Hydrology and hydraulic modelling for Stage 1A of the Victorian Constraints Measures Program

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Key Points

- One objective for Stage 1A of the Victorian Constraints Measures Program was to better understand how relaxing operational constraints may change the flow behaviour along the Goulburn and Murray rivers, under a range of climate conditions.
- To meet this objective, hydrology and hydraulic models were applied to simulate a large range of potential future scenarios.
- Key outcomes and lessons learnt from the hydrology and hydraulic modelling for Stage 1A of the Victorian Constraints Measures Program are likely to be useful for other basin-scale stream management projects that involve hydrology or hydraulic modelling.

Abstract

Hydrological and hydraulic modelling of the Goulburn River and River Murray was an important component of work done for Stage 1A of the Victorian Constraints Measures Program. The hydrology modelling involved the coordinated application of models developed by the University of Melbourne, the Department of Energy, Environment and Climate Action (DEECA) and the Murray-Darling Basin Authority (MDBA). Likewise, different aspects of the hydraulic modelling were completed by the MDBA, Manly Hydraulics Laboratory (MHL) and HARC. This paper summarises how the modelling was done, the key outcomes, and lessons learnt.

Keywords

Goulburn River, River Murray, constraints relaxation, hydrology modelling, hydraulic modelling

Introduction

An objective for Stage 1A of the Victorian Constraints Measures Program was to better understand how relaxing constraints may change the flow behaviour in the Goulburn and Murray rivers, under a range of climate conditions. To meet this objective, hydrology and hydraulic modelling was undertaken. The outputs from the hydrological modelling, in combination with the inundation extents predicted by hydraulic models, were then used to assess the expected environmental, cultural, social and economic outcomes of constraints relaxation.

Hydrology modelling

Hydrological modelling is used to simulate how water will flow through a river system under different climate sequences and operating conditions. This involves simulating factors such as inflow volumes and patterns (rainfall-runoff), river operating rules (such as how dams are managed to supply water and mitigate flood impacts) and water demands (such as irrigation, environmental and trade volumes). Hydrology modelling can therefore be used to test how flow behaviour is expected to respond to potential changes to the river system.

Three hydrological models were used for Stage 1A of the Victorian Constraints Measures Program:

1) The University of Melbourne's Stochastic Goulburn Environmental Flow Model (SGEFM) was used for a high-level analysis of the hydrological and ecological outcomes of relaxed constraints on the mid-Goulburn and lower Goulburn (John et al., 2022).
2) The DELWP's Goulburn Broken Campaspe Coliban Loddon (GBCCL) Source Model was used to analyse in more detail the hydrological outcomes of relaxed constraints on the mid-Goulburn and lower Goulburn (DEECA, 2023).
3) The MDBA's Source Murray Model (SMM) was used to analyse the hydrological outcomes for the River Murray if constraints are relaxed at Doctors Point, Yarrawonga Weir and in the mid-Goulburn and lower Goulburn (MDBA, 2022a).

The SGEFM represents a higher-level view of the Goulburn system and runs at a monthly timestep (with flows then disaggregated to a daily time-step). The GBCCL Source model runs on a daily time step and simulates the spatial and temporal complexity of water management in the Goulburn system in more detail. Because the SGEFM can be quickly run thousands of times, it was applied for "range finding" to understand the sensitivity of hydrological outcomes to incremental changes in flow constraints and climate projections. The GBCCL Source model was then run for selected flow constraint relaxation options in the mid- and lower Goulburn, to assess the expected hydrological outcomes in more detail.

The SMM simulates the hydrology of the southern connected Murray-Darling Basin at a daily time-step, and was run for selected flow constraint relaxation options at Doctors Point, downstream of Yarrawonga Weir, and in the mid- and lower Goulburn. This work built on the hydrological modelling done for the NSW Reconnecting River Country Program, which was also done using the SMM. Linkage between the Goulburn and Murray models was achieved via running a sequence of simulations with the GBCCL Source model and SMM and feeding input and output data between the two models.

Figure 1 shows how the models were linked for the hydrological modelling that was undertaken in Stage 1A of the Victorian Constraints Measures Program:

- The SGEFM was run for initial design of constraint relaxation, with all Goulburn system environmental water holdings used to meet Kaiela (lower Goulburn River) environmental demands (box A in Figure 1).
- The SGEFM was then re-run to test the sensitivity of outcomes to using held environmental water in the Goulburn to meet environmental water demands in both the Kaiela and River Murray (box B in Figure 1).
- The results from the SGEFM – for example shown in Figure 2 – were used to inform the constraint relaxation scenarios that were tested in the GBCCL Source model (Table 1). The GBCCL Source model was then run, with all Goulburn system environmental water holdings used to meet Kaiela environmental demands (box C in Figure 1).
- End of system flows from the GBCCL Source were provided as a daily time series of inputs to the SMM, for the current constraint scenario and each constraint relaxation scenario. The SMM was then run to produce outcomes on the assumption that all Goulburn system environmental water holdings were used to meet Kaiela environmental demands (box D in Figure 1).
- Results from the SMM were used to identify periods when Murray environmental water demands could be supplied with 'unused' held environmental water in the Goulburn system. The GBCCL Source model was then run, with environmental water holdings used to meet a combination of environmental water demands in the Murray and Kaiela (box E in Figure 1).
- The outputs from the second iteration of the GBCCL Source model runs were used as inputs to the second iteration of the SMM runs to produce final modelled outputs for the River Murray system for the scenarios listed in Table 2 (box F in Figure 1).

The SGEFM was run for a wide range of current and potential future climate conditions. The current constraint scenario and all constraint relaxation options investigated using the GBCCL Source model and SMM were simulated using historic climate conditions representing the period from the 1890s to June 2020. The current constraint scenario and one constraint relaxation option were also run in the GBCCL Source model and SMM for post-1975 conditions and projected climate conditions for the year 2070.

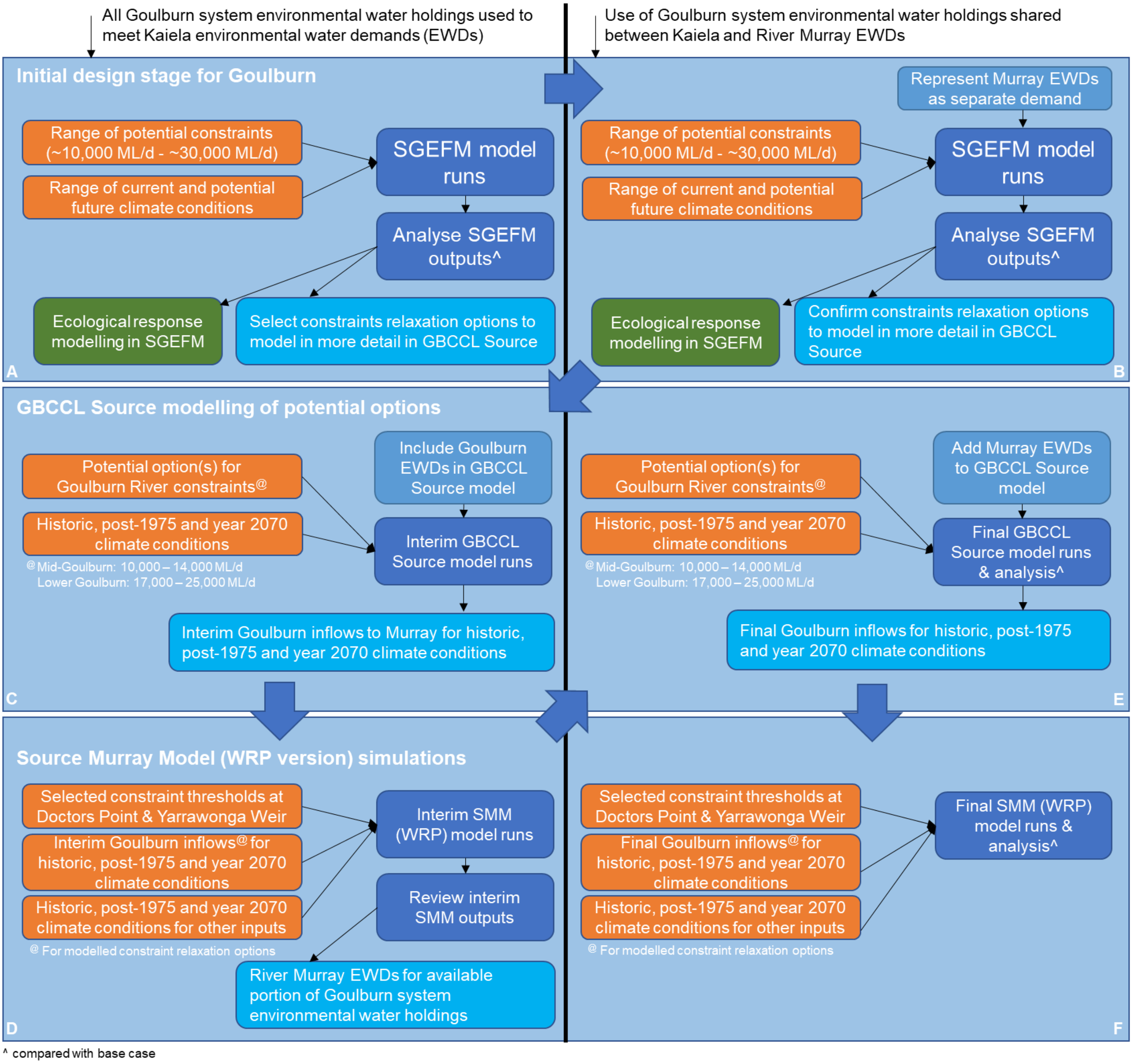


Figure 1. An overview of hydrology modelling for Stage 1A of the Victorian Constraints Measures Program

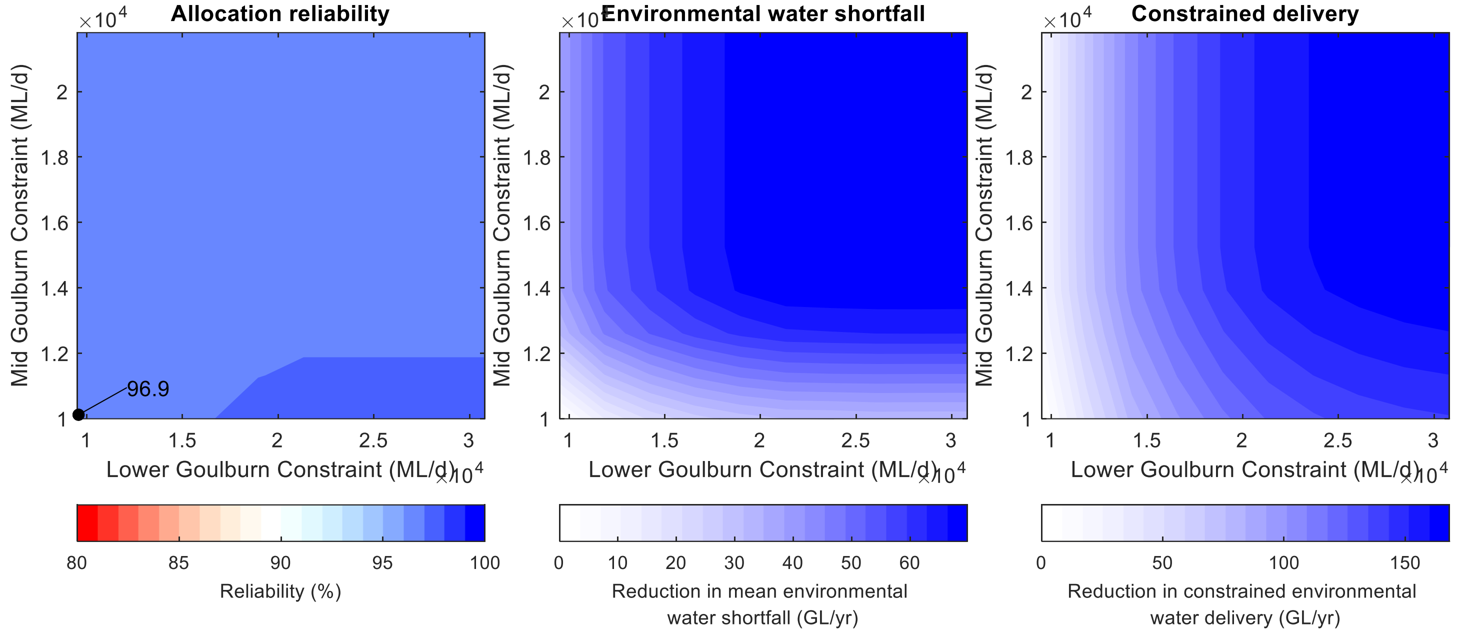


Figure 2. Example outcomes from the SGEFM (John et al., 2022), which were used to inform the constraint relaxation scenarios tested in the GBCCL Source model (Table 1).

Table 1. Constraint relaxation scenarios simulated in the GBCCL Source model (DEECA, 2023)

Location (gauge number)	Constraint at given location for simulated scenario				
	Current (M10L9.5)	Scenario 1 (M10L17)	Scenario 2 (M10L21)	Scenario 3 (M12L21)	Scenario 4 (M14L25)
Eildon (405203)	9,500 ML/d	9,500 ML/d	9,500 ML/d	12,000 ML/d	13,700 ML/d
Molesworth	10,000 ML/d	10,000 ML/d	10,000 ML/d	Jul-Oct*: 12,000 ML/d Nov-Jun: 10,000 ML/d	Jul-Oct*: 14,000 ML/d Nov-Jun: 10,000 ML/d
Murchison (405200)	9,500 ML/d	17,000 ML/d	21,000 ML/d	21,000 ML/d	25,000 ML/d
Shepparton (405204)	9,500 ML/d	17,000 ML/d	21,000 ML/d	21,000 ML/d	25,000 ML/d

Table 2. Constraint relaxation scenarios simulated in the Source Murray Model (MDBA, 2022)

Scenario Label	Scenario category	Flow constraint (ML/d) at location			
		Doctors Point	Yarrawonga Weir	Mid-Goulburn	Lower Goulburn
Y15D25	Current	15,000	25,000	10,000	9,500
Y25D25	G17 set	25,000	25,000	10,000	17,000
Y30D30		30,000	30,000	10,000	17,000
Y35D35		35,000	35,000	10,000	17,000
Y40D40		40,000	40,000	10,000	17,000
Y45D40		40,000	45,000	10,000	17,000
M10L17 - Y40D40	Y40D40 set	40,000	40,000	10,000	17,000
M10L21 - Y40D40		40,000	40,000	10,000	21,000
M12L21 - Y40D40		40,000	40,000	12,000	21,000
M14L25 - Y40D40		40,000	40,000	14,000	25,000

Key outcomes

Using the outputs available from the GBCCL Source model and SMM, several representations of the hydrological outcomes were prepared for stakeholders and those assessing the environmental and socio-economic outcomes of constraints relaxation. These were:

- Time-series of the maximum flow within each month at key locations (e.g. Figure 3).
- Box plots of the number of days per year above thresholds of interest, either considering all seasons or winter-spring only.
- Spell plots showing the timing and duration of flows at or above key thresholds (e.g. Figure 4).

The time-series of the maximum flow within each month showed the modelled difference in the magnitude and timing of peak flows because of constraints relaxation. The box plots of the number of days per year above flow thresholds summarised the expected change in how often per year flows of a given magnitude would be exceeded. The spell plots showed the anticipated timing and duration of flows at or above key thresholds at locations of most interest.

These hydrological modelling outputs demonstrated that in the mid-Goulburn River, and at Doctors Point and downstream of Yarrawonga Weir on the River Murray, constraint relaxation increases the number of winter-spring days when flows are greater than current constraints but less than or equal to the relaxed constraint. For example, the days per year of winter-spring flow greater than 25,000 ML/d or 35,000 ML/d increased at Doctors Point and downstream of Yarrawonga Weir if constraints were relaxed to 35,000 ML/d or 40,000 ML/d at both locations, and Figure 4 shows that this increase is most likely to be observed in August, September and October.

Once the flow of interest is above the relaxed constraint, the pattern changes. For example, downstream of Yarrawonga Weir the number of days of winter/spring flow with flow greater or equal to 45,000 ML/d reduces if the constraint is relaxed to 25,000 ML/d – 40,000 ML/d, but increases if the constraint is relaxed to 45,000 ML/d.

The hydrology modelling also demonstrated that the influence of constraint relaxation on peak flow magnitudes and frequencies reduced moving downstream.

Lessons learnt

Some important lessons learnt from the hydrology modelling for Stage 1A of the Victorian Constraints Measures Program were:

- The availability of a lower fidelity model for the Goulburn River (i.e. the SGEFM) meant that a large range of potential constraint relaxation scenarios could be tested under different climate conditions, before a subset of scenarios were modelled in more detail. This improved the efficiency of the hydrology modelling and scenario selection process.
- The development and application of hydrology modelling for a large connected river system such as the River Murray required careful consideration and coordination of approaches and inputs/outputs between multiple modelling teams (Figure 1). For example, Stage 1A of the Victorian Constraints Measures Program was the first time that outputs from the DEECA GBCCL Source model had been used as inputs to the MDBA Source Murray Model.
- The hydrology modelling outputs needed to be presented in a variety of ways to a) convey the full range of information contained in the results, and b) communicate the outcomes with both technical and non-technical audiences. The time-series of maximum daily flows within each month (e.g. Figure 3) were most readily understood, but needed to complemented with other plots (e.g. Figure 4) to demonstrate how the duration of flows at key thresholds are likely to change if constraints are relaxed.

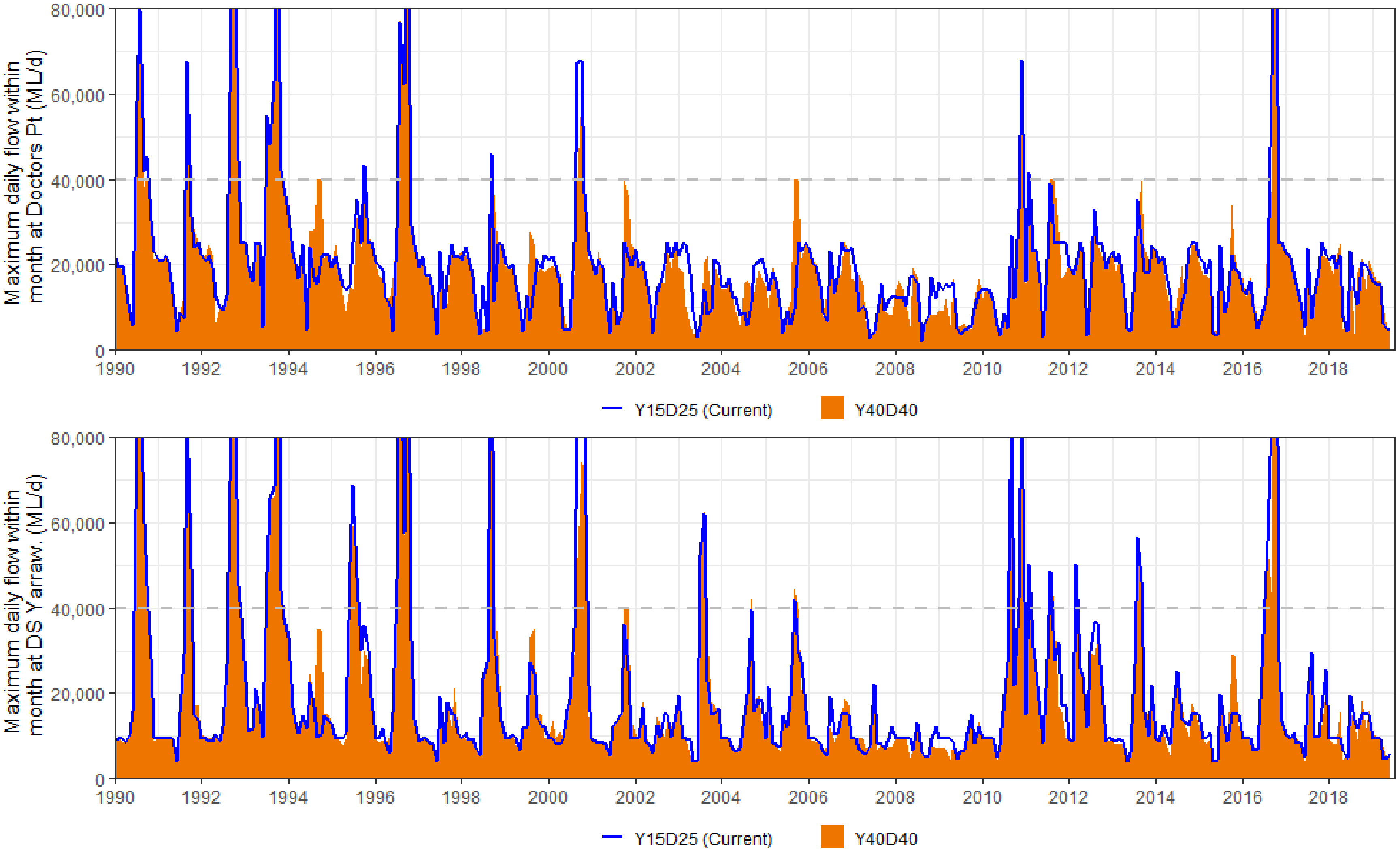
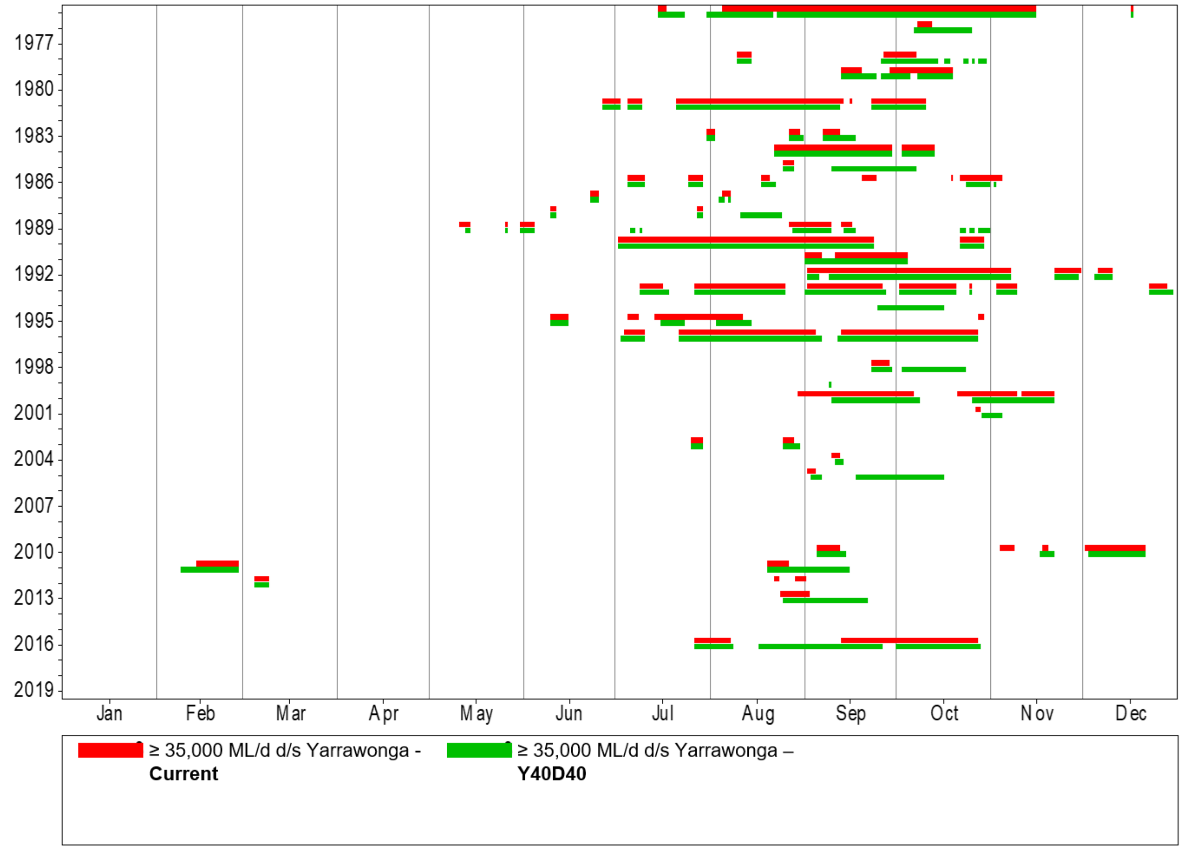


Figure 3: Example time-series of maximum daily flow within each month at Doctors Point (top) and downstream of Yarrawonga Weir (bottom) under current constraints (blue line) and for a modelled relaxed constraints scenario (orange)



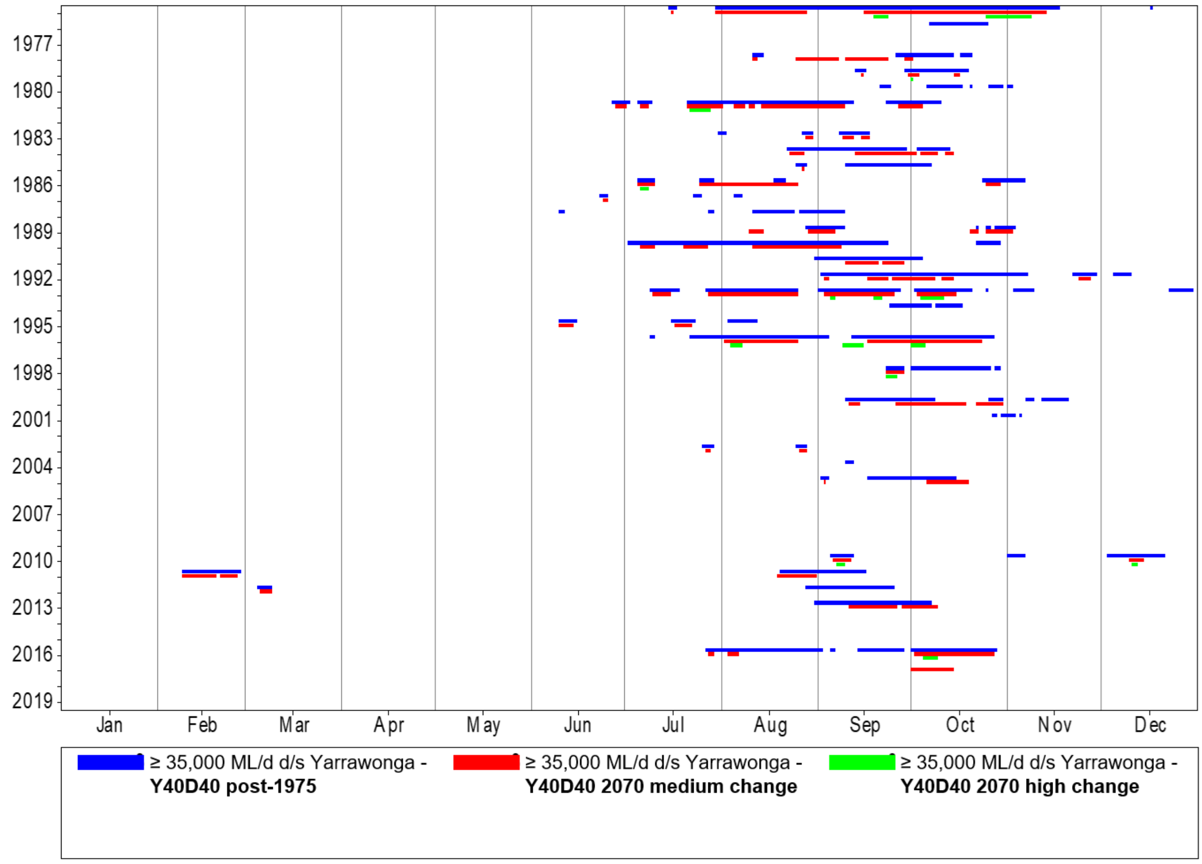


Figure 4. Example analyses of spells above 35,000 ML/d downstream of Yarrawonga Weir under current and relaxed constraint scenarios (top) and under relaxed constraints but different climate cases (bottom)

Hydraulic modelling

Hydraulic modelling is used to map the expected depth and extent of inundation under different flow conditions. For Stage 1A of the Victorian Constraints Measures Program, separate models were developed for the mid-Goulburn and lower Goulburn, and 7 zones of the River Murray system bordering Victoria (Table 3).

The key differences between the Goulburn River hydraulic modelling for Stage 1A of the Victorian Constraints Measures Program and the previous work reviewed by Wilson et al. (2019) were that:

- Additional bathymetry datasets (depth soundings and cross-section surveys) for the mid-Goulburn were incorporated into the digital elevation model used in the hydraulic model.
- The hydraulic modelling results were produced using 2 m grid cells, rather than 10 m grid cells. This meant the information was more meaningful at the scales that property owners and public land managers are most interested in.
- The steady-state flows simulated for the mid-Goulburn (10,000 – 14,000 ML/d) and lower Goulburn (10,000 – 25,000 ML/d) were generally lower than the range of flows modelled for previous constraint relaxation business cases (e.g. Water Technology, 2016).

Compared with the hydraulic modelling that informed previous business cases for constraints relaxation along the River Murray, the information available from the hydraulic models developed by the MDBA and MHL for the zones between Hume Dam and the Wakool Junction was a step-change improvement.

This is because the 1D/2D and fully 2D hydraulic models developed by the MDBA and MHL simulate the movement of water through the river channels and floodplain, and these models have been calibrated to flow data and aerial imagery available for recent flow events. In contrast, the previous estimates of inundation extents along the River Murray used for constraint relaxation investigations were based on the RiM-FIM approach (Sims et al., 2014), which estimated a static water level for a given flow threshold by interpolating between historical inundation extents that were linked to corresponding flows at gauged locations. The estimates of inundation extents available from the MDBA and MHL hydraulic models are therefore more defensible, particularly for river reaches with no or very few streamflow gauges.

Table 3. Hydraulic models used for Stage 1A of the Victorian Constraints Measures Program

River – Reach	Hydraulic model	Done by
Goulburn River – mid-Goulburn and lower Goulburn	TUFLOW 2D	HARC
River Murray – Hume to Yarrawonga (Zone 7)	MIKE FLOOD (1D / 2D)	MDBA
River Murray – Yarrawonga to Tocumwal (Zone 8)	MIKE21 Flow Model FM	MDBA
River Murray – Barmah-Millewa (Zone 1)	MIKE FLOOD (1D / 2D)	MDBA
River Murray – Barmah to Torrumbarry (Zone 9)	TUFLOW 1D / 2D	MHL
River Murray – Koondrook-Perricoota (Zone 3)	MIKE FLOOD (1D / 2D)	MDBA
River Murray – Wakool River reach (Zone 2)	MIKE21 Flow Model FM	MDBA
River Murray – Niemur-Murray-Boundary Bend (Zone 5)	MIKE21 Flow Model FM	MDBA

Figure 5 shows the extent of the hydraulic models developed for the mid-Goulburn and lower Goulburn, with a callout box demonstrating the type of hydraulic modelling results available along these river reaches for the various constraint relaxation scenarios simulated. Figure 6 presents similar information for the River Murray, and this inundation mapping is now publicly available from the NSW Reconnecting River Country website[1].

[1] https://water.dpie.nsw.gov.au/our-work/water-infrastructure-nsw/sdlam/reconnecting-river-country-program;
For the River Murray zones downstream of zone 1 (i.e. zones 2-6 and 9), the steady-state flows that best corresponded with steady-state flows of varying magnitude downstream of Yarrawonga Weir were estimated by the NSW Department of Planning and Environment

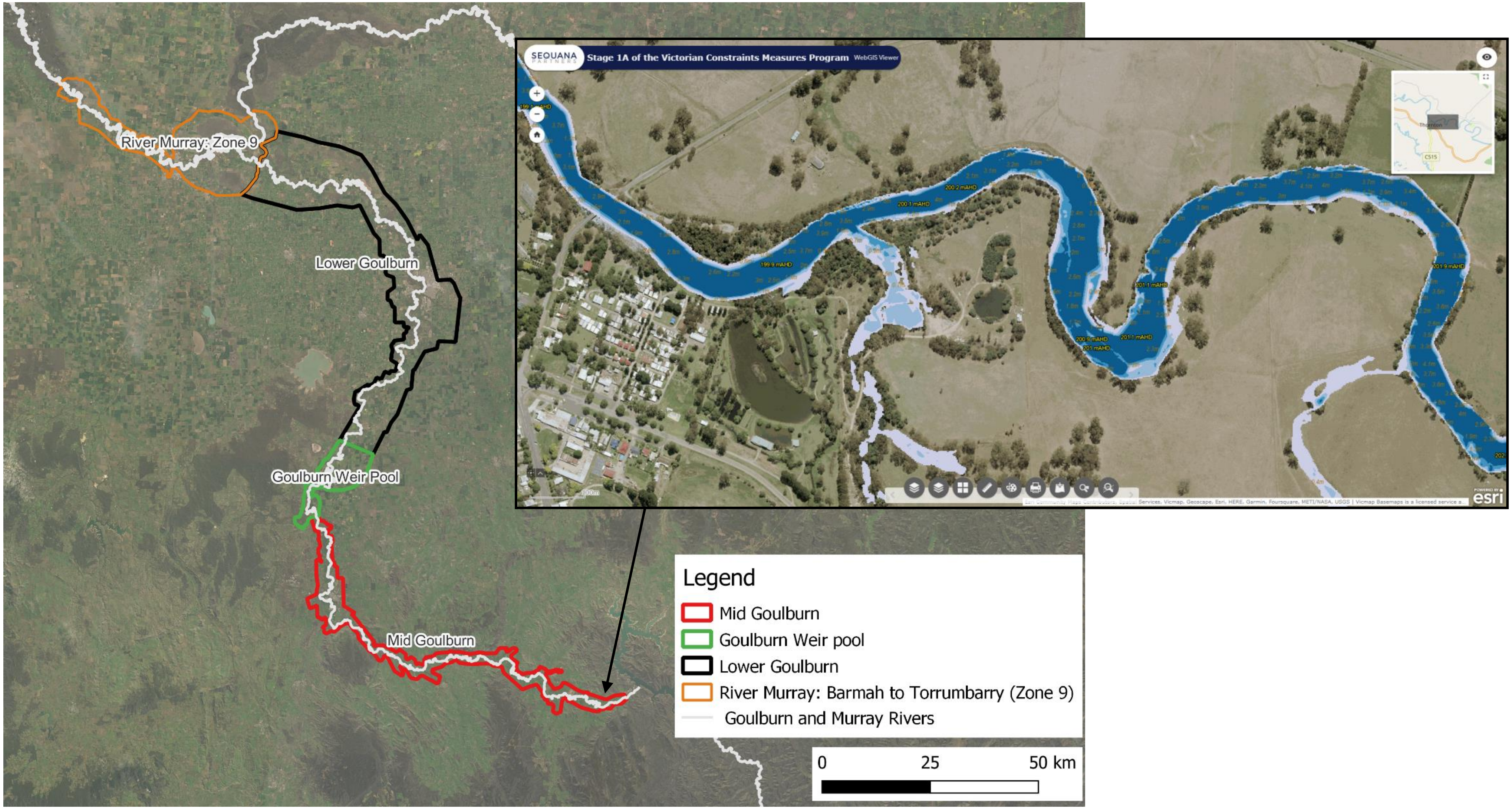


Figure 5: A map showing the extent of the hydraulic models developed for the mid-Goulburn and lower Goulburn, with the callout box demonstrating the type of hydraulic modelling results available along these river reaches

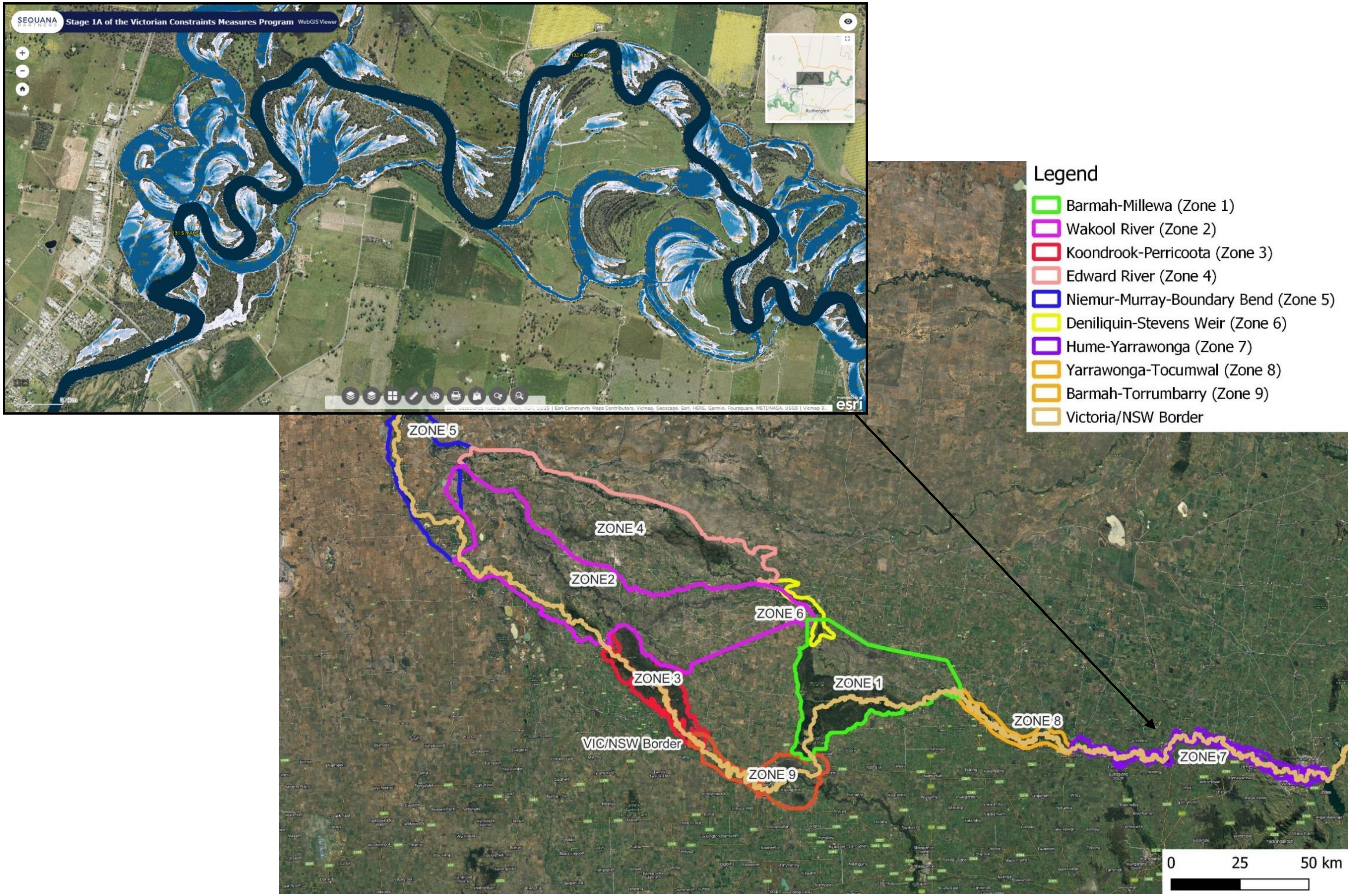


Figure 6: A map showing the extent of the hydraulic models developed for the River Murray, with the callout box demonstrating the type of hydraulic modelling results available along the river reaches through these zones

Key outcomes

The key outcomes from the hydraulic modelling completed for Stage 1A of the Victorian Constraints Measures were:

- The development and calibration of hydraulic models tailored to simulate flow magnitudes relevant to constraint relaxation investigations for the mid-Goulburn, lower Goulburn and the River Murray between Hume Dam and Wakool Junction.
- The use of these hydraulic models to simulate steady-state flows at intervals of 2,000 ML/d – 5,000 ML/d between current operational constraints and potentially relaxed constraints for the Goulburn River and River Murray.
- The conversion of the hydraulic modelling results to high-resolution GIS grids of predicted water level, inundation area and water depth along the Goulburn River (e.g. Figure 5) and River Murray (e.g. Figure 6) corresponding with the steady-state flows simulated. For the Goulburn River scenarios, the hydraulic model was also used to produce GIS grids of bed shear stress.

Outputs from the hydraulic modelling task were used to inform the assessment of the environmental benefits of constraint relaxation along the Goulburn River and River Murray, and the evaluation of potential impacts on private property and public assets.

Lessons learnt

Some important lessons learnt from the hydraulic modelling for Stage 1A of the Victorian Constraints Measures Program were:

- There is a trade-off between model extent and run times. If a model is larger, upstream and downstream boundaries at potentially arbitrary locations can be avoided, but the time taken to complete a simulation can become unwieldy. On the other hand, the calibration and application of smaller models can be completed more quickly, but breaking rivers into zones represented by different hydraulic models can introduce discontinuities in model predictions at zone boundaries.
- Ground-truthing of hydraulic model results means different things to different people. For some, calibration of the model results to gauged rating curves and historic inundation extents is sufficient, and for others ground-truthing means property-by-property validation of the results with landholders. Either way, it will be important during future communications with the community to supplement the hydraulic modelling results with aerial imagery of inundation extents captured when October 2022 flows were in the range of constraint relaxation being considered for the mid-Goulburn.
- If there are additional stages of the Victorian Constraints Measures Program, and there is contention in some areas about the land subject to inundation under relaxed constraint scenarios, smaller site-specific models could be developed for these locations. This will allow local-scale refinements to simulated landscape elevations and / or roughness coefficients to be made without influencing model results for regions upstream or downstream.

Conclusions

This paper has described how the hydrology and hydraulic modelling was done for Stage 1A of the Victorian Constraints Measures Program[2], and summarised the key outcomes and lessons learnt. These insights will be useful if the Program proceeds to the next stage, and potentially to others doing hydrology or hydraulic modelling for basin-scale stream management investigations.

[2] Reports from Stage 1A of the Victorian Constraints Measures Program are publicly available for download from https://www.water.vic.gov.au/our-programs/murray-darling-basin/victorian-constraints-measures-program

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