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Developing a Source model of the Upper Macquarie and Upper Coxs river systems

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Abstract: The Fish River Water Supply Scheme (FRWSS) model integrates the Upper Macquarie and Coxs River systems to support regional water security planning in New South Wales. It simulates physical and management processes affecting water availability, incorporating detailed spatial and temporal data to evaluate water supply reliability for various users including urban, energy, and rural sectors.

The FRWSS connects subsystems including the Upper Macquarie River (above Burrendong Reservoir), Wywandy system (upper Coxs River), and Blue Mountains Water Supply System, serving towns, power stations, and industries with storages totalling over 160GL capacity (Figure 1).

The model aims to be robust, flexible, and integrable with downstream models, using a 10,000-year climate dataset with detailed spatial resolution to capture key processes and reliably quantify water supply security for critical users. It incorporates spatial data (topography, climate, river networks), time series (flows, extractions), and physical characteristics. There are 44 rainfall-runoff models calibrated to reproduce historical flows across the system's river reaches and storages. The model includes multiple urban demand and wastewater return models, power station demand model, irrigation demands, and mine water returns, capturing diverse water uses and returns in the system. The model incorporates relevant water sharing plan and operational rules for storages, treatment plants, and supply distribution, aligning with policies and observed behaviours to simulate water allocation and restrictions accurately.

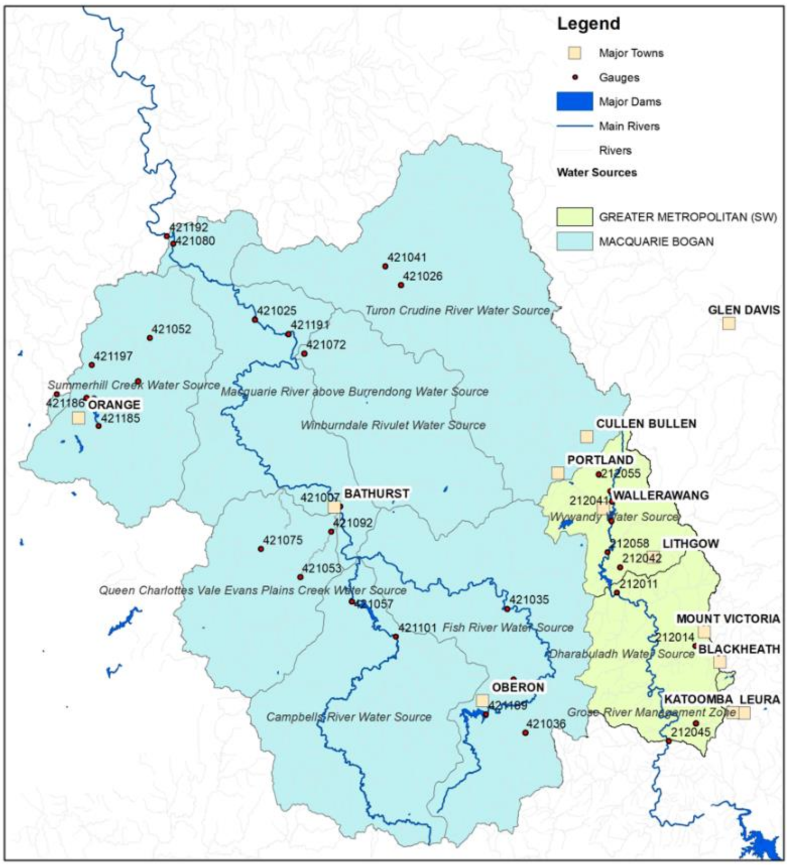


Figure 1 Extent of the Fish River Wywandy System

Calibration shows good replication of flow regimes, storage volumes, and urban water demands across multiple gauges and storages, with Nash-Sutcliffe efficiencies indicating reliable simulation of hydrological and operational dynamics.

The FRWSS model represents a significant advancement over previous models, offering detailed, accurate simulations to support water security planning amid climate variability and infrastructure and population changes, meeting all design criteria for integrated water resource management

Keywords: *Integrated modelling, eWater Source, river system models, urban water security, Regional Water Strategy*

1. INTRODUCTION

Over the past six years, the New South Wales Government has developed 12 regional water strategies using the latest climate data and hydrological modelling to manage each region's water needs for the next 20–40 years. These models simulate river system processes over long periods (100-10,000 years), providing reliable estimates of water availability, requirements, security, and equitable sharing, with a consistent approach across NSW.

The latest strategy, the Fish River-Wywandy Regional Water Strategy (FRW RWS), which is being developed, focuses on the Upper Macquarie and Coxs Rivers to address economic transition in Lithgow due to declining coal-fired power and water security challenges for Oberon, Bathurst, and Orange. The Fish River Water Supply Scheme connects these systems, supplying essential water to Mount Piper Power Station, Lithgow, the Blue Mountains, and Oberon in Upper Macquarie.

This modelling is part of an integrated modelling framework that will be used to assess the economic and environmental impacts of options for improving water security in a changing climate. The models are used to evaluate current and future town water security and explore solutions for energy and urban supply.

Accurate simulation of town water supply is crucial for understanding long-term water security, especially under rare events and changing conditions from change in infrastructure, population growth and climate change. These models inform and guide the region's water strategies. This paper outlines the building and integration of models for the Fish River, Upper Macquarie, and Wywandy systems, detailing their conceptualisation, construction, calibration, and the incorporation of rainfall-runoff, demand, return, and reach models, as well as water management operations.

2. SYSTEM OVERVIEW

FRWS sits at the headwaters of the Macquarie and Hawkesbury-Nepean river systems. The headwaters start both in the east and west the Great Dividing Range, in the central NSW highlands. The Upper Macquarie river system begins at Shooters Hill (southwest of the Jenolan Caves) and flows northwards towards Burrendong Dam, near Wellington, NSW. The Wywandy system begins in the upper reaches of the Cox's River system (northwest of Katoomba) which initially flows south and then eastward into Warragamba Dam, which is part of the Hawkesbury-Nepean system (Figure 1).

There are several subsystems within these river systems. The Upper Macquarie system includes the Fish River Water Supply Scheme (FRWSS), Oberon, Bathurst and Orange town water supplies before running into Burrendong dam – which is the start of the regulated Macquarie river system. The Cox's River includes energy generation infrastructure and associated water storages and coal mines as well as urban water supplies to Lithgow and regional towns, some of which are outside of the catchment.

The Blue Mountains Water Supply System (BMWSS), though not within the two main catchments, relies on water from the FRWSS and Warragamba Dam via Orchard Hills Water Treatment Plant (OHWTP). The FRWSS began in response to chronic water shortages in Lithgow, Wallerawang, Portland, and Oberon, worsened by the 1940-43 drought and WWII demands, including supplying the now-closed Glen Davis shale oil works and later, the Wallerawang and Mount Piper Power Stations (MPPS). Expansion of the FRWSS included raising Oberon Dam, building new pipelines, and supplying additional communities in the Lithgow region.

Wallerawang Power Station closed in 2021; MPPS will close in 2040, shifting much of its water use to recycled mine water, altering FRWSS demand. The scheme involves Oberon Dam, Duckmaloi Weir and Water Treatment Plant, Rydal Dam, and pipelines serving MPPS, BMWSS, and Lithgow regional towns. The Oakey Park Water Treatment Plant (OPWTP) can also supply regional towns, while raw water is supplied to MPPS and BMWSS, supplemented by Duckmaloi Creek when available and sufficient quality.

The Upper Macquarie River system features many unregulated rivers and creeks critical for communities, industry, and ecosystems. Water variability due to rainfall affects access, especially in Campbells River, Fish River, and upper Macquarie. Major headwaters include Fish River and Campbells River, merging into the Macquarie, which flows to Burrendong Reservoir. Key tributaries and six major dams with a combined capacity of 101.2GL (Oberon, Chifley, Winburndale, Gosling Creek, Spring Creek, Suma Park) support water needs for Oberon, Bathurst and Orange.

The Wywandy system covers the regulated upper Cox's River and several unregulated streams vital for local supply, energy, and the environment, with major storage at Thompson Creek Reservoir (TCR), Lake Wallace, Lake Lyell, Rydal Dam, and Farmers Creek Dam No. 2 (FCD) with a combined capacity of 65.5GL. These storages serve power generation, town water, and recreation, with connections to both FRWSS and direct local sources.

In the Upper Blue Mountains, water for the BMWSS comes from the FRWSS, local runoff treated at Katoomba Cascade Water Treatment Plant (CWTP) and supplemented by OHWTP. The system supplies 15 zones across the

Blue Mountains, operated by Sydney Water with a focus on utilising CWTP supplies first and supplemented by OHWTP. The balance point between supply sources determines how far up the mountain pumped water is required.

3. MODEL CONCEPTUALISATION

The model conceptualisation and build has 3 key overarching objectives: (i) to build a robust and defensible model to support Regional Water Strategy water security investigations, (ii) to be sufficiently flexible to allow a range of different options to be explored and (iii) designed to integrate with downstream models. 7 design criteria were established to realise these objectives:

1. Represent key physical and management processes affecting water availability and sharing
2. Use a sufficiently long period of climate data to capture the climate variability (10,000 years)
3. Have detailed spatial resolution to allow system analysis and reporting at multiple spatial scales
4. Report at multiple time scales
5. Quantify reliability of water supply for critical water users (Energy, urban and rural)
6. Provide a pathway to update and improve accuracy (i.e. be updateable and extensible).
7. Be able to integrate with downstream models (Hawkesbury-Nepean and regulated Macquarie).

Taking into consideration these criteria, the functionality required and the data that is available, the model was built using the Source modelling platform, which is as the best tool for this purpose. Source provides the software architecture and functionality for the simulation of water availability and to support effective water management and operations. Undertaking the model build process also provides an opportunity to use new data and techniques to improve the calibration of model components, and to ensure the design criteria were satisfied.

3.1. Data

The types of data that are required to model the FRWS are spatial information (topography, climate surfaces, river and pipe networks, extraction and discharge locations, catchment delimitation, soils and irrigated areas), times series data (climate, flow, storage behaviour, extractions and discharges), physical characteristics (dams and pipe, pump and production constraints), and water management and operation rules.

Data was sourced from a range of different internal sources and external stakeholders. The external data providers included; WaterNSW, Energy Australia, Centennial Coal, Sydney Water, Lithgow City Council, Bathurst Regional Council and Orange City Council. Time series data includes climate (rainfall and evapotranspiration), streamflow, water extraction, water discharge, storage volume/level, water quality and water accounts.

3.2. Inflows

Sacramento rainfall–runoff models (Burnash et. al. 1973) were used to simulate the conversion of rainfall and evapotranspiration into streamflow. The FRWS has an extensive network of climate and river gauge stations, and 44 models (covering every river reach and inflow into the model) were built and calibrated to reproduce historical flows.

Inflows into Blue Mountains (BM) storages (Medlow, Greaves, and Cascade dams), Wywandy storages (Oberon, Rydal, FCD, TCR, Wallerawang and Lyell dams), Bathurst water supply (BWS) (Chifley and Winburndale dams), and Orange Water Supply (OWS) (Gosling, Spring Creek, Suma Park and holding pond) were used to simulate physical processes (e.g. the effect of evaporation and rainfall on the storage volume) and operating rules.

3.3. Water demands and returns

There are a range of different demand and return models developed for the FRWSS. There are five urban demand models, and three wastewater return models. Additionally, a model was specifically developed for MPPS demand, as well as water treatment supply models for four water treatment plants. There are seven mine return models for coal mines in the Coxs River.

Unregulated water use occurs throughout the system and is particularly concentrated upstream of Bathurst. This has been included in the model, as it is significant with respect to some of the options that the NSW Regional Water Strategy team wishes to explore.

Urban water demands are represented using a model developed by the Murray Darling Basin Authority for the Murray and Lower Darling system (Bethune, 2016). This model has been modified to represent local conditions. The urban model has been calibrated to demands for the BM, Lithgow region, Oberon, Bathurst and Orange.

An **urban wastewater return** model has been developed for this project to represent the return of wastewater from Lithgow, Bathurst and Orange. These returns are significant for their respective local areas. The model considers baseload returns that are related to water supply and local catchment runoff that enters sewer systems.

Historically, **power station demand** was the largest water user in the system. However, with aging infrastructure and the transition to green energy there are significant changes over time and into the future that need to be taken into consideration. In addition to this, significant amounts of treated mine water have become available. This has caused a significant decrease in the use of Coxs River water and the water from the FRWSS. This unused water is potentially available to secure supplies for other water users. The power station demand is difficult to model as it is driven by factors outside of a hydrologic model such as energy markets. As a strong correlation with climate was not found It was decided to replicate historical cycles by fitting a trigonometric function to demand.

Water treatment models are largely driven by urban demands and supplies. However, they are capped at maximum capacities and production losses are taken into consideration. There are water treatment models for Cascade, Lithgow, Springvale and Duckmaloi. The daily production of Springvale and Duckmaloi water treatment plants is extremely variable. Springvale influences the distribution of water within the Coxs River system and consequently a (beta distribution) stochastic model was built to represent this variability. Duckmaloi influences the distribution of OPWTP water within the Lithgow region. To capture this variability a stochastic model (Cauchy distribution) was developed.

I**rrigation** upstream of Bathurst and below Chifley Dam and Tarana on the Fish River is significant. This also includes irrigation in Queen Charlottes Creek. The irrigators in Macquarie and Campbell Rivers are supplied from Chifley when Bathurst is above level 3 restrictions. The demand is for several small irrigators which were lumped for four river reaches; Fish River below Tarana, Campbells River below Chifley Dam, Queen Charlottes Creek and Macquarie to Bathurst. Diversion and crop area data is not collected for these water users. Contemporary and detailed sources of information were used to parameterise each water user. Information gathered this way included licenced pump capacities; areas developed for irrigation and irrigated areas for the period 2005-2010 and 2015-2022. Spatial data were used to derive crop areas. Standard crop and farm efficiency parameters were adopted.

There are two types of **mine returns** that are considered, those from groundwater aquifers that are not impacted by climate, and those that are impacted by climate including runoff from mine sites. For mine returns from groundwater aquifers not affected by climate an average of recent return data was used. For other returns a rainfall runoff model was developed.

3.4. Water management and operations

There are two unregulated **Water Sharing Plans** (WSPs) that are relevant to the FRWS: the Macquarie Bogan Unregulated and Alluvial Water Sources 2012 (NSW Government 2012), and the Greater Metropolitan Region Unregulated River Water Sources 2023 (NSW Government 2023). The relevant licence categories in these plans are Major Utility, Local Water Utility, Domestic and Stock, Unregulated River and Aquifer. The overarching water management principle is:

- Average 3-year extraction must not exceed annual entitlement
- Unused water, up to the entitlement, may be carried over to the next water year.

Operational rules sit outside of WSPs and specify how stakeholder groups manage the flows and storage of water within systems. Some of these rules are well-defined in policy documents, and others are estimated to represent observed operational behaviour. In instances where operational rules were well-defined but observed data suggests that they were not followed, then the observed behaviours were adopted for modelling purposes.

The model incorporates operational rules for these entities:

- Cascade water supply: combining five storages, FRWSS access, and BM supply.
- Energy Australia: managing TCR, Lake Lyell, and nearby sources.
- Lithgow water supply: operating FCD and OPWTP to support FRWSS.
- FRWSS: overseeing Duckmaloi Weir, DWTP, water allocation, distribution, and Rydal dam management.
- Bathurst water supply: governing Chifley and Winburndale dam operations.
- Orange water supply: applying rules for four dams, local/adjacent sources, stormwater harvesting, Macquarie River access and supplying water to Cadia mine.

4. MODEL PERFORMANCE

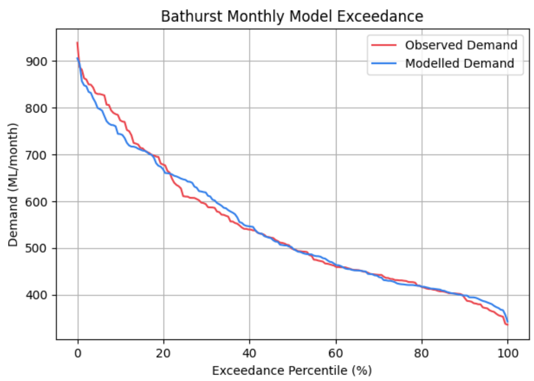
Results are presented on the calibration of the FRWS model and its overall model performance. For flow calibration, testing was focussed on whether the model was able to replicate important parts of the flow regime. Overall performance was measured by comparing modelled simulations against available recorded data such as flows, storage volumes, metered diversions and returns.

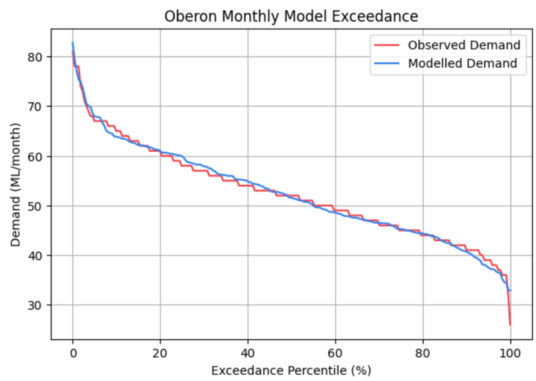
Mean annual and inter-annual variability of flows are well reproduced for headwater inflows and storage flows. The model performance in terms of runoff proportion, overall bias and Nash Sutcliffe Efficiency (NSE) (Nash et. al. 1970) are shown in Table 1. Note in nearly all cases the performance is very good. The higher runoff proportions are for urban areas. The poorest performing NSE is at Cascade Dams which is not gauged, and catchment inflow is small compared to other fluxes (FRWSS and Medlow and Greaves inflow and supply to CWTP). As this flows into a storage the overall bias is considered more important and this is zero.

Table 1 Model flow performance

System	River/Dam	Gauge	Runoff proportion of rainfall (%)	Overall bias (%)	NSE
Blue Mountains	Medlow + Greaves		20	0.0	0.40
	Cascade Dams		40	0.0	-0.81
Coxs	Megalong Creek at Narrow Neck	212013	26.9	-0.2	0.84
	Blackheath Creek at Mount Boyce	212014	19.8	0.0	0.91
	Wangcol Creek u/s Wallerawang	212055	15.9	0.0	0.51
	Rydal		19	0.0	0.85
	Wallace		12	0.0	0.73
	Lyell		15	0.0	0.92
	Farmers Ck No. 2		19	0.0	0.21
Macquarie	Turon River at Sofala	421026	9.4	0.0	0.78
	Slippery Creek at Dam Site	421034	21.6	0.0	0.69
	Duckmaloi River Below Dam Site	421036	21.5	0.0	0.79
	Crudine Creek upstream Turon River Junction	421041	8.6	0.0	0.74
	Blackmans Swamp Creek at STP	421051	25	-0.2	0.88
	Queen Charlottes Creek at Georges Plains	421053	8.4	0.0	0.40
	Evans Plains Creek near Bathurst	421075	9.9	0.0	0.62
	Emu Swamp Creek at Llewelyn	421103	8.8	0.0	0.75
	Summer Hill Creek at Icely Road	421185	9.2	0.0	0.89
	Ploughmans Swamp Creek	421186	28.5	0.0	0.73
	Oberon		13	0.0	0.62
	Chifley		8	0.1	0.34
	Winburndale		7	0.0	0.78

Simulation of urban water use and return are well reproduced over a range of climatic conditions which is essential for understanding water security. This is demonstrated in the monthly demand distribution curves for Bathurst, Oberon, Blue Mountains and Orange (Figure 2). Note Orange is the poorest performing demand.





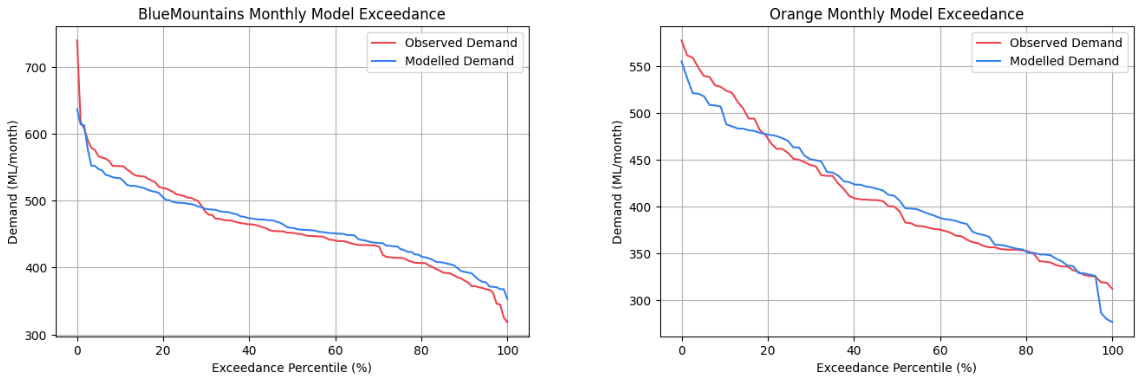


Figure 2 Bathurst, Oberon, Blue Mountains and Orange monthly urban demand performance.

Water restrictions are also well represented by the model. The water restrictions are tied to storage volumes, and the performance of storage volume gives the best indication of restriction performance. Total storages volume patterns over time matched reasonably well with observed data when development over time was considered (Figure 3).

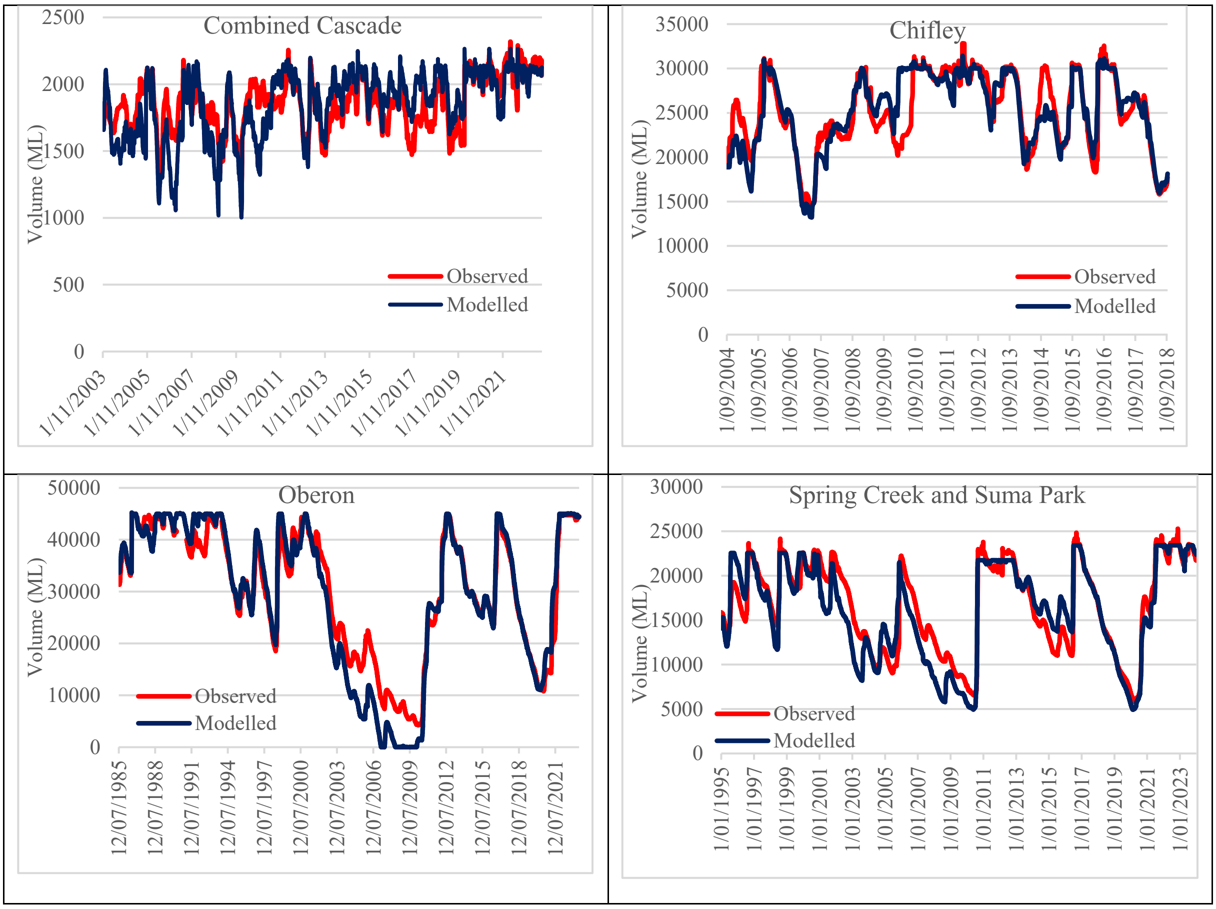


Figure 3 Combined Blue Mountain, Oberon, Chifley and Combined Suma Park and Spring Creek monthly storage performance.

The fully assembled model performance is assessed at the various calibration reaches in the model. However, to make a fair comparison the development of the system over time needs to be take into consideration. The results in Table 2 show the full model simulation with development over time taken into consideration. Overall, the performance of all sites across flow ranges is very good.

Table 2 Reach Performance

Downstream Gauge	Total Flow Bias (%)	Low Flow Bias (%)	Mid Flow Bias (%)	High Flow Bias (%)	Non-matching zero flow days (%)	NSE
421052	0	-10.1	3.9	-0.6	0	0.65
421191	12.9	-0.1	5.2	14.7	0.8	0.86
421025	-1.7	2.4	2.1	-2.6	0.6	0.85
421035	6.2	14.6	13.8	2.9	0.3	0.83
212054	-5.8	-26	6.7	-9.9	0	0.74
212042	-5.9	-5	-7.3	-5.3	0	0.69
212058	-0.4	-9.6	-7	2.9	0	0.84
421007	-6	39.7	-2	-7.4	3.9	0.75
421197	3.7	4.5	3.3	3.7	0.3	0.86
421072	-0.5	7.6	-0.3	-0.5	3.8	0.72
421192	4.5	1.7	4.2	4.6	0.8	0.89
212045	-0.6	-5.1	-1.2	-0.4	2.7	0.87
421080	-4	-16.3	3.7	-6.4	0	0.92
421080&421192	0	-5.4	4.4	-0.9	0.5	0.9
421025&421191	-0.4	3.5	2.6	-1.1	0.4	0.85

5. DISCUSSION AND CONCLUSION

This paper captures the considerable body of intellectual effort and modelling expertise that sits behind the construction of the FRWS model covering three different hydrological systems, which are connected for water supply. It reports on the modelling approach adopted, how the component parts were put together, and model performance. Significant effort went into understanding how sensitive model results were to uncertainties in climate and flow data, diversion data, model assumptions and simplifications, and model parameters. This effort was made to reduce these uncertainties where possible, either through access to better data, improved parameterisation, or re-configuration of the model.

The FRWS model represents the key physical and management processes that affect water availability and sharing within both the Coxs and Upper Macquarie river systems. This model is proposed as the best available to simulate flow and water use for water planning purposes. All design criteria have been met.

The updated FRWS model represents the FRWSS and Cox's River system much better than previous models and is capable of providing more detailed results at a finer spatial resolution. Significant effort has gone into detailed data collection and model conceptualisation. The model has been developed using multiple lines of evidence and best available industry data to ensure that water security is represented accurately.

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