Department of Climate Change, Energy, the Environment and Water

Hydraulic modelling summary report

Reconnecting River Country Program
Murrumbidgee Project

March 2025

Acknowledgement of Country

Department of Climate Change, Energy, the Environment and Water acknowledges the traditional custodians of the land and pays respect to Elders past, present and future.

We recognise Australian Aboriginal and Torres Strait Islander peoples' unique cultural and spiritual relationships to place and their rich contribution to society.

Artist and designer Nikita Ridgeway from Aboriginal design agency – Boss Lady Creative Designs, created the People and Community symbol.

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Contents

Figures

Tables

1 Introduction

1.1 About the Reconnecting River Country Program

The NSW Department of Climate Change, Energy, the Environment and Water's Reconnecting River Country Program is a key NSW Government commitment under the Murray-Darling Basin Plan, involving the relaxation of constraints on environmental water releases in the Murray and Murrumbidgee River systems.

The program's goal is to increase the frequency rivers connect to wetlands and floodplains, to improve the health of the Murray and Murrumbidgee Rivers and make the best use of water recovered for the environment. The frequency of higher flows connecting to wetlands and floodplains has reduced over time due to river regulation and consumptive use of water, and the health of important habitats has declined. This has had significant negative impacts on native plants and animals including native fish populations.

The program proposes to establish a new, higher limit on environmental water releases in the Murrumbidgee Valley. The new limit would enable higher environmental water releases to overtop riverbanks and inundate low-level wetland and floodplain habitats along the length of the river. Flow easements and other proposed landholder agreements would establish the environmental flow corridor and impacted landholders would be compensated for the impacts on their land.

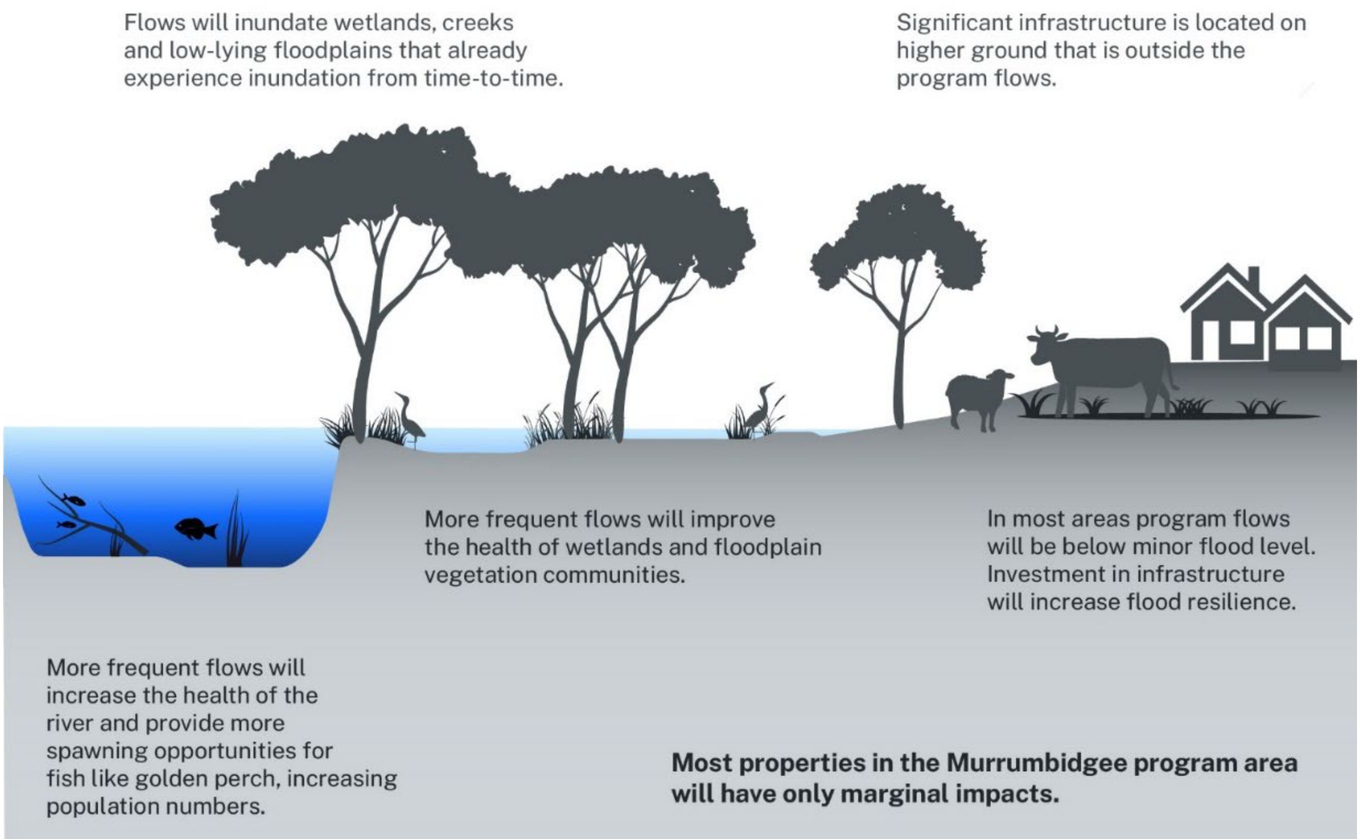


Figure 1 - Overview of Reconnecting River Country Program.

1.2 Hydraulic modelling for the program

High accuracy inundation mapping is required across the full extent of the program area to accurately understand program impacts and to support negotiation with landholders and other stakeholders to establish the environmental flow corridor. Accurate inundation mapping is required to build confidence among landholders and other stakeholders that the impacts of the program are understood, and to provide a common understanding of those impacts to support negotiation and agreements.

In 2019, the NSW and Victorian Governments commissioned an independent panel to review the modelling available to support the constraints management program and provide recommendations on future work required to fill any gaps[1]. The panel concluded the modelling available at the time was not suitable for the assessment and communication of program impacts and recommended more detailed modelling was required.

To meet program requirements and address the independent panel review recommendations, the department commissioned a work program of hydraulic modelling and associated data collection specifically aimed at meeting the requirements of the program.

This report describes this work program of hydraulic modelling and data collection for the program's Murrumbidgee Project which has involved:

- extensive data collection to inform hydraulic modelling
- procurement and building of hydraulic models covering the full project area
- internal and external review processes to ensure consistent and quality outputs
- processing and publishing of inundation maps on the program's web portal
- field validation of inundation maps with private landholders and other stakeholders
- ongoing model review and updates considering feedback from landholders and other stakeholders, and in response to hydraulic modelling software updates.

[1] Murray-Darling Basin constraints modelling, NSW and Victorian Minister's Independent Expert Panel, 2019. Available from: https://www.water.vic.gov.au/__data/assets/pdf_file/0027/670464/murray-darling-basin-constraints-modelling-independent-expert-panel.pdf

2 Project area and model reaches

The Reconnecting River Country Program's Murrumbidgee Project proposes the delivery of flexible, including higher, environmental flows in the Murrumbidgee River from downstream of Burrinjuck Dam to the Murray River junction. This also includes the Yanco-Colombo-Billabong Creek system to Moulamein. These watercourses and their associated wetlands and floodplains define the extent of the Murrumbidgee project area.

To provide modelling outputs at a high resolution with practical model run-times, the project area has been broken up into a series of smaller connected models, covering specific reaches, referred to as model work packages (see Figure 2).

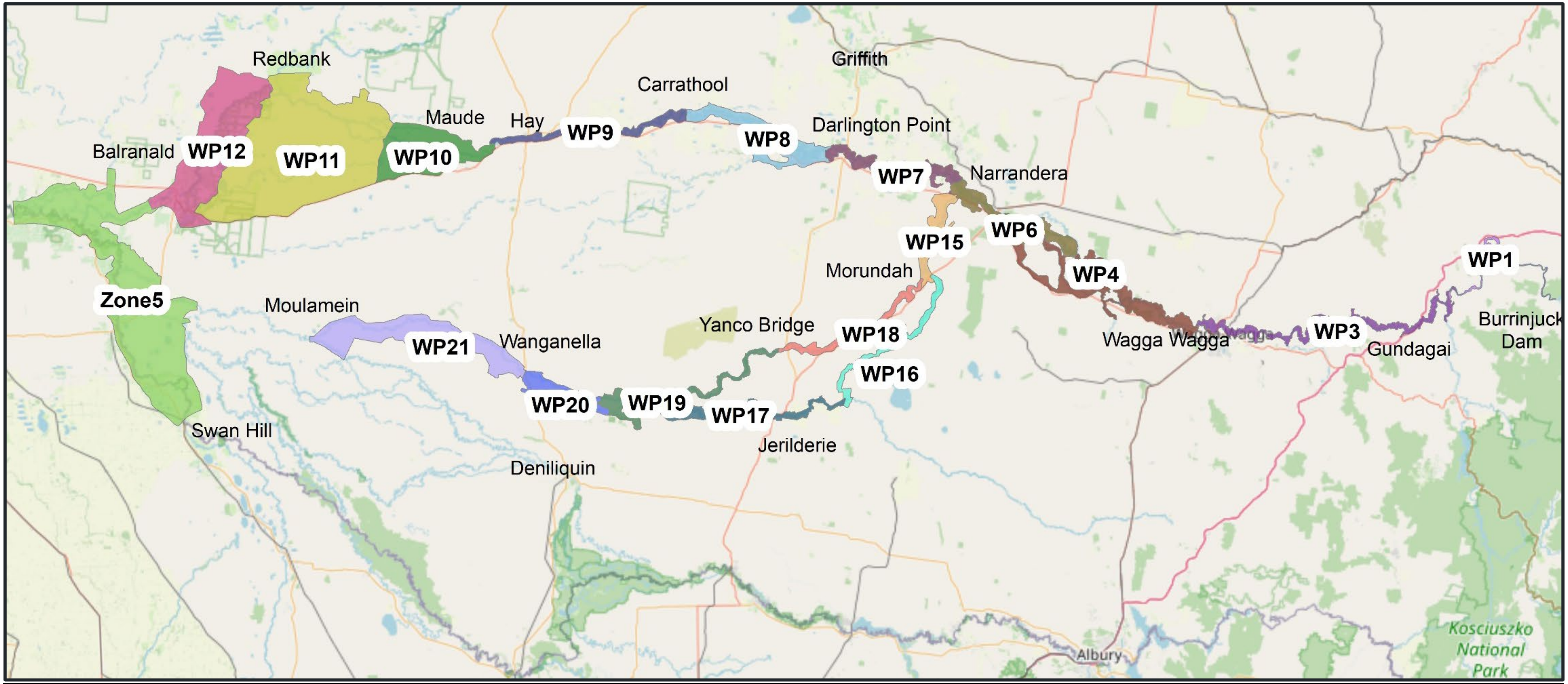
The extent of the model reaches was determined considering:

- practical model sizing to enable efficient model run times and suitable model mesh sizing (which determines spatial resolution of outputs)
- the location of hydrometric (flow gauging) stations required for model calibration, validation and the establishment of model boundary conditions including inflows
- the hydrology of the system – where possible models should have simple inflow and outflow boundaries with gauge data available.

The delivery of higher environmental flows in the Murrumbidgee River system will also contribute higher flows into the Murray and Edward Rivers. The modelling of the Murray and Edward Rivers was managed under a separate parallel work program and included the consideration of higher inputs from the Murrumbidgee River. That work is ongoing and will be documented in a separate report.

The model reach breakdown for the Murrumbidgee project originally included Work Packages 2, 5, 13 and 14. These work packages were subsequently merged with other work packages or assessed as being out of scope for the project as follows:

- Work Package 2 is the Tumut River. A hydraulic model was developed by WaterNSW for this work package. However, the Tumut River is not included in the Murrumbidgee project area as there are no proposed changes to flow limits in the Tumut River
- Work Packages 5 and 13 were merged with Work Packages 4 and 12 respectively. Merging these models allowed the complex floodplain and anabranch systems of these reaches to be covered by a single model and reduced the number of ungauged model boundaries. This simplified the modelling process and improved model accuracy
- Work Package 14 was incorporated in the Murray River zone 5 model, covering the Murrumbidgee River downstream of Balranald, and the Murray River from Swan Hill to Boundary Bend. Inundation in this area is governed by flows in both the Murray and Murrumbidgee Rivers, and incorporation of both rivers into a single model enables this process to be effectively captured in the one model.



WP1	Murrumbidgee River, Burrinjuck Dam to Tumut Junction	WP12	Murrumbidgee River, Redbank weir to Balranald weir
WP3	Murrumbidgee River, Gobarralong to Wagga Wagga	Zone 5	Murrumbidgee River from Balranald weir to Murray Junction (and Murray River from Swan Hill to Boundary Bend)
WP4	Murrumbidgee River, Wagga Wagga to Berembed weir including Old Man Creek	WP15	Yanco Creek, Yanco offtake to Morundah
WP6	Murrumbidgee River, Berembed weir to Yanco weir	WP16	Colombo Creek, Morundah to Billabong Creek
WP7	Murrumbidgee River, Yanco weir to Darlington Point	WP17	Billabong Creek, Colombo to Hartwood
WP8	Murrumbidgee River, Darlington Point to Carrathool	WP18	Yanco Creek, Morundah to Yanco Bridge
WP9	Murrumbidgee River, Carrathool to Hay weir	WP19	Yanco Creek, Yanco Bridge to Piccaninny weir (including Forest Creek)
WP10	Murrumbidgee River, Hay weir to Maude weir	WP20	Billabong Creek, Piccaninny weir to Wanganella (including Forest Creek)
WP11	Murrumbidgee River, Maude weir to Redbank weir	WP21	Billabong Creek, Wanganella to Moulamein

Figure 2 - Project area and model reaches/work packages.

3 Data collection

Extensive data collection was undertaken to support the development of the hydraulic models and to achieve accurate inundation mapping outputs for the program's Murrumbidgee project. This process involved acquiring bathymetric river channel survey, LiDAR floodplain topographic survey, hydraulic structure surveys and aerial photography during high flow events. Collectively this data acquisition provided a high standard of data to support the hydraulic modelling work program.

3.1 River channel bathymetric survey

For each flow option considered by the Murrumbidgee project, the river channel will carry the majority of flows. Accurate definition of river channel geometry was therefore a key input to the development of hydraulic models.

River channel geometry was obtained from several sources:

1. A detailed bathymetric survey of the Murrumbidgee River and other watercourses, commissioned by the department, specifically for the Murrumbidgee project.
2. Pre-existing bathymetric survey of Yanco, Colombo and Billabong Creeks collected by previous NSW Government water programs.
3. LiDAR data collected in 2007 and 2008 during the Millenium drought, which provided a sound representation of channel geometry in some watercourses where water levels were very low.

The extent of data collection commissioned for the Murrumbidgee project and pre-existing bathymetric survey of Yanco and Billabong Creeks is shown in Figure 3.

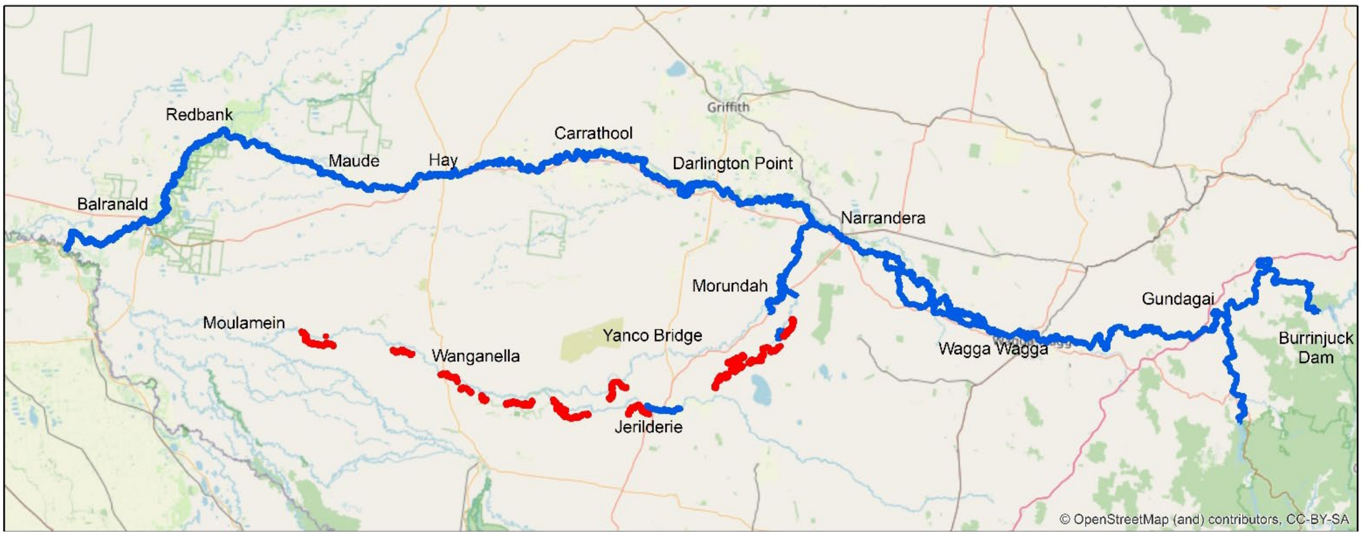


Figure 3 - Extent of bathymetric data collected by the program (blue) and pre-existing Yanco/Billabong Creek data (red).

Data collection specifically for the Murrumbidgee project is shown in Table 1. The surveys involved continuous single-beam soundings collected in a Z shaped pattern along the watercourses with bank-to-bank cross sections collected at 100 m intervals along the Murrumbidgee River and a finer cross section interval of 25 m for the surveyed creeks. These intervals are equivalent to the width of the surveyed watercourses and allowed for suitable coverage of the riverbed. An example of the Z shaped survey pattern for a section of the Murrumbidgee River near Balranald is shown in Figure 4.

Table 1 - Summary of bathymetric survey data collection

Reach	Date surveyed	Surveyor
Burrinjuck Dam to Tumut River	23 Nov 2020 - 3 Dec 2020	HCSurvey
Tumut River to Wagga Wagga	26 Oct 2020 - 22 Nov 2020	Cardno Limited
Wagga Wagga to Yanco Weir including Beavers Creek and Old Man Creek	27 Oct 2020 - 8 Dec 2020	AAM Group
Yanco Weir to Carrathool Bridge	30 Nov 2020 - 14 Feb 2021	Cardno Limited
Carrathool Bridge to Maude Weir	5 Dec 2020 - 3 Feb 2021	HCSurvey
Maude Weir to Murray River	10 Dec 2020 - 12 Jan 2021	AAM Group
Yanco Creek and parts of Colombo Creek and Billabong Creek	20 Oct 2020 - 14 Nov 2020	HCSurvey
Mundarlo Creek, Morleys Creek, Smith Anabranch	22 Jan 2021 - 1 Feb 2021	AAM Group

Figure 4 - Example of Z shaped survey pattern and 100 m cross section interval for a section of the Murrumbidgee River near Balranald (overlain on LiDAR floodplain topography data).

3.2 LiDAR floodplain topography

LiDAR (Light Detection and Ranging) is an airborne survey technology used to capture high resolution models of ground surface elevation and other attributes. The department acquired LiDAR data for large parts of the project area in 2021. This provided up-to-date floodplain topography data reflecting current conditions and enabled the program to fill gaps in pre-existing LiDAR datasets such as a 2009 LIDAR collection covering much of the Murrumbidgee floodplain. Acquisition of the data was undertaken by the NSW Department of Customer Services (Spatial Services) and followed another large acquisition in 2020. The areas of LiDAR captured in the project area in 2020 and 2021 by the NSW Department of Customer Services are shown in Figure 5.

Consistent with typical LiDAR data standards, the LiDAR data captured in 2020 and 2021 typically has a vertical accuracy of +/-0.3 m and horizontal accuracy of +/-0.8 m. The data was processed to provide a digital elevation model with 1 m resolution.

Multiple LiDAR datasets are available for most model work packages, allowing for strategic processing of datasets to fill gaps and to reflect differences in water level conditions when the data was collected.

LiDAR datasets were used to define floodplain topography for the hydraulic models, with model grid resolution sizes of 10 to 20 m adopted. Finer grid size (10 m) was adopted where the floodplain is relatively confined (upstream of Darlington Point), and a coarser grid size was adopted in the models with more expansive floodplains (downstream of Darlington Point). Levees and embankments were also identified and digitised from the most recent LiDAR datasets and represented in the models.

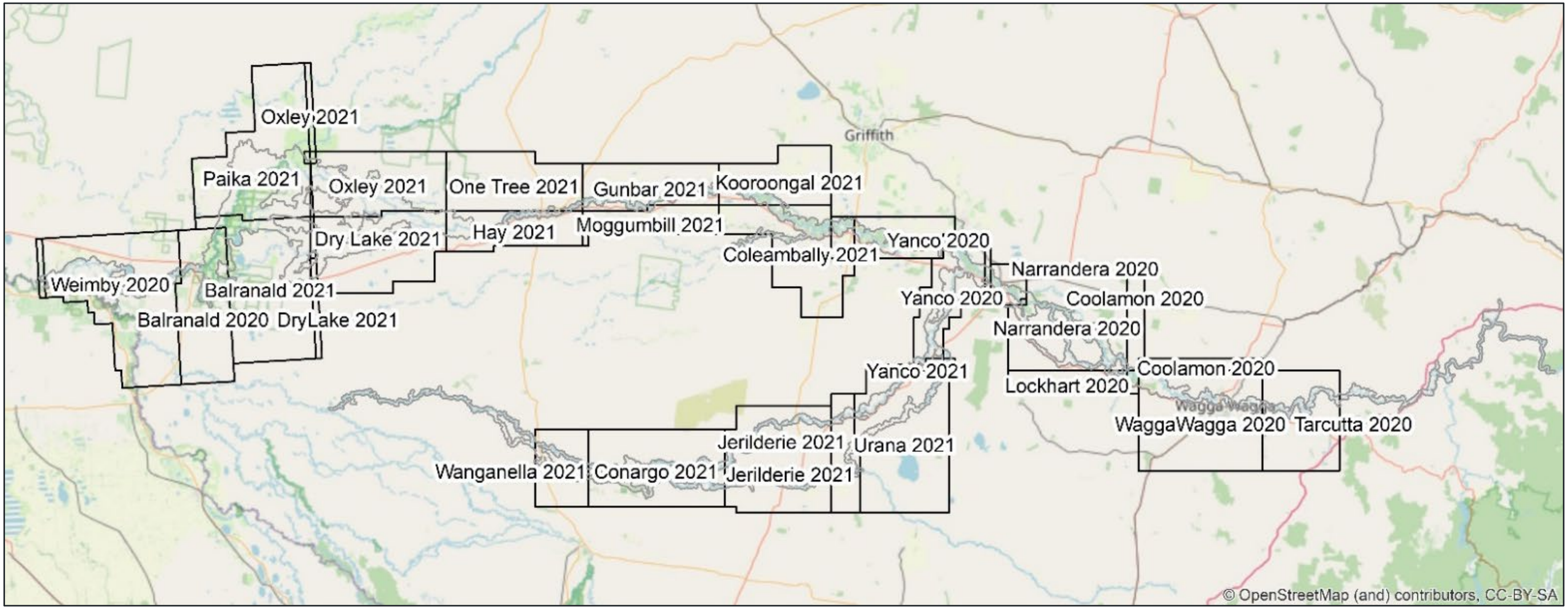


Figure 5 - Areas of LiDAR captured in the project area in 2020 and 2021.

3.3 Structure surveys

Surveys of structures impacting the movement of flow within the Murrumbidgee project area (e.g., weirs, bridges, culverts and pipes) were commissioned to supplement the river channel bathymetry and LiDAR floodplain topography survey. A multi-stage approach was used to first identify structures within the project area and then identifying those requiring field survey. Structure surveys were used to provide data for representation of those structures in the hydraulic models.

The following approach was used:

Step 1 - desktop structure identification and data collation

High resolution satellite imagery and aerial photography, together with LiDAR data were used to identify the location of structures across the project area. In total 1806 structures were identified and then reviewed by the department for their priority for field inspection and topographic survey.

Step 2 – field inspection and measurement

Structures identified in Step 1 were prioritised for field inspection. Field inspection involved the collection of photographs and structure dimensions (e.g., culvert dimensions, embankment heights and widths). Field inspections were undertaken on 1305 structures in 2021 and 2022.

Step 3 – topographic survey

Structures inspected during Step 2 were prioritised for topographic survey in Step 3. Structures prioritised were those considered to have a significant potential impact on project flows and inundation extents, and where topographic survey would be required to support representation of the structures in hydraulic models. Topographic surveys were undertaken at 133 structures. Topographic survey involved the collection of structure dimensions and elevations, together with cross sections upstream and downstream of structures, and longitudinal sections along the watercourse and through the structure.

Figure 6 shows the location of all inspected structures in blue and surveyed structures in red.

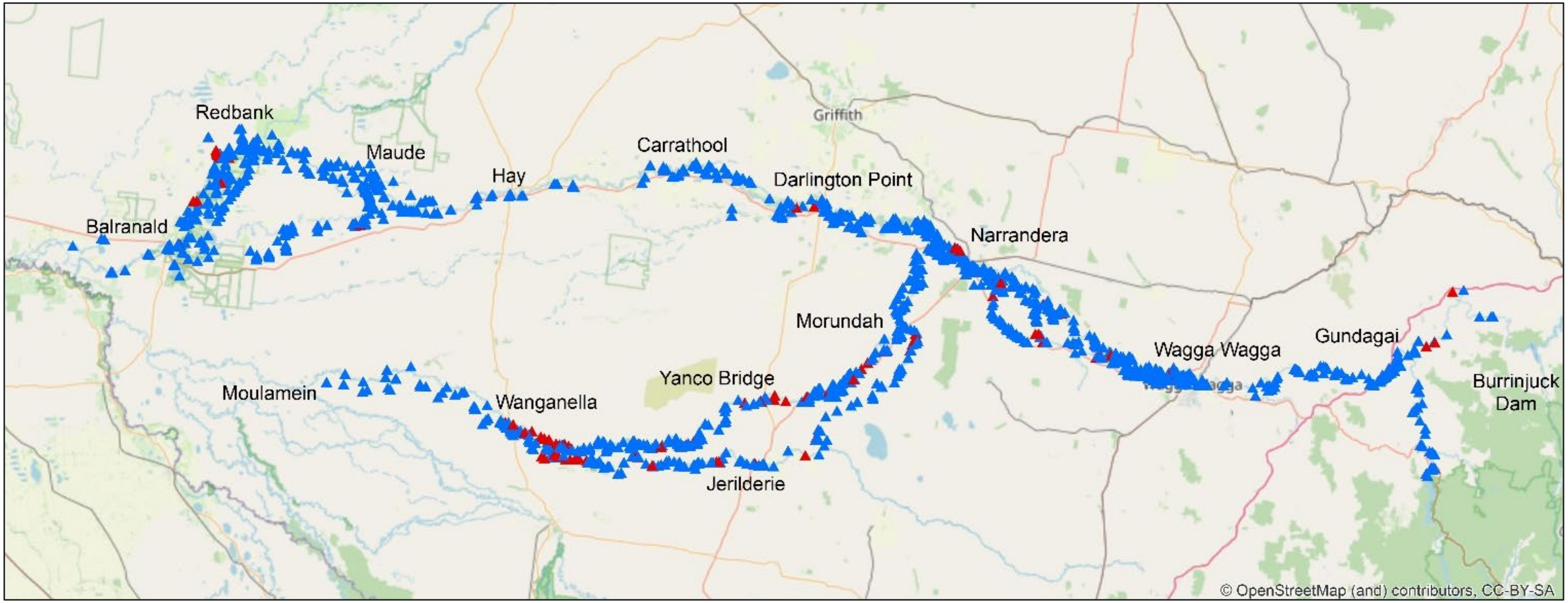


Figure 6 - Location of structures subject to field inspection and measurement (blue) and topographic survey (red).

3.4 Aerial photography

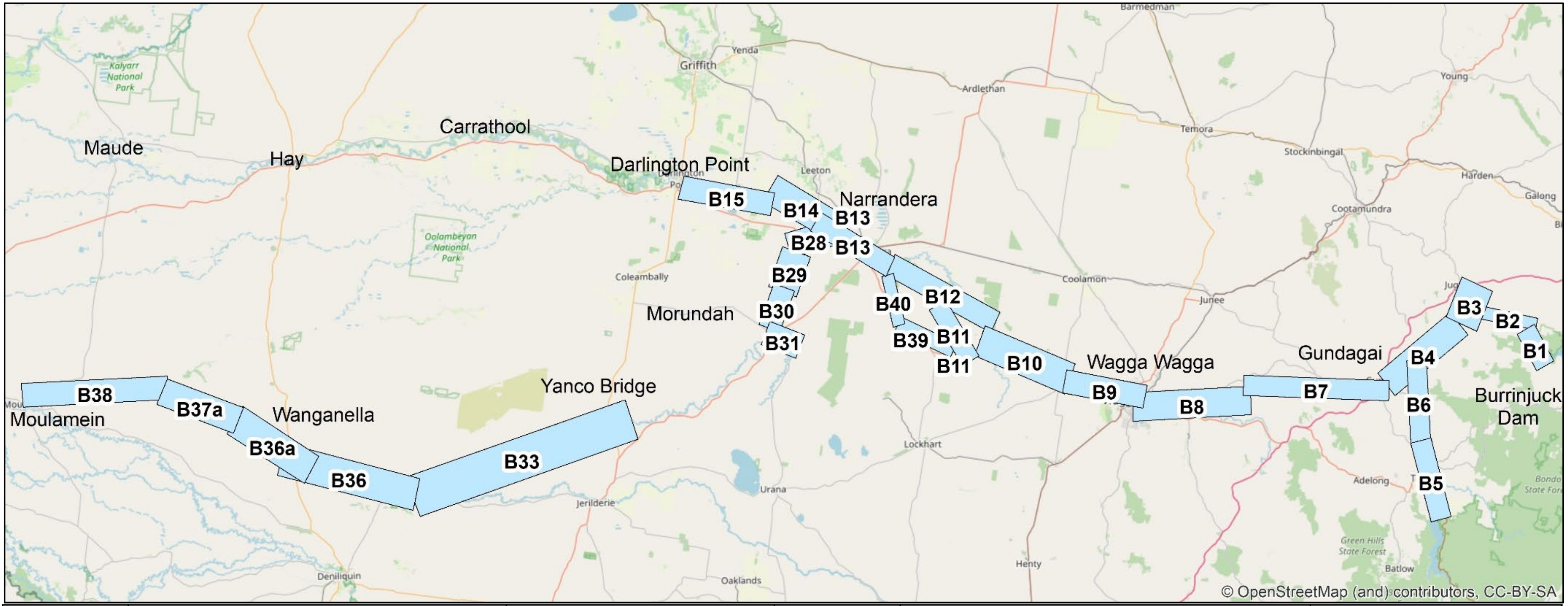
Elevated flows from rainfall events in late October/November 2020 and July to December 2021 provided the opportunity to collect high resolution aerial photography to assist in calibrating and verifying the hydraulic models for the Murrumbidgee project. Aerial photography was captured for a large proportion of the project area, as show in Figure 7. Aerial photography was captured during the following flow events:

- October/November 2020 – flows peaked at about 28,000 ML/day at Wagga Wagga, providing an example of a modest flow above the current operating limit of 22,000 ML/day at Wagga Wagga
- July/August 2021 and November/December 2021 – during these events flows peaked at 44,000 ML/day and 49,000 ML/day at Wagga Wagga respectively, providing 2 examples of flows near the maximum buffer flow of 45,000 ML/day at Wagga Wagga.

The aerial photography was captured in a staged manner along the river with the date of the imagery selected to target the flow peaks as they moved through the system.

Cloud coverage for extended periods prevented the capture of aerial photography in some reaches (e.g., B32 between Morundah and Yanco Bridge). Satellite imagery (e.g., Sentinel-2, which is captured regularly at intervals of approximately 3 to 5 days) of these flow events was used for model validation, outside of areas where aerial photography was captured (example, downstream of Darlington Point).

The aerial photography was used to assist in model calibration, along with satellite imagery from these and other flow events. Aerial photography captured for the project has been published on the program's inundation mapping portal found at water.nsw.gov.au/rrcp-inundation-mapping



Label	Description	Photography dates	Label	Description	Photography dates
B01	D/S Burrinjuck	29/11/2021	B14	Yanco Weir to Gogeldrie Weir	10/08/2021
B02	Burrinjuck to Jugiong	29/11/2021	B15	Gogeldrie Weir to Darlington Point	10/08/2021
B03	Jugiong	29/11/2021	B28	Yanco Weir to Devlins Bridge Road	11/08/2021
B04	Jugiong to Gundagai	30/11/2021	B29	Devlins Bridge Road to Yarrabee	11/08/2021
B05	Tumut River upstream	12/08/2021	B30	Yarrabee to Morundah	11/08/2021
B06	Tumut River downstream	12/08/2021	B31	Morundah	11/08/2021
B07	Gundagai to Wantabadgery	30/11/2021	B33	Yanco upstream Billabong Junction	6/09/2021
B08	Wantabadgery to Wagga Wagga	3/12/2021	B36	Conargo to Wanganella	6/09/2021
B09	Wagga Wagga to Collingullie	3/11/2020, 11/8/2021	B36a	Conargo to Wanganella	23/12/2021
B10	Collingullie to Sandigo	3/11/2020, 11/8/2021	B37a	Downstream Wanganella	23/12/2021
B11	Old Man Creek	14/8/2021, 3/12/2021	B38	Upstream Moulamein	23/12/2021
B12	Sandigo to Narrandera	3/12/2021	B39	Sandy Creek Upstream	11/08/2021
B13	Narrandera to Yanco Weir	27/07/2021, 10/8/2021	B40	Sandy Creek Downstream	10/08/2021

Figure 7 – Extent of aerial photography captured during 2020 and 2021 for the program,

4 Quality assurance

Delivery of this work program involved building 18 models, over a large area, with complex watercourse and floodplain systems, multiple model delivery partners and the need for high quality outputs. Achieving the objectives of the work program required structured quality assurance processes including:

- the establishment of a dedicated and skilled team to oversee and coordinate the work, drawing upon resources across the department and other agencies
- development and adoption of standard specifications to define the required modelling standards and ensure consistency
- rigorous model calibration, validation and sensitivity testing processes comparing model outputs with observed water level and flow data, and aerial photography and satellite imagery
- staged internal and external model review processes ensuring the achievement of quality outcomes.

The quality assurance processes developed for the program's Murrumbidgee project built on processes used in similar projects (e.g., urban flood studies supported by the department and other agencies).

4.1 Oversight

The project's hydraulic modelling work program was led by the department's Conservation Programs, Heritage and Regulation Group. The team was supported with resources and input from Manly Hydraulics Laboratory, SMEC (as SDLAM owners engineer), WaterNSW, the department's Water Group and the Murray-Darling Basin Authority (MDBA) as follows:

- Manly Hydraulics Laboratory provided technical and strategic advice, assisted with model procurement and data processing and quality assurance
- SMEC provided external model review services (further described below)
- WaterNSW provided valuable technical support, particularly in the provision of data to enable model building and proving
- the Water Group and MDBA's modelling teams provided technical advice.

The establishment of the work program, data collection and procurement of modelling services was overseen by a working group comprising representatives of the program, the department's Conservation Programs, Heritage and Regulation Group and Manly Hydraulics Laboratory.

4.2 Standard specifications

Standard specifications were developed to define the modelling standards required for the Murrumbidgee project and to ensure consistency across the multiple models.

Separate standard specifications were developed for 1D-2D and full 2D model types. Hydraulic models containing the Murrumbidgee River were specified as 1D-2D. This approach was adopted to allow for integration of the new models with existing river modelling systems and to accurately represent the large operational weirs along the Murrumbidgee River. Full 2D models were specified in the Yanco-Billabong Creek system.

The standard specifications included:

- model build conventions to meet project requirements and ensure consistency
- a structured process and standards for model proving (calibration, validation and sensitivity testing)
- scope and task management requirements including required activities, deliverables, hold points and model review processes
- model file naming conventions and a schema for GIS outputs to ensure consistency.

The project adopted the use of TUFLOW software as a standard across the work program. TUFLOW is the most widely used software platform in the consulting sector, with significant advantages in enabling efficient model building using multiple partners.

For model calibration, the project adopted the minimum standards that models should achieve an accuracy of +/- 250 mm or better for inundation depth (based on comparison with hydrometric data and/or spot elevation data) and 5% of inundation width (based on comparison with aerial photography and/or satellite imagery). These standards were informed by specifications for flood studies and consideration of project requirements. All models achieved or exceeded this minimum standard, typically achieving greater accuracy.

Standard specifications for TUFLOW 1D-2D and TUFLOW Full-2D models are provided in Appendix A.

4.3 Model calibration, validation and sensitivity testing

4.3.1 Calibration and validation

Model calibration is the process by which models are configured to represent observed conditions during specific flow events relevant to the context of a project. The models are run for the specific flow events and then outputs from the models are compared directly, and in detail, to the observed data from those events. Models are checked against flows and water levels from flow gauges and other recorded observations, and inundation extents from aerial photography and satellite imagery.

If required, model parameters may be adjusted during the calibration process to ensure the model adequately represents observed conditions during calibration events. These adjustments are typically limited to hydraulic roughness of instream and/or floodplain components of the model, and adjustments to topographic data such as commence to flow levels of wetlands or creek systems (if there is uncertainty in the datasets used for model building).

Model validation is the process of testing the calibrated model to demonstrate the model adequately represents conditions during other flow events.

Calibration and validation events were selected based on the following considerations:

- events with flows within, or near to, the flow range of interest (i.e., 22,000 to 45,000 ML/day at Wagga Wagga, or equivalent flows at other gauges)
- events with good availability of gauge data for hydrograph calibration and aerial photography and/or satellite imagery for calibration of commence to flows of wetlands and inundation extents

- preference towards recent events minimising the difference between the topographic and bathymetric representation included in the model (which reflects 2020 to 2021 conditions as this is the time the LiDAR and bathymetric data was collected) and conditions at the time of the event
- preference towards discrete flow events where gauged flows and heights, and inundation extents, represent the modelled flow event rather than flows in the recent past.

Events used in model calibration and validation are listed in Table 2.

Table 2 - Calibration and validation events.

Work Package	Reach description	Calibration and validation events
WP1	Murrumbidgee River, Burrinjuck Dam to Tumut Jcn	July – August 2021 September 2021
WP3	Murrumbidgee River, Gobarralong to Wagga Wagga	September 2016 October 2017 November 2020 July 2021
WP4	Murrumbidgee River, Wagga Wagga to Berembed weir including Old Man Creek	June – July 2014 August – September 2016 October – November 2020 July – August 2021
WP6	Murrumbidgee River, Berembed weir to Yanco weir	August – September 2016 July – August 2017 June – September 2021
WP7	Murrumbidgee River, Yanco weir to Darlington Point	August – September 2016 July – August 2017 June – September 2021
WP8	Murrumbidgee River, Darlington Point to Carrathool	August 2017 August – September 2016 June – August 2021
WP9	Murrumbidgee River, Carrathool to Hay	June – August 2016 August 2021
WP10	Murrumbidgee River, Hay to Maude	August – September 2011 August 2017 July – August 2021 October – November 1992
WP11	Murrumbidgee River, Maude to Redbank	May – August 2016 December 2017 October 2010 – January 2011 June – September 2021

Work Package	Reach description	Calibration and validation events
WP12	Murrumbidgee River, Redbank to Balranald	August 2016 December 2017 December 2010 – January 2011 June - September 2021
Zone 5	Murrumbidgee River, Balranald to Murrumbidgee Junction	August – September 2016 August – October 2022
WP15	Yanco Creek, Yanco offtake to Morundah	June – July 2016 June - July 2021 July - August 2021
WP16	Colombo Creek, Morundah to Billabong Creek	September – November 2016 August – November 2017 July – September 2021 November 2021 – January 2022
WP17	Billabong Creek, Colombo to Hartwood	June – September 2016 August – September 2020 September – October 2021 July – September 2022
WP18	Yanco Creek, Morundah to Yanco Bridge	July 2016 August 2017 July – August 2021
WP19	Yanco Creek, Yanco Bridge to Warriston	August – September 2017 July – October 2022
WP20	Billabong Creek, Warriston to Wanganella	July – September 2021 September – October 2021 October – November 2021 August – September 2017
WP21	Billabong Creek, Wanganella to Moulamein	October – December 2010 August – September 2022

4.3.2 Sensitivity analysis

Hydraulic models require the adoption of parameters that vary according to the different hydraulic characteristics of river systems. An example is infiltration and evaporation loss parameters that can vary significantly between and within river systems. Each of these parameters can impact on the results generated by the model. In addition to models undergoing calibration and validation, it is best practice to undertake sensitivity analysis to understand how any uncertainties and variability in model input parameters may impact on the results produced by the model.

In accordance with requirements of the standard specifications, sensitivity analysis was undertaken on each of the calibrated models. The calibrated models were used as a 'base case' and then adjustments were made to the following parameters to test sensitivity:

- hydraulic roughness: adjusted by ±20% in both the channel and floodplain
- infiltration and evaporation losses: adjusted by ±20%
- downstream boundary flow-level relationship: adjusted by ±20%
- HPC Stability Control Factor: adjusting the default value of 1.0 to 0.5.

For each model the sensitivity analysis was undertaken using a flow event representative of the highest flow scenario (i.e., 45,000 ML/d flow at Wagga Wagga or the corresponding flow at other gauges). Outcomes of the sensitivity analysis must show changes in model behaviour consistent with the scale of change in input parameters. Models demonstrating instability during the testing were refined further before acceptance.

4.4 Model review

The Murrumbidgee project adopted a structured and consistent process for model review. The process involved internal and external review at 3 hold points, as shown in Table 2.

Hold point 1 and 2 reviews were undertaken both internally and externally for each model. Internal reviews were undertaken by experienced hydraulic modellers from the department or Manly Hydraulics Laboratory. External reviews were undertaken by experienced hydraulic modellers from SMEC (as the SDLAM owners engineer), as well as 1 review by Cumulus Engineering (WP21). This was due to the unavailability of SMEC modellers at the time. Reviewers provided feedback to model reviewers and satisfactory resolution of all issues was required before models proceeded to the next phase of development. All models satisfactorily passed all review steps.

Table 3 - Model review hold points and review requirements

Hold point number	Hold point name	Review requirements
Hold point 1	Model conceptualisation	• To confirm the model construct and model proving process proposed by the model developer meets the requirements of the standard specification and the project. • To confirm a thorough data review has been undertaken, adequate data is available, or additional data procurement is identified.

Hold point 2	Model build, and model proving	• To review the draft model build, to ensure it is of appropriate standard, meets the requirements of the standard specification and is as proposed in the model conceptualisation report. • To confirm the model has been demonstrated to adequately represent flow behaviour and that model proving meets the requirements of the standard specification. • To confirm the model build report meets the requirements of the standard specification.
Hold point 3	Model scenario outputs	• To confirm the draft outputs reflect expected flow behaviour (based on outcomes of model proving). • To confirm the draft outputs are in a form that meets the requirements of the standard specification.

5 Model procurement and delivery

Modelling resources were drawn from multiple suppliers to provide the modelling needs of the project. Multiple suppliers were required given the size of the project area, the number of model builds required and the need for modelling to be completed in a practical timeframe. Modelling was undertaken by multiple specialist consultants, modellers from the department's Conservation Programs, Heritage and Regulation Group and the WaterNSW modelling team.

The Conservation Programs, Heritage and Regulation Group undertook model builds for Work Packages 4, 12 and 21.

- Work Package 4 has a high degree of floodplain complexity due to multiple anabranch systems. Delivery of this work package using internal resources was undertaken to provide extra assurance of a quality outcome, allowing for extensive model testing and multiple iterations.
- Work Package 12 covers Yanga National Park, an area of frequent environmental watering activity. In addition to program requirements, this model is likely to be used to support environmental water planning into the future. It was delivered by the Conservation Programs, Heritage and Regulation Group so corporate knowledge of the model is retained within the department.
- Work Package 21 covers an area for which the Conservation Programs, Heritage and Regulation Group had previously developed a model for the department's floodplain management planning program. Engagement of the Conservation Programs, Heritage and Regulation Group to modify the floodplain management plan model for program requirements was an efficient mechanism to obtain the modelling needed for the program.

WaterNSW was engaged to undertake the model build for Work Package 1 because WaterNSW has a high degree of interest in this reach, being located immediately downstream of Burrinjuck Dam. WaterNSW had also previously undertaken hydrologic investigations in this reach, with the knowledge gained from those investigations being valuable in the model build process.

Work Package 14 was incorporated in the pre-existing MDBA Murray River zone 5 model, which covers the Murrumbidgee River downstream of Balranald Weir, and the Murray River from Swan Hill to Boundary Bend. Inundation in this area is governed by flows in both the Murray and Murrumbidgee Rivers, and incorporation of both rivers into a single model enables this process to be effectively captured in the model.

Consulting firms Jacobs and GHD were engaged to provide models for Work Packages 19 and 20. Jacobs and GHD were selected due to their pre-existing engagement providing modelling support for the SDLAM Yanco modernisation project in this same area, yielding efficiencies for both projects.

All other model builds were procured from consultant suppliers through a structured procurement process involving the following key steps:

1. Development and approval of a procurement strategy outlining the procurement approach, procurement tranches and tender evaluation criteria.
2. Procurement tranche 1, an open tender process for procurement of suppliers for Work Packages 3, 6 and 7, and to inform a pre-qualification assessment of suppliers to be invited to tender on future tranches.
3. Procurement tranche 2, an invited tender process of pre-qualified suppliers for Work Packages 8, 9, 10 and 11.

4. Procurement tranche 3, an invited tender process of pre-qualified suppliers for Work Packages 15, 16, 17 and 18.

The selected supplier and model type for each work package are shown in Table 4.

Table 4 - Model reaches, model builders and model types.

Work Package	Reach description	Model builder	Model type
WP1	Murrumbidgee River, Burrinjuck Dam to Tumut Jcn.	WaterNSW	1D-2D
WP3	Murrumbidgee River, Gobarralong to Wagga Wagga	Water Technology	1D-2D
WP4	Murrumbidgee River, Wagga Wagga to Berembed weir including Old Man Creek	DCCEEW CPHR	1D-2D
WP6	Murrumbidgee River, Berembed weir to Yanco weir	Catchment Simulation Solutions	1D-2D
WP7	Murrumbidgee River, Yanco weir to Darlington Point	Catchment Simulation Solutions	1D-2D
WP8	Murrumbidgee River, Darlington Point to Carrathool	Rhelm	1D-2D
WP9	Murrumbidgee River, Carrathool to Hay	GRC Hydro	1D-2D
WP10	Murrumbidgee River, Hay to Maude	BMT	1D-2D
WP11	Murrumbidgee River, Maude to Redbank	Aurecon	1D-2D
WP12	Murrumbidgee River, Redbank to Balranald	DCCEEW CPHR	1D-2D
Zone 5	Murrumbidgee River, Balranald to Murrumbidgee Junction	Murray-Darling Basin Authority	Full 2D
WP15	Yanco Creek, Yanco offtake to Morundah	Catchment Simulation Solutions	Full 2D
WP16	Colombo Creek, Morundah to Billabong Creek	Royal Haskoning	Full 2D
WP17	Billabong Creek, Colombo to Hartwood	Royal Haskoning	Full 2D
WP18	Yanco Creek, Morundah to Yanco Bridge	Catchment Simulation Solutions	Full 2D
WP19	Yanco Creek, Yanco Bridge to Warriston	Jacobs and GHD	Full 2D
WP20	Billabong Creek, Warriston to Wanganella	Jacobs and GHD	Full 2D
WP21	Billabong Creek, Wanganella to Moulamein	DCCEEW CPHR	Full 2D

Model briefs were prepared for each model outlining the scope of work, characteristics of the reach and any specific requirements, in addition to those set out on the standard specifications.

Model user reports were produced for each model documenting input data, model schematisation, key aspects and assumptions of model development, sensitivity testing and model proving outcomes, and a summary of results.

All models were successfully delivered in accordance with the briefs and specification and after completing the model review process described above.

6 Model inflow scenarios

The program's Murrumbidgee project is investigating an increase in the current limit placed on environmental flows and is exploring 3 flow limit options:

- current operational limit (W22) – 22,000 ML/day at Wagga Wagga (base case)
- flow limit option 1 (W32) – 32,000 ML/day at Wagga Wagga plus buffer allowance to 36,000 ML/day
- flow limit option 2 (W36) – 36,000 ML/day at Wagga Wagga plus buffer allowance to 40,000 ML/day
- flow limit option 3 (W40) – 40,000 ML/day at Wagga Wagga plus buffer allowance to 45,000 ML/day.

Flows delivered under each of these options are expected to peak for 3 to 5 days at Wagga Wagga and include a gentle rise to the peak and gentle recession after the peak, over several days.

Completion of hydraulic model scenarios and inundation maps for each flow option requires an estimation of the equivalent flows at each of the model inflow locations. These flows were estimated by the department's Conservation Programs, Heritage and Regulation Group based on analysis of observed flows at model inflow gauges and based on key assumptions (described below).

6.1 Assumptions

Flow outcomes and inundation extents across the Murrumbidgee project area (and especially downstream of Wagga Wagga) will vary from event to event, according to catchment conditions and recent flow history (antecedent conditions), and the magnitude and duration of environmental flows delivered. The project's objective is to provide inundation mapping reflective of an upper limit of what is possible with future environmental flows up to each of the flow limit options being investigated, including the maximum buffer (noting the buffer is a risk mitigation measure and not a target for environmental water delivery). Upper limit inundation extents are required to ensure the flow corridor reflects the full range of outcomes potentially achieved with environmental flows in the future under varying antecedent conditions. This approach ensures the established flow corridor covers the full range of potential inundation, providing certainty to landholders. It also provides river operators and environmental water managers the flexibility to deliver environmental flows under a range of conditions.

Accordingly, the approach to determining model inflows at each of the required gauges, for each of the flow limit options, sought to provide 'upper limit' estimates of inflows achievable with environmental flows. Key aspects of the approach include:

- peak flow rates are intended to be reflective of the upper limit of what may occur under each of the flow limit options. As an example, for gauges downstream of Wagga Wagga, statistical analysis of observed flows was used to understand the potential range of flow outcomes that may occur under different antecedent conditions. Conservative 99th percentile estimates of downstream flows were assumed from the statistical analysis (more detail in Section 6.2)
- while managed releases are likely to involve peak flows for a duration of between 3 to 5 days at Wagga Wagga, substantially longer releases of 10-day peak flow duration were modelled.

Together, these assumptions contribute to an upper bound estimate of the inundation extent for each flow limit option.

6.1.1 Base case

For the base case, different assumptions were adopted. For this scenario a more likely/probable estimate of flows potentially achieved with environmental water releases, is appropriate given the base case inundation extents are used as a benchmark from which project impacts and compensation are assessed. This assumption will provide a more appropriate benchmark for determining compensation payments.

This was achieved by using a combination of 75th percentile estimates from statistical analysis, and the flows observed during the August 2017 environmental water release as a point of reference. The August 2017 event represents a practical and achievable set of conditions for a base case scenario. For many gauges the flows that were observed during the August 2017 managed release align well with 75th percentile estimates from the statistical analysis.

6.2 Peak flow rates

Flow rates adopted for each model inflow location to reflect each of the flow limit options are shown in Table 6. The text below describes the basis for these estimates.

Upstream of Wagga Wagga

Peak flow rates upstream of Wagga Wagga were estimated considering likely contribution from respective tributaries, as follows:

- for flows up to and including 36,000 ML/d, the Tumut River was assumed to be operating at its current limit (9,300 ML/d at Tumut plus tributary inflows to a total of 9,500 ML/d at Brungle Bridge), with the balance of flows provided from Burrinjuck Dam
- for the 40,000 ML/d flow limit option and 45,000 ML/d maximum buffer flow, additional flows are assumed from tributaries upstream of Wagga Wagga, as shown in Table 4. This assumption reflects that these scenarios would involve elevated tributary inflows, in addition to dam releases.

For base case flows, observed flows from the August 2017 event which peaked at 22,000 ML/d at Wagga Wagga, were used as a basis.

Downstream of Wagga Wagga

The Conservation Programs, Heritage and Regulation Group developed a method and tool specifically for the purposes of estimating peak flow rates downstream of Wagga Wagga. The tool estimates the probability distribution of peak flows at a downstream gauge from a specified flow at an upstream gauge based on statistical analysis of observed flow records. The method was applied through a scripted tool called the Flow Peak Estimation Tool (FPET) which provides a systematic approach to:

- downloading timeseries of observed, daily flow data for user selected gauges
- identifying and matching flow peaks between the selected gauges. Flow peaks are matched according to a travel time 'window' that is entered by the user and can be adjusted to optimise peak matching

- enabling user selected filtering of matched peaks, to remove erroneous events or events with characteristics irrelevant to the analysis
- computing quantile regression models to estimate the range of downstream peak flow responses for a given upstream reference gauge flow.

Example outputs from the tool, showing a sample of matched flow peaks and an output from the quantile regression model, is provided in Figure 8 and Figure 9 respectively.

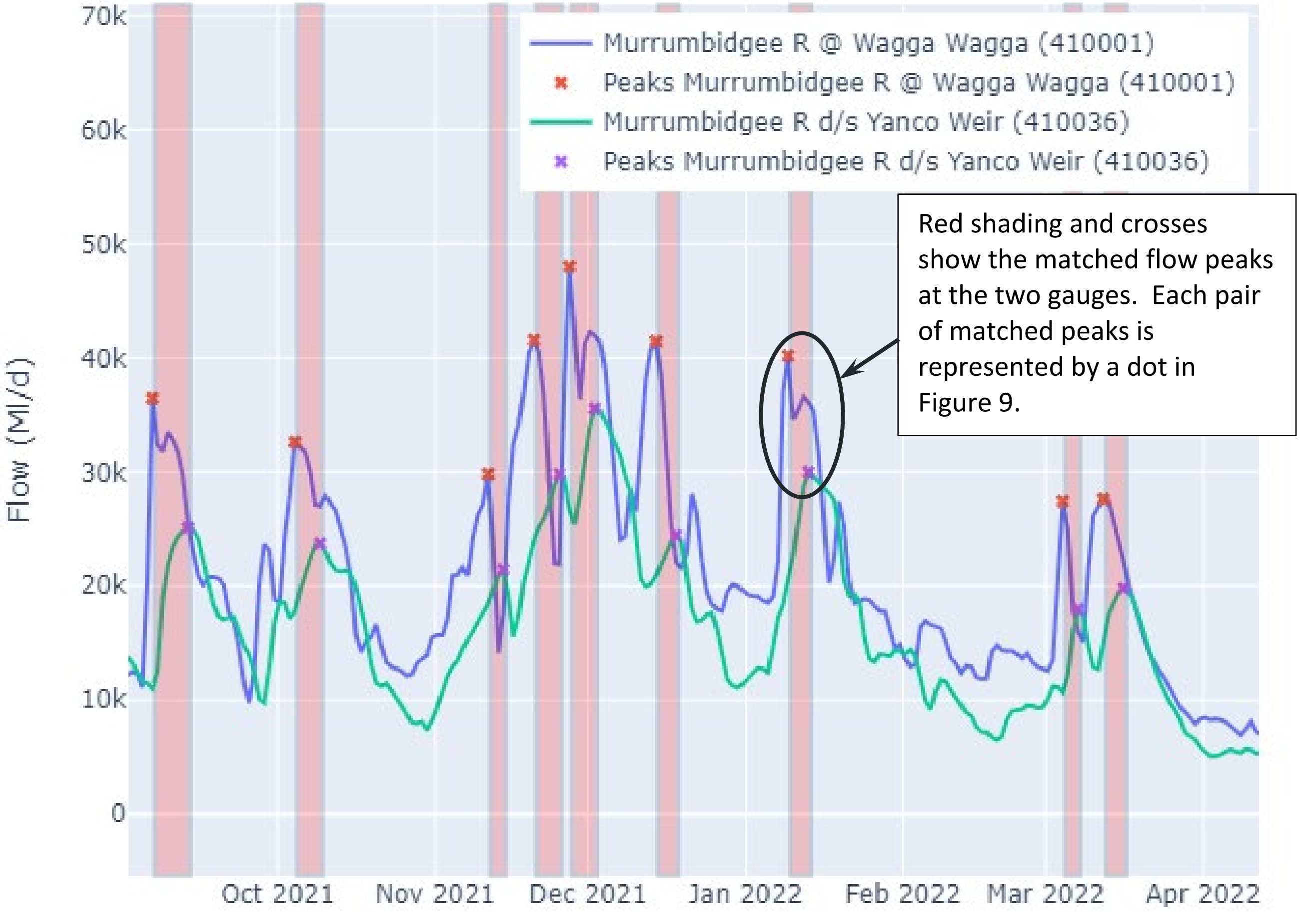


Figure 8 - Example of flow peak identification and matching.

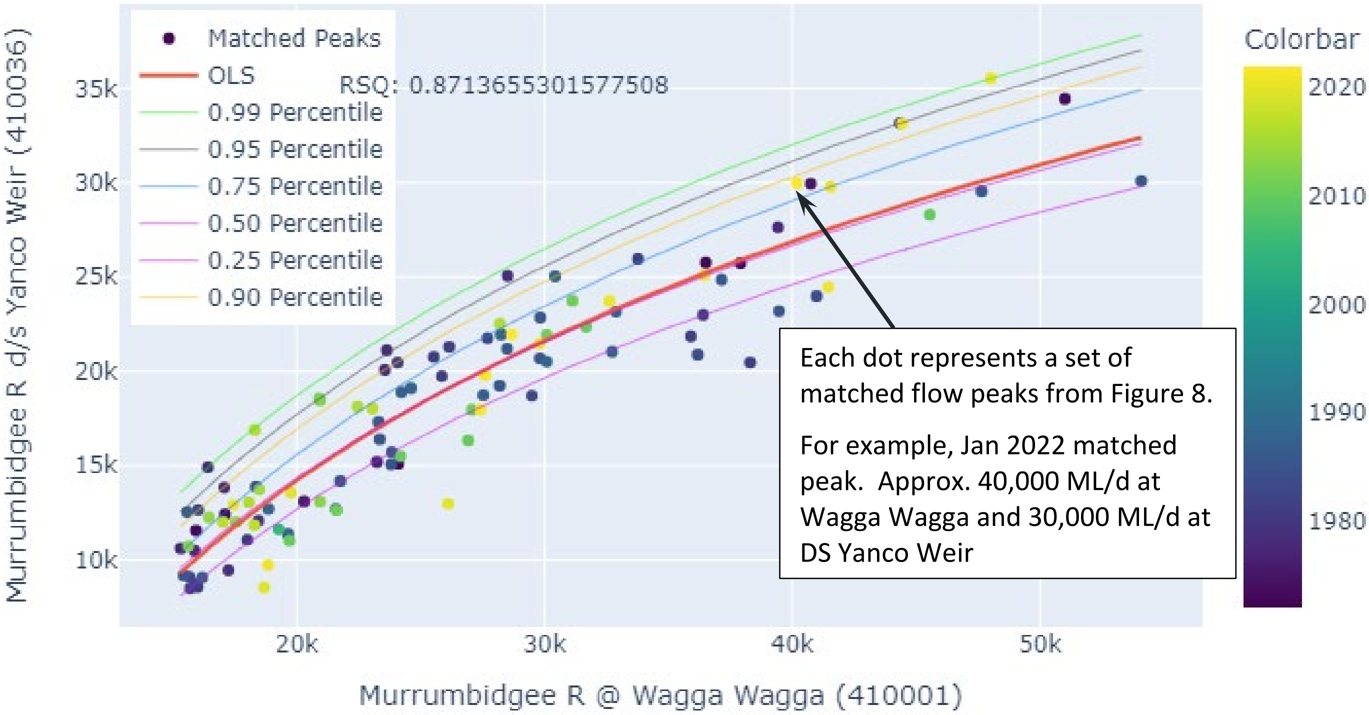


Figure 9 - Example output from quantile regression models.

From the quantile regression model 99th percentile estimates were typically adopted. These are considered to reflect an effective upper limit for possible outcomes from environmental flows, and most environmental water deliveries would result in lower flows. Higher estimates (i.e., above 99th percentile) are likely to reflect unusual or extreme events, such as flow peaks following recent major flooding, a situation where environmental flows would not be delivered.

Some model upstream boundaries involve multiple ungauged inflow points meaning this approach is unable to estimate all model inflows. For these models, outflows from upstream models were used to provide model inflows.

6.3 Rates of rise and fall

Environmental flow orders aim to achieve gradual rates of rise and fall, to reduce bank erosion and public safety risks, and support ecological processes like fish movement and migration. Rates of rise and fall for flows at Wagga Wagga were set based on recommendations in the Murrumbidgee Long-Term Water Plan[2].

For each of the other model inflow locations, rates of rise and fall were determined using analysis of multiple observed flow events with gradual rates of rise and fall, consistent with the rates of rise and fall at Wagga Wagga. This analysis showed rates of rise reduce downstream of Wagga Wagga, but rates of recession are relatively consistent. Rates of rise and fill used are listed in Table 6.

Table 5 - Approach used to estimate peak flow rates in each work package.

[2] NSW Department of Planning, Industry and Environment, Murrumbidgee Long-Term Water Plan, 2020. Available from: https://www2.environment.nsw.gov.au/publications/murrumbidgee-long-term-water-plan-part-a-catchment

Work Package	Reach description	Model inflow estimation approach
WP1	Murrumbidgee River, Burrinjuck Dam to Tumut Jcn.	Based on assumptions: Blowering releases up to Tumut flow limit plus some tributary inflows
WP3	Murrumbidgee River, Gobarralong to Wagga Wagga	Based on assumptions: Blowering releases up to Tumut flow limit plus some tributary inflows
WP4	Murrumbidgee River, Wagga Wagga to Berembed weir including Old Man Creek	Flow limit options are specified at Wagga Wagga
WP6	Murrumbidgee River, Berembed Weir to Yanco Weir	Flow regression analysis (Wagga Wagga to Berembed Weir and Old Man Creek at Kywong)
WP7	Murrumbidgee River, Yanco Weir to Darlington Point	Flow regression analysis (Wagga Wagga to Yanco Weir)
WP8	Murrumbidgee River, Darlington Point to Carrathool	Flow regression analysis (Wagga Wagga to Darlington Point)
WP9	Murrumbidgee River, Carrathool to Hay	Flow regression analysis (Darlington Point to Carrathool Bridge)
WP10	Murrumbidgee River, Hay to Maude	Flow regression analysis (Darlington Point to Hay Weir)
WP11	Murrumbidgee River, Maude to Redbank	Outflows from WP10, due to multiple ungauged inflow points
WP12	Murrumbidgee River, Redbank to Balranald	Outflows from WP11, due to multiple ungauged inflow points
Zone 5	Murrumbidgee River, Balranald to Murrumbidgee Junction	Analysis of historical events cross checked with outflows from WP12.
WP15	Yanco Creek, Yanco offtake to Morundah	Flow regression analysis (Wagga Wagga to Yanco offtake)
WP16	Colombo Creek, Morundah to Billabong Creek	Flow regression analysis (Yanco offtake to Morundah)
WP17	Billabong Creek, Colombo to Hartwood	Flow regression analysis (Yanco offtake to Coonong Weir) plus statistical analysis of Billabong Creek catchment inflows

Work Package	Reach description	Model inflow estimation approach
WP18	Yanco Creek, Morundah to Yanco Bridge	Flow regression analysis (Yanco offtake to Morundah)
WP19	Yanco Creek, Yanco Bridge to Warriston	Flow regression analysis (Yanco offtake to Yanco Bridge) plus statistical analysis of Billabong Creek catchment inflows
WP20	Billabong Creek, Warriston to Wanganella	Outflows from WP19, due to multiple ungauged inflow points
WP21	Billabong Creek, Wanganella to Moulamein	Outflows from WP20, due to multiple ungauged inflow points

7 Ground truthing and model review

Inundation mapping for the majority of the program's Murrumbidgee project area was published on the program web portal in July 2022[3]. Publishing of the inundation mapping was undertaken to inform landholders and other stakeholders of potential impacts of the project and to seek feedback on the mapping, enabling revision and improvement over time.

Since initial publication in July 2022, several revisions have been made to the mapping reflecting the addition of some model work packages, the corrections of some model errors and improvements to options and functionality available in the mapping portal in response to feedback. The revisions are summarised on the opening page of the inundation mapping portal.

Inundation mapping has also been shared and tested with private landholders as part of the project's landholder engagement activities. By October 2024, approximately 250 landholders in the Murrumbidgee had been directly engaged and provided with property specific maps for review and feedback. Most feedback received has been positive, with only minor localised errors identified for some properties, typically associated with how infrastructure is represented in the models.

The department developed an ArcGIS Field Maps app for engagement staff to collect and record feedback on the mapping. Feedback is recorded spatially with the app and passed on to the Conservation Programs, Heritage and Regulation Group for review. The associated database also provides for recording of the actions taken, if required, to address the feedback.

In 2024, the modelling team migrated each of the models into the latest TUFLOW software version (2023-03-AE) available at the time, which included significant improvements to processing and mapping outputs.

The Conservation Programs, Heritage and Regulation Group is currently reviewing all feedback received and making required revisions to each of the work package hydraulic models, to support the development of the program. As part of this work the analysis of flows used to determine the model inflow parameters in Table 6 is also being reviewed, including extending the period of gauge data used in the analysis to incorporate the additional 3 years of gauge data since the original analysis was undertaken.

As landholder engagement continues, including through the easement negotiation process, it is expected further feedback will be received. Updates to the models will continue to be made as required to address errors, achieve the level of accuracy required to build confidence among landholders and other stakeholders and to support potential negotiation and agreements.

[3] https://water.dpie.nsw.gov.au/our-work/water-infrastructure-nsw/sdlam/reconnecting-river-country-program/inundation-mapping

Table 6 – Model inflow parameters for model reaches.

Note: Analysis used to inform parameters set out in this table is currently under review. Parameters are subject to change following completion of that review.

If you are experiencing any accessibility issues in viewing this table, please contact the Water Enquiries team for assistance at 1300 081 047 or email us at water.enquiries@dpie.nsw.gov.au.

Work Package	Reach description	Gauge	Gauge number	Estimated flows for the program flow limit options					Duration	Rates of rise and fall (% per day)	
				W22 (base case)	W32	W36	W40	W45 (buffer)	Days at Peak	Rise	Fall
WP1	Burrinjuck Dam to Tumut Junction	Murrumbidgee River DS of Burrinjuck Dam	410008	14,000	22,500	26,500	28,500	32,500	8	20%	15%
		Tributary inflows	various	0	0	0	1,000	1,000			
WP3	Gobarralong to Wagga Wagga	Murrumbidgee River at Gobarralong	410195	14,000	22,500	26,500	29,500	33,000	10	20%	15%
		Tumut at Brungle Bridge	410039	9,000	9,500	9,500	9,500	10,000			
		Adelong Creek	No gauge ID	0	0	0	1,000	2,000			
WP4	Wagga Wagga to Berembed weir (including Old Man Creek)	Murrumbidgee River at Wagga Wagga	410001	22,000	32,000	36,000	40,000	45,000	10	20%	15%
WP6	Berembed weir to Yanco weir	Murrumbidgee River DS of Berembed weir	410023	17,000	25,000	27,000	29,000	32,500	10	10%	15%
		Old Man Creek at Kywong	410093	4,500	6,800	8,100	8,700	9,000			
		Sandy Creek outflow	No gauge ID	0	0	500	1,000	1,500			
WP7	Yanco weir to Darlington Point	Murrumbidgee River downstream of Yanco weir	410036	18,000	27,000	29,000	31,000	34,000	10	8%	15%
WP8	Darlington Point to Carrathool	Murrumbidgee River at Darlington Point	410021	17,000	26,000	28,000	30,000	32,000	10	6%	15%
WP9	Carrathool to Hay	Murrumbidgee River at Carrathool Bridge	41000281	15,000	24,000	26,000	28,000	29,000	10	4%	15%
WP10	Hay to Maude	Murrumbidgee River DS Hay weir	410136	14,000	23,000	25,000	27,000	28,000	10	3%	15%
WP11	Maude to Redbank	Murrumbidgee River DS Maude weir	410040	Based on WP10 model outflows due to multiple ungauged inflow locations							
WP12	Redbank to Balranald	Murrumbidgee River DS Redbank weir	410041	Based on WP11 model outflows due to multiple ungauged inflow locations							
Murray Zone 5	Balranald to Murrumbidgee Junction, including junction Wetlands	Murrumbidgee River DS Balranald weir	410130	9,000	10,000	11,000	11,500	11,500	Steady state flows used		
WP15	Yanco Creek, Yanco offtake to Morundah	Yanco Creek at Yanco offtake	410007	1,800	3,100	3,600	4,000	4,600	10	10%	15%
WP16	Colombo Creek, Morundah to Billabong Creek	Colombo Creek at Morundah	410014	550	1,100	1,300	1,400	1,500	10	5%	15%
WP17	Billabong Creek, Colombo to Hartwood	Colombo Creek at Coonong Weir	41000210	580	930	1,000	1,100	1,200	10	5%	15%
		Billabong Creek at Cocketgedong	410012	2,000	2,000	2,000	2,000	2,000	5	20%	20%
		Nowrannie Creek	410185	300	300	300	300	300	5	20%	20%
WP18	Yanco Creek, Morundah to Yanco Bridge	Yanco Creek at Morundah	410015	980	1,700	1,900	2,100	2,400	10	6%	15%
WP19	Yanco Creek, Yanco Bridge to Warriston	Yanco Creek at Yanco Bridge	410169	770	1,200	1,300	1,400	1,600	10	5%	15%
		Hartwood weir inflows	No gauge ID	2,240	2,400	2,500	2,500	2,600	10	8%	15%
WP20	Billabong Creek, Warriston to Wanganella (including Forest Creek)	Billabong Creek at Conargo	410148	Based on WP19 model outflows due to multiple ungauged inflow locations							
WP21	Billabong Creek, Wanganella to Moulamein	Billabong Creek at Wanganella	410148	Based on WP20 model outflows due to multiple ungauged inflow locations							

8 Summary

This report provides a summary of the hydraulic modelling work program undertaken for the Reconnecting River Country Program's Murrumbidgee Project.

The work program undertook extensive data collection and developed and adopted rigorous standards and quality assurance processes, to provide high resolution and high accuracy inundation mapping to meet the requirements of the project.

The hydraulic models were calibrated and validated against observed water level data, together with aerial photography and satellite imagery. The inundation map outputs have also been 'ground truthed' with many landholders across the Murrumbidgee project area.

The process of checking and review will continue as the project develops, to achieve the level of accuracy required to support potential landholder negotiations and agreements to secure the flow corridor.

9 Appendix A – RRCP Hydraulic Modelling Standard Specifications

RRCP Hydraulic Modelling (TUFLOW 1D-2D) Standard-Specification_v3.1

RRCP Hydraulic Modelling (TUFLOW 2D) Standard-Specification_v3.2