weir pool. For a given weir level, the water level at the weir is the same for each flow scenario, but further upstream the water level increases more rapidly for a high flow scenario than for a low flow scenario. When the weir is raised or lowered for a given flow, the effect on the water level is greatest just upstream of the weir with decreasing impact further upstream. In some cases, such as for weir pool 3 for flow scenarios 30 and 50 GL/day, raising the weir has a minimal effect on the water levels furthest upstream of the weir (Fig. 10).

It can be seen that weir level manipulation has a greater effect for lower flows than for higher flows. For example, in weir pool 4 when raising the weir by 114 cm the water level at the most upstream chainage (562 km) increases by 90 cm for the 10 GL/day flow scenario while only increasing 60 cm for the 20 GL/day scenario (Fig. 11).

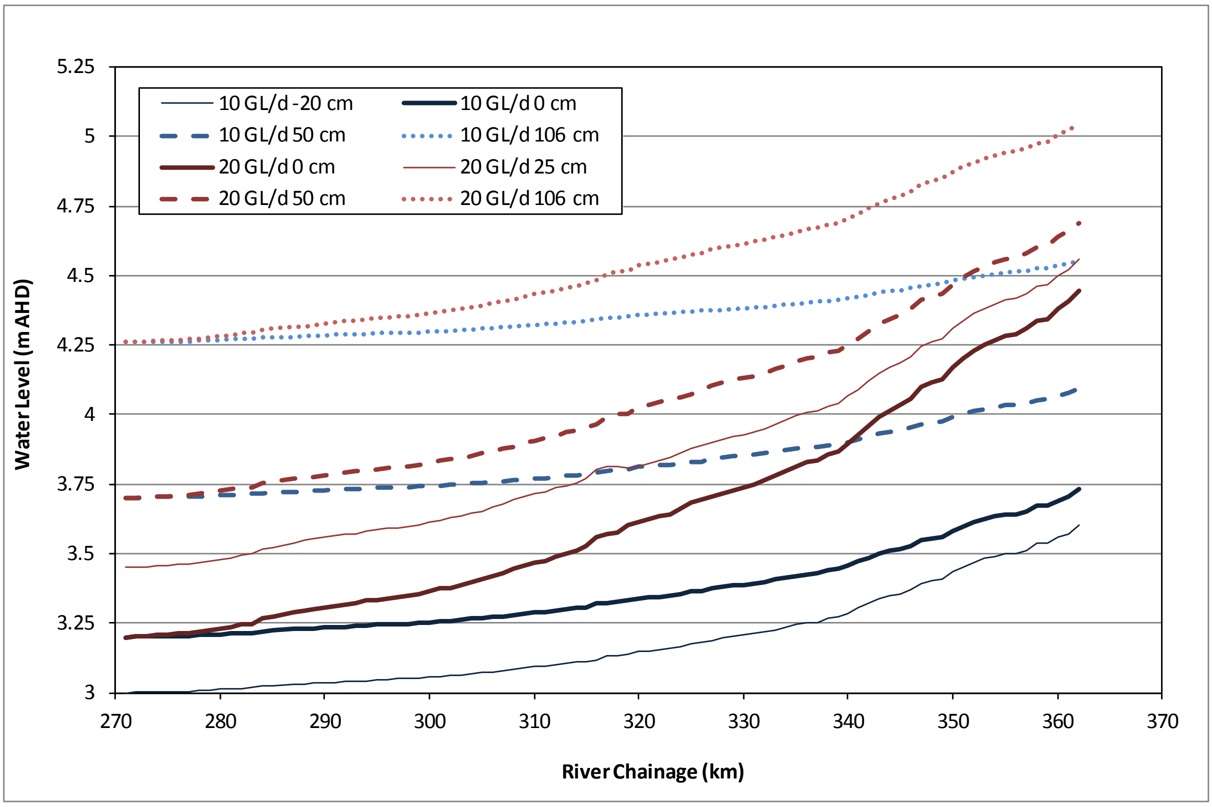


Figure 8: Weir Pool 1 modelled weir manipulation backwater curves for the modelled scenarios

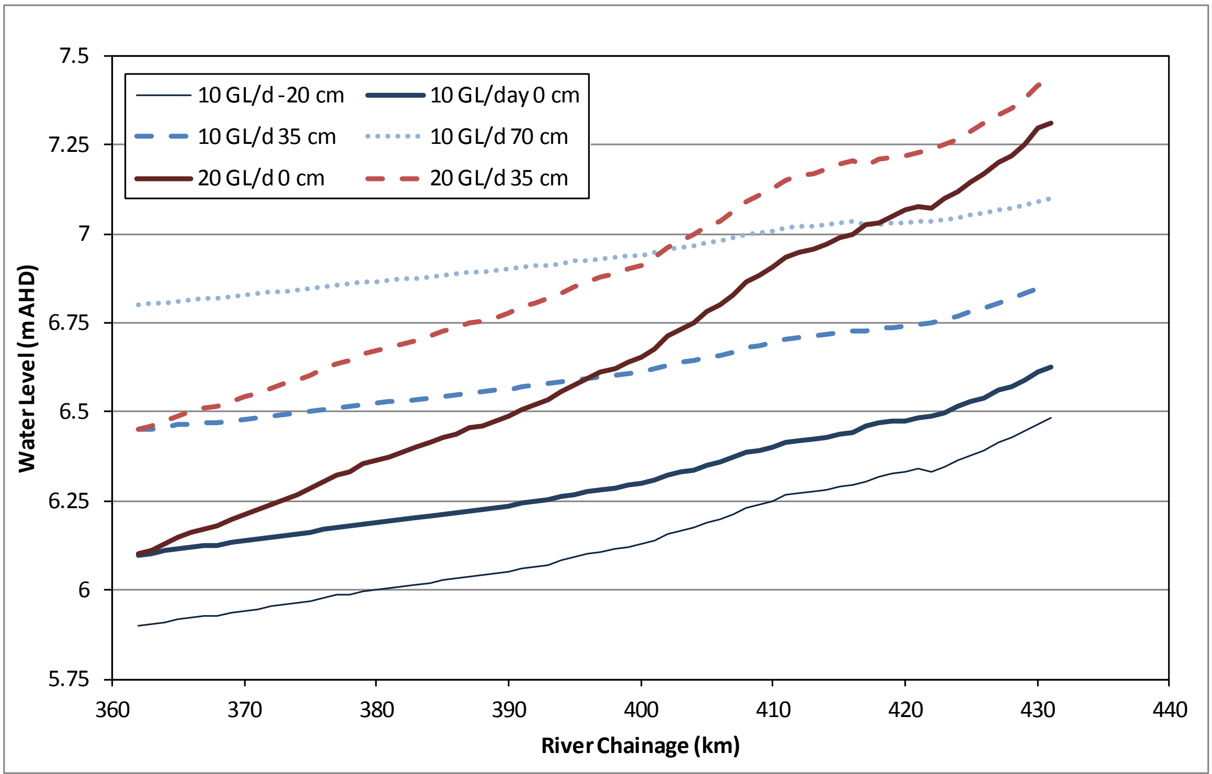


Figure 9: Weir Pool 2 backwater curves for the modelled scenarios

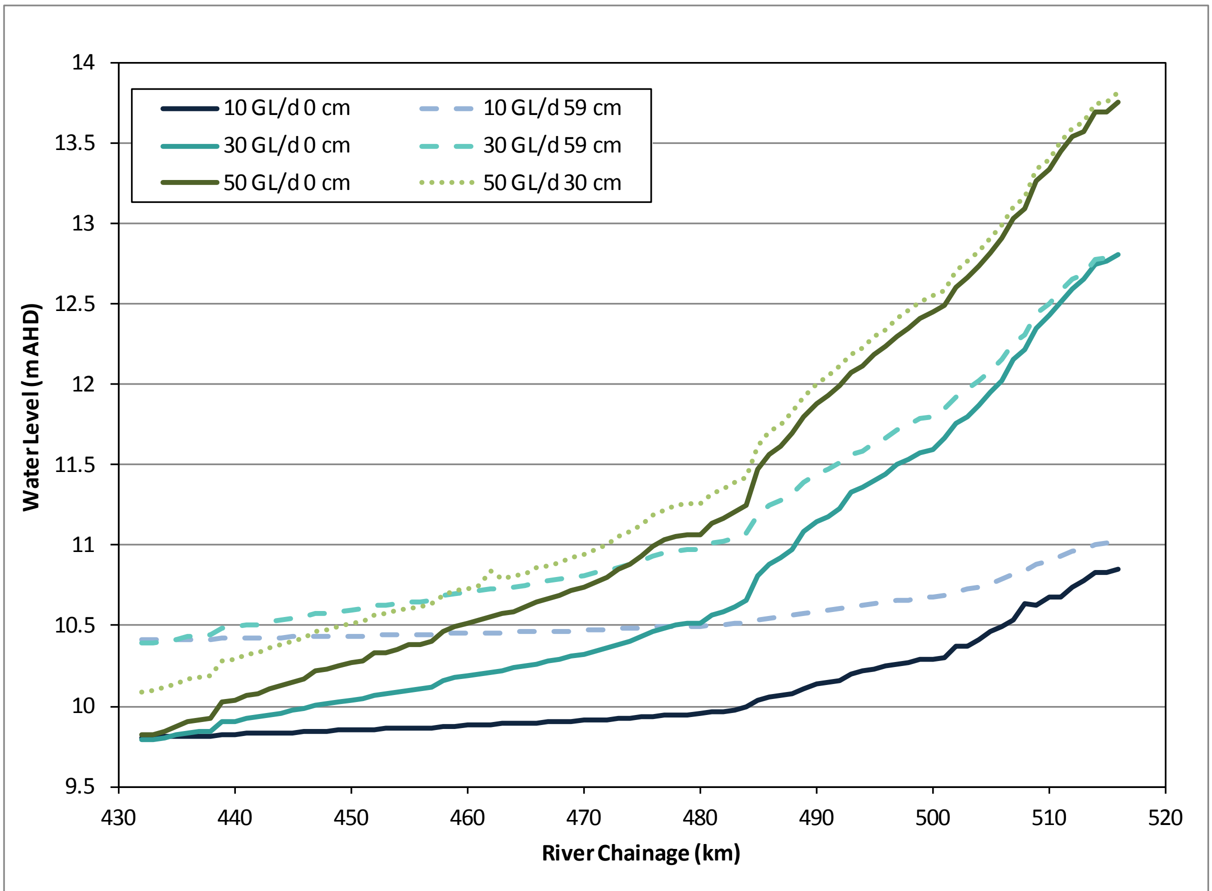


Figure10: Weir Pool 3 backwater curves for the modelled scenarios

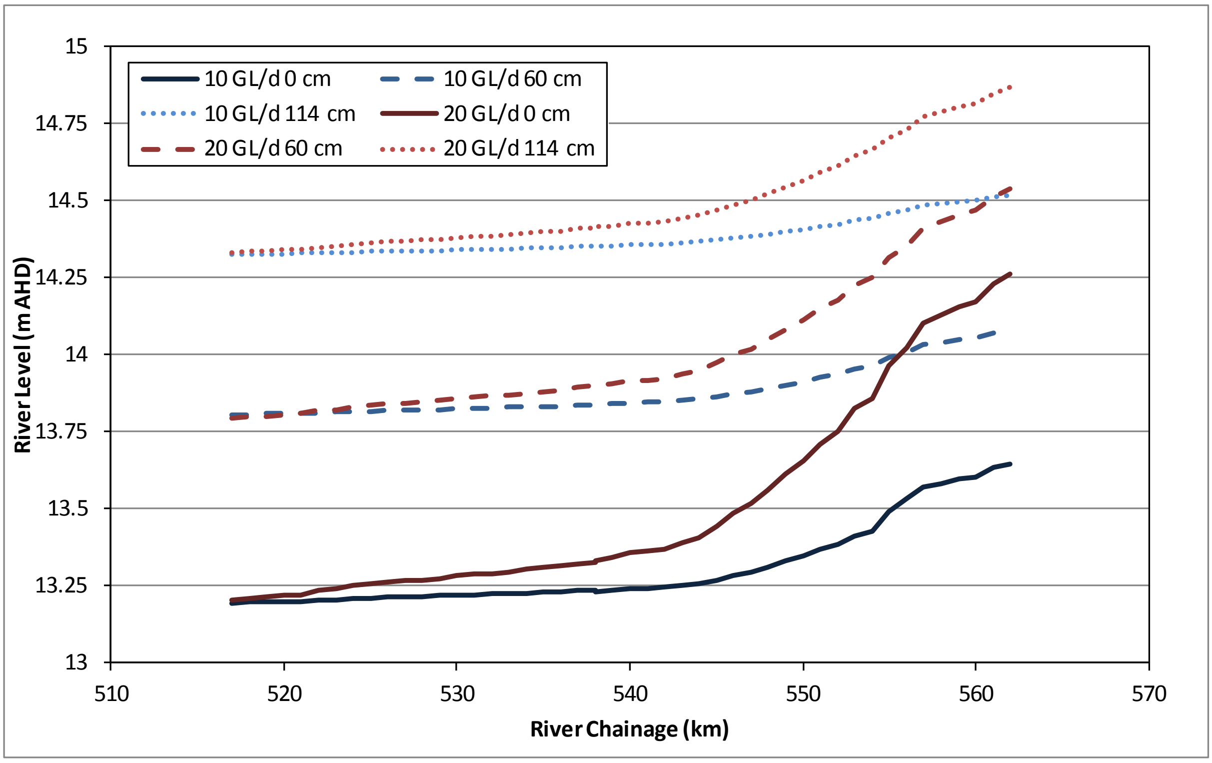


Figure 11: Weir Pool 4 backwater curves for the modelled scenarios

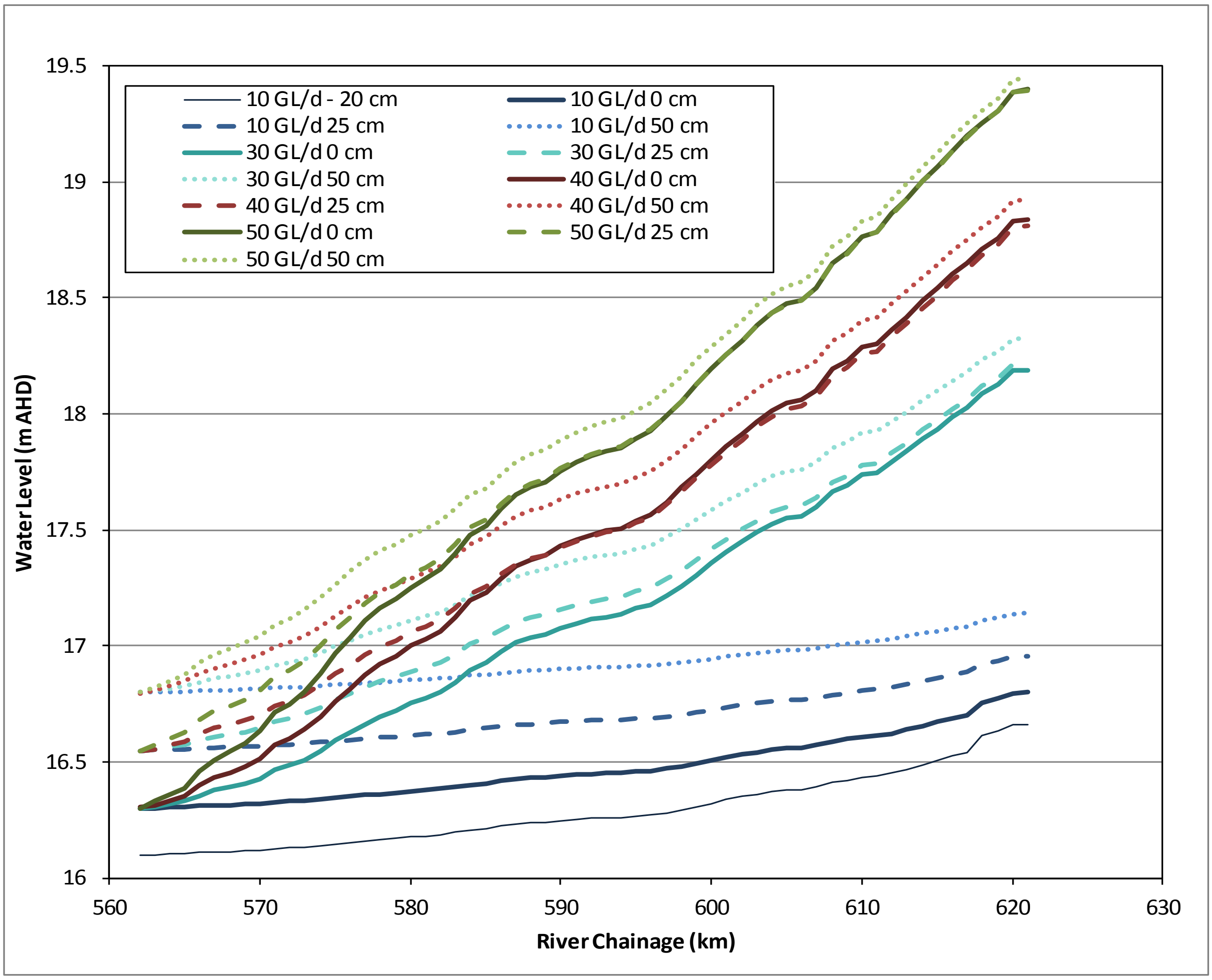


Figure 12: Weir Pool 5 backwater curves for the modelled scenarios

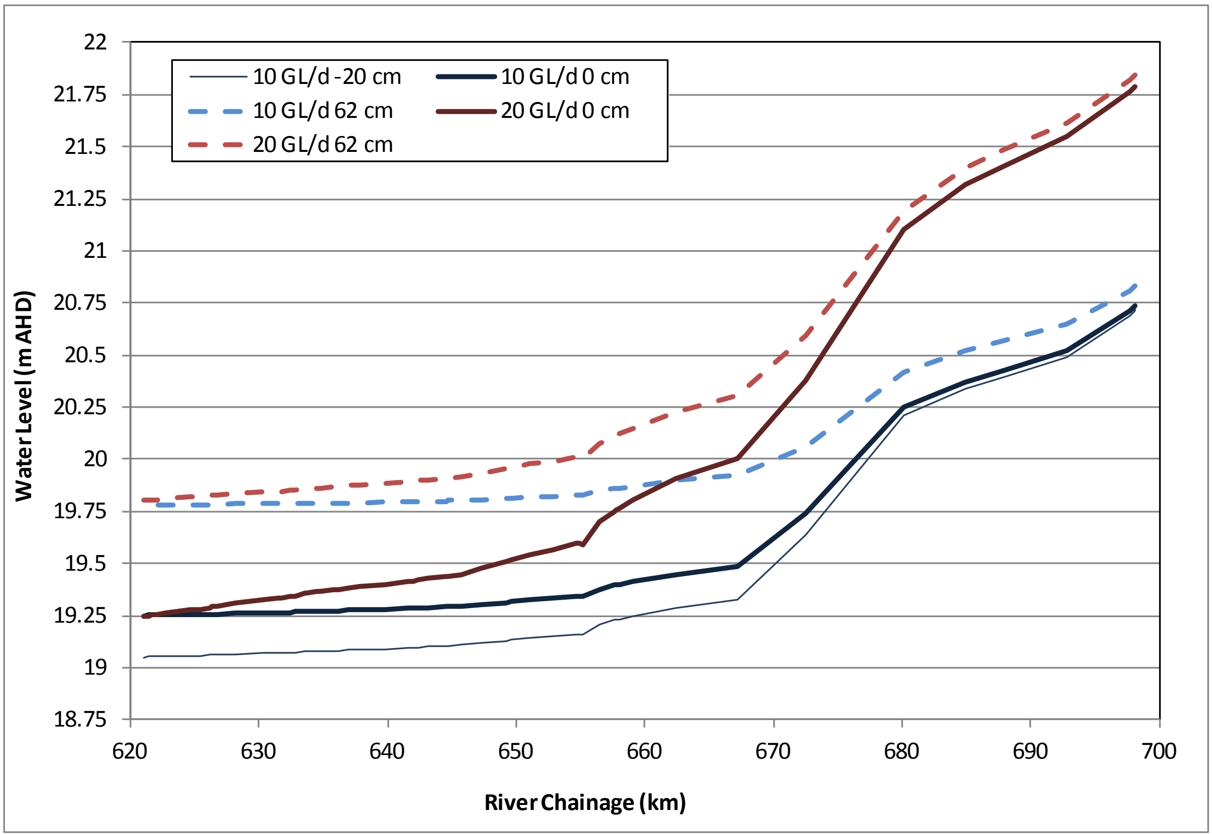


Figure 13: Weir Pool 6 backwater curves for the modelled scenarios

5. Assumptions and Limitations

The modelling summarised by this report has been undertaken to estimate variations in the extent of inundation that would arise from manipulation of the operating level of weirs. To this end, a modelling approach has been adopted which is deemed appropriate to develop estimates of inundation extents for future planning and operations. Factors that have affected the modelling approach and outcomes include the lack of bathymetric data of anabranches and wetlands and time constraints resulting from the computationally demanding model runs. This means that the models and their outputs have the following limitations:

- The modelling assumes steady-state conditions, that is, that river levels will be elevated for a long enough period to allow anabranches and wetlands to fill and stabilise to their final level. The time taken for wetlands to fill is dependent on the size of the inlet channel (and structure, if applicable), which due to the lack of adequate bathymetry data, has not been accurately represented in the present modelling. Short duration weir manipulation events deviate from the steady-state assumption and may result in a lesser extent of inundation, where inlet channels and/or structures constrain the rate of flow into wetlands to such a degree that levels have not stabilised by the time the weir level is changed again.

- The 15 m and 30 m grid sizes for the bathymetry data may have omitted some channels. Whilst considerable effort has been made to identify these channels from aerial photos, it is quite likely that some have been missed. A field check, carried out at suitable river flow rates, might be the only way of ensuring that all such channels have been identified and that connectivity of wetlands is appropriately represented by the model. Surveying of sill levels may also be warranted in some locations.

- Where connecting channels have been manually added, they have been represented by shallow channels with the same width as the model grid (15 m), whereas they are likely to be deeper and narrower in reality. This approximation should have an insignificant effect on water levels and extent of inundation, but may affect modelled flow rates and (particularly) velocities. This means that the current models should not be used for modelling non-steady state conditions where the time to fill and drain a wetland can be of importance, nor should they be used for detailed, hydraulic design studies where flow rates and velocities must be captured more realistically. Such modelling purposes would require further investment in data collection for these channels (refer to previous dot point) and changes to the setup of the hydraulic model.

- For the wetlands that were inundated at the time the LiDAR data was collected, the bed levels were estimated using depths of surrounding wetlands which were not inundated. Using the land surface elevation around the wetland, a best estimate of the wetland bed level was made. There is uncertainty related to these estimates of wetland bed level, but this should have a minimal effect on the simulated water levels for the weir raising scenarios, as the water level is at pool level or higher for these scenarios. For weir pool lowering, the unknown bathymetry can have a greater impact because water levels in wetlands fall below pool level. For this reason, the modelled inundation extents for the weir lowering scenarios are more uncertain and the project outcomes have therefore been more targeted at the weir raising scenarios.

- The grid size selection for the model calculation grid and the bathymetry data was a critical decision to ensure that estimated floodplain inundation extent was of an appropriate resolution for the objectives of this project, while ensuring model run times could be accommodated within the timeframe of the project (higher spatial resolution can increase model run times considerably). To achieve this balance, grid sizes of 15 m and 30 m were selected.

6. Opportunities for Further Investigations

The modelling approach adopted in this assessment is considered appropriate to define an upper envelope of inundation due to weir pool manipulation. Nonetheless, there are some areas where future improvements could be made if additional confidence in the results and/or detail was required:

- Prediction of the extent of inundation due to weir pool lowering is hampered by the lack of bathymetric surveys of channels and wetlands normally submerged under current pool level. Further surveys of these areas would enable estimates of the reduced area of inundation due to weir pool lowering to be made.

- The current modelling is unable to predict flow behaviour such as the filling of wetlands and variations in hydraulic conditions through creeks and anabranches due to a lack of bathymetric data and their simplistic representation in the current modelling. Survey of wetland inlet channels and structures would enable more detailed modelling to be undertaken to determine hydraulic conditions through these channels (flow, level, velocity) and filling times of wetlands. It may prove impracticable to survey all channels within a weir pool, but it should be possible to prioritise those representative cross-sections where the channel size is critical to affecting flow conditions and wetland water levels.

- Future modelling could be undertaken to estimate the impacts of integrating weir pool manipulations with wetland management as is being developed in the Wetlands project element of the Riverine Recovery Project. This may warrant a more complex modelling approach using MIKE FLOOD, such as has been adopted for the hydraulic modelling of the Chowilla, Pike and Katarapko floodplains.

7. Conclusions

The proposed scenarios for the raising and lowering of the weirs at Locks 1 to 6 have been modelled using a series of two-dimensional hydraulic models. These have provided longitudinal profiles of the backwater curve along the main river channel and shape files of inundated areas.

The modelling output shows which areas are flooded under different weir manipulation scenarios at different flow rates. The results are considered to be sufficiently accurate for identifying those scenarios that offer significant ecological benefits. However, some assumptions were necessary in the absence of bathymetry data for wetlands and channels that are normally under water. This should be considered if the models are used for detailed design or for other investigations.

8. References

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