ASSESSING WATER SECURITY UNDER LONG-TERM CLIMATE TO SUPPORT WATER MANAGEMENT: A CASE STUDY FROM BEGA-BROGO RIVER NSW

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Received: 4/8/2025; Accepted: 17/8/2025

Abstract: *In New South Wales (NSW), water resources are governed by water sharing plans (WSPs). WSPs are legally binding instruments under the Water Management Act 2000 that regulate how water is allocated between environmental needs and consumptive uses. As the cornerstone of NSW's broader water management framework, WSPs establish rules for sharing water across social, economic, agricultural, cultural, and environmental domains.*

Many waterways in NSW Coastal region have been classified as being under high or medium hydrological and environmental stress. While there is enough water in the region to meet agricultural demands on an annual basis, most extraction takes place in the drier summer period when temperatures are high and flows are low. This puts high stress on the flora and fauna that rely on the rivers. Longer droughts and reduced flows due to climate variability and change will amplify these impacts.

The NSW Government has invested in new climate datasets and improved modelling that provide a more sophisticated understanding of historic climate variability in the South Coast region, as well as likely future climate risks moving from making decisions that are based largely on single worst-case scenarios to a much more comprehensive understanding of natural variability and potential extreme events based on modelling using daily stochastic data of 13,000 years.

This paper presents a case study of the Bega-Brogo River System, detailing how water is allocated under the relevant WSPs. The paper further examines water security analysis under long-term climate variability. The impact of climate change and East Coast Lows on water availability and allocation within the catchment is also assessed to better understand the climate risks faced by water users and the environment.

Keywords: *Water sharing plan, Bega-Brogo river system modelling, water resources management, climate change, water security.*

1. Introduction

Balancing the competing needs of the environment and consumptive water users is critical to sustainable management of water resources. Several research studies have been conducted in pursuit of goals for the multiple-objective development and management of water resource systems [1]. A participatory approach was used to monitor changes in economic and social indicators [2]. A modelling framework was employed to undertake a socio-economic assessment of the impacts of water sharing rules [3]. Despite recent advances in environmental flow science, water governance, and management, there is still no universal systematic approach for determining water security and environmental flow requirements for all regions worldwide, including both the natural and social science fronts and, in particular, the interaction between social/political and environmental systems.

In NSW, water sharing plans (WSPs) [4] have been developed for rivers and groundwater systems following the introduction of the Water Management Act 2000 [5]. Under the Act, WSPs are legally binding instruments that regulate how water is allocated between environmental

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needs and consumptive uses. These plans protect the health of our rivers and groundwater while also providing water users with perpetual access licenses, equitable conditions, and increased opportunities to trade water through separation of land and water. Once a WSP is developed and enacted, it remains in effect for ten years.

NSW Governments have developed comprehensive regional water strategies for 12 regions across NSW, bringing together the latest climate evidence with a wide range of tools and solutions to plan for and manage each region's long-term water needs. The regional water strategies set out a long-term 'roadmap' of actions to deliver five objectives. Among the most important are improving water security for regional towns and communities and enhancing the health and integrity of environmental systems.

This paper presents a case study of water security in Bega-Brogo River system. It analyzes surface water availability, management and operational rules. The paper explores improvement of climate modelling and data for long-term water security.

2. Catchment description

The Bega River Catchment, shown in Figure 1, is a coastal catchment situated on the far south coast of NSW. The 1,940 km² catchment is dominated by an escarpment which rises steeply from rounded foothills, a floodplain and an estuary. The Bega River has two major arms that meet 20 km upstream from the mouth of the river: The Bemboka River arm and the Brogo River arm [4].

The Brogo River is regulated by Brogo Dam, while the Bemboka arm is mainly unregulated with flows supplemented by releases from Cochrane Dam.

The Bega River starts at the confluence of the Bemboka River and the smaller Tantawangalo Creek. The headwaters of the Bemboka River lie on the Kybeyan Range at elevations above 1,200 mAHD. The Bega-Bemboka trunk stream is around 80 km in length, which is roughly equivalent to the length of the Brogo River. Most creeks in both arms of the catchment are short, not extending more than 35 km from source to the trunk stream confluence. The only exception is Tantawangalo Creek in the Bega-Bemboka arm which extends past the escarpment into the uplands to more than 60-km in length.

The Brogo arm is a tributary of the Bega River. Brogo Dam is situated about two-thirds of the way up the Brogo River. The dam is operated to regulate flows past the confluence of the Bega and Brogo Rivers into the lower Bega River (downstream to the Jellat Jellat Creek confluence) for consumptive users and environmental targets. The 120 km² of catchment area below the Bega and Brogo Rivers confluence is relatively flat with many small tidal coastal streams; Jellat Jellat Creek being the largest stream.

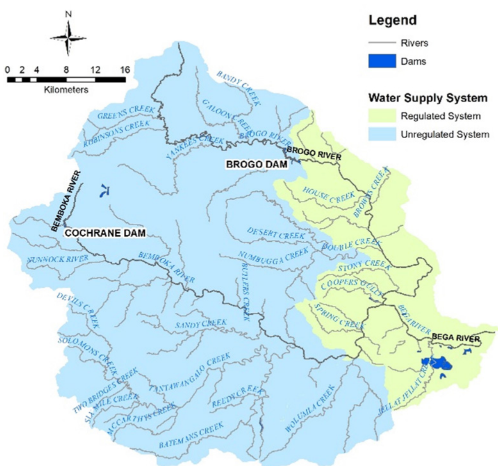

Figure 1. Bega-Brogo catchment

3. Water users

The primary consumptive water users within the catchment include water for town water utilities, irrigators, landholders and stock and domestic purposes [1, 6]. Entitlements for landholders and stock and domestic purposes have a priority for water access. Town water utilities and irrigators' usage depends on water availability.

Bega Valley Shire Council operates four town water supply systems across the study area, including the Brogo-Bermagui water supply system, the Bega-Tathra water supply system, the Tantawangalo-Kiah water supply system and the Bemboka water supply system

The irrigated agricultural sector is primarily composed of dairy farming, an industry heavily reliant on water for pasture irrigation to ensure a consistent feed supply. There are 96 dairy farms and approximately 25,000 dairy cows in the catchment. The amount of irrigation water required varies inversely with rainfall and can range from 1.4 to 10 ML/ha/year [4].

4. Water sharing plan rules

Most water extracted from rivers and groundwater in the catchment is licensed. The Brogo and Bemboka Rivers are dammed: Brogo Dam regulates the lower Brogo River for agricultural water supply, whereas Cochrane Dam on the Bemboka River feeds a small hydroelectric power station. The Brogo River downstream of Brogo Dam is declared a regulated water source, while all other streams are classified as unregulated water sources. WSPs divides the catchment area into three distinct types of water systems:

• The regulated Brogo and Bega Rivers Water Source

• The unregulated rivers, which include most rivers in the Bega Catchment

• The groundwater in the highly connected alluvial aquifer, including the Mid Bega River Sands

At the commencement of the Bega-Brogo WSP [8], there were approximately 54,784 ML as per WSP. This entitlement is divided between surface water (51,141 ML) and alluvial groundwater (2,643 ML). Surface water entitlements consist of 26,836 ML from the unregulated system, 9,100 ML from harvesting rights, and 328 entitlements for Riparian release. The regulated system is licensed for Town Water Supply, High Security, and General Security, totalling 14,877 ML (see Table 1).

Table 1. License entitlement and estimated rights

Type of licence or right	**Volume taken (entitlement or estimate), ML/year**
Unregulated	26,836
General security (regulated)	13,954
High security (regulated)	223
Town water supply (regulated)	700
Groundwater	3,643
Riparian (estimated)	328
Harvestable rights	9,100
Total	**54,784**

4.1. WSP rules in unregulated system

The unregulated Bega-Brogo system comprises the Bega-Bemboka arm, with flows supplemented by releases from Cochrane Dam. Water entitlements are categorised into four types: Irrigation (unregulated river), domestic and stock, local water utility, and basic landholder right. Water sharing is managed daily through extraction rules, environmental flow targets and Cochrane Dam environmental releases.

Access rules for take of surface water

The amount of surface water that can be extracted is based on water availability in the rivers and is limited by Cease-to-Pump (CtP) rules and some exceptions. CtP rules ensure that minimum environmental flow requirements at reference locations are met. Water extraction is prohibited when flows at reference gauges fall below the very low flow criteria (see Table 2 for examples of flow classes). Unused water can be traded or carried over to subsequent years.

To improve the health of the riverine ecosystem by reducing reliance on low flows, the plan allows conversions from unregulated access licences (which provide access to low flows) to high flow licences. The conversion rate is 3 to 1.

Table 2. Example of flow classes

Water source/Management zone	Flow class	Flow class threshold	Flow reference point
Bermagui River	Very Low Flow Class	No more than 1.4ML/day	Narira Creek at Cobargo gauge (219016)
Candelo Creek	Very Low Flow Class	No more than 3ML/day	Candelo Creek at Greenmount Road gauge (219034)
Dry River	Very Low Flow Class	No more than 1.4ML/day	Murrah River at Quaama gauge (219018)
	C Class	More than 74ML/day	
Lower Bega/Lower Brogo Rivers Tributaries	Very Low Flow Class	No more than 2ML/day	Double Creek near Brogo gauge (219017)

Cochrane Dam release rules:

The primary function of Cochrane Dam is hydroelectricity generation. However, the operator of Cochrane Dam must manage both the dam primary functions while maintaining the Cochrane Dam Drought Reserve account in accordance with the following:

1. Between 1 October and 31 March in each water year, the lesser of the following must be released on a daily basis of (a) 3.5 ML/day and (b) the inflow to Cochrane Dam on that day, as measured at the Cochrane Dam storage gauge (219033).

2. Maintain the Cochrane Dam Drought Reserve account, with a reserve volume of 500 ML on 1 July or 800 ML on 1 October, conditional on the Combined Drought Indicator indicating a Drought or Intense Drought Phase.

4.2. WSP rules in the regulated system

The Brogo River is regulated by Brogo Dam, which has a capacity of 8,980 ML and was constructed in 1976. The dam is operated to regulate flows downstream of the confluence of the Bega and Brogo Rivers into the lower Bega River. Water cannot be extracted under an access licence in this water source unless the licence holder has submitted a water order in the approved form and the order has been authorised.

The priority order between different categories of licences was set as follows:

1. Local water utility access licences (Town Water Supply - TWS), major utility access licences, and domestic and stock (SD) access licences have the highest priority.

2. Regulated river licences (High Security - HS) come next.

3. All other access licences, such as General Security (GS), follow.

4. Supplementary water access licences have the lowest priority, below all other licences.

Licences with higher priority are afforded a greater level of reliability. Therefore, allocations are established according to the rules used for the Available Water Determination (AWD) process. The total resource available is determined by considering the volume of water stored in Brogo Dam, expected minimum inflows during the water year, and losses (see Table 3). Allocation for each licence type is based on the water availability in Brogo Dam and is shown in the table below.

Table 3. Allocation table

License type	Water Availability (ML)	Carryover (%)	Stock and domestics (%)	Town Water Supply (%)	High Security (%)	General Security (%)
Stock and domestics	54	100	100			
Stock and domestics and Town Water Supply	754	100	100	100		
Stock and domestics, Town Water Supply and High Security	1,165	100	100	100	100	
Stock and domestics, Town Water Supply, High Security and General Security	14,943	100	100	100	100	100

Brogo Dam release rules

Brogo Dam must follow the following rules for the storage and release of water:

1) Sufficient volume of water must be held in Brogo Dam to satisfy the following rights and available water determinations in the water source, based on a repeat of the worst period of low inflows to the water source using historical flow data held by the Department when this Plan commenced:

• Native title rights

• Domestic and stock rights

• Available water determinations of 100% of the access licence share component for:

o Domestic and stock access licenses, and

o Local water utility access licenses

• Available water determinations of 0.8 ML/unit share component for regulated river (high security) access licenses

2) When the volume of water in Brogo Dam is at or above 20% of full supply level, the daily inflow to the dam must be released, up to a maximum of 15 ML/day. The release must not be used to meet a water order or a basic landholder rights requirement in river reach 1A.

5. Water resources management model

The WSP model was developed using the eWater SOURCE [7] modelling platform and is conceptualized in Figure 2. The system comprises headwater catchments, residual river reaches, irrigation and town water supply (TWS) nodes, and two major dams. The headwater catchments were represented solely by a rainfall-runoff models, while the residual catchments incorporate five primary components: A rainfall-runoff model, river routing, transmission losses, a crop demand model, and a TWS demand model.

Runoff generation in both headwater and residual catchments were simulated using the Sacramento rainfall-runoff model. River reach routing was modelled using the Muskingum method, and transmission losses were represented as a fixed proportion of river flow. Irrigator water demand was estimated using the daily soil water balance method developed for FAO [8]. The TWS demand model was developed by the Murray-Darling Basin Authority (MDBA) which was conceptualized as an evaporation deficit model [9].

A Resource Assessment System has been established to support the processes of Available Water Determination (AWD), resource allocation, and water use accounting. For each water user, an account entity is created to systematically limit and monitor water usage. Account balances are maintained by calculating the net volume of water available, defined as the cumulative sum of credits minus the cumulative sum of debits. Account balances are assessed on 1 July each year for the unregulated system and throughout the year for the regulated system. Carryover provisions are applied. In regulated sections of the river system, water is actively managed by an allocation operator, who issues regular announcements detailing the volumes available for extraction.

Model calibration was conducted using observed streamflow data from multiple gauging stations distributed across the catchment. Additional calibration inputs included recorded diversions for TWS, allocation announcements for High Security (HS), and General Security (GS) account holders.

6. Model development

The model was calibrated for the instrumental period and was also used for the following climate periods: Stochastic and climate change using The New South Wales and Australian Regional Climate Modelling version 01 (NARCliM 1.0) and -1_ECL

• Instrumental scenario: Historical climate data was used to simulate baseline conditions, covering a 130-year period from 1889 to 2019. A key limitation of this scenario is that the simulation period is not long enough to fully capture long-term climate variability. To address this, stochastic climate data were generated.

• Stochastic scenario: A synthetic dataset representing 13,000 years of climate was generated based on statistical properties derived from historical records. This extended dataset allows the analysis to capture a wider range of climate variability, including extreme drought events with a probability of occurrence as low as 0.01%

• Climate Change scenario: The impact of climate change on water security was assessed using data from the NSW and ACT Regional Climate Modelling project (NARCliM). NARCliM provides high-quality regional climate projections for South-Eastern Australia, developed by bringing together globally recognised scientific and multidisciplinary expertise. The data and products are co-designed with stakeholders to ensure they are fit-for-purpose for a variety of user needs.

• East Coast Lows (-1_ECLs) scenario: East Coast Lows are intense low-pressure systems that develop along the eastern coast of Australia, typically between Fraser Island and East Gippsland. These systems can intensify rapidly and are among the most hazardous weather phenomena affecting the region. However, they also represent a valuable water source of rainfall for coastal water supply catchments. This study explores the impact of removing one ECL event each year on water resources.

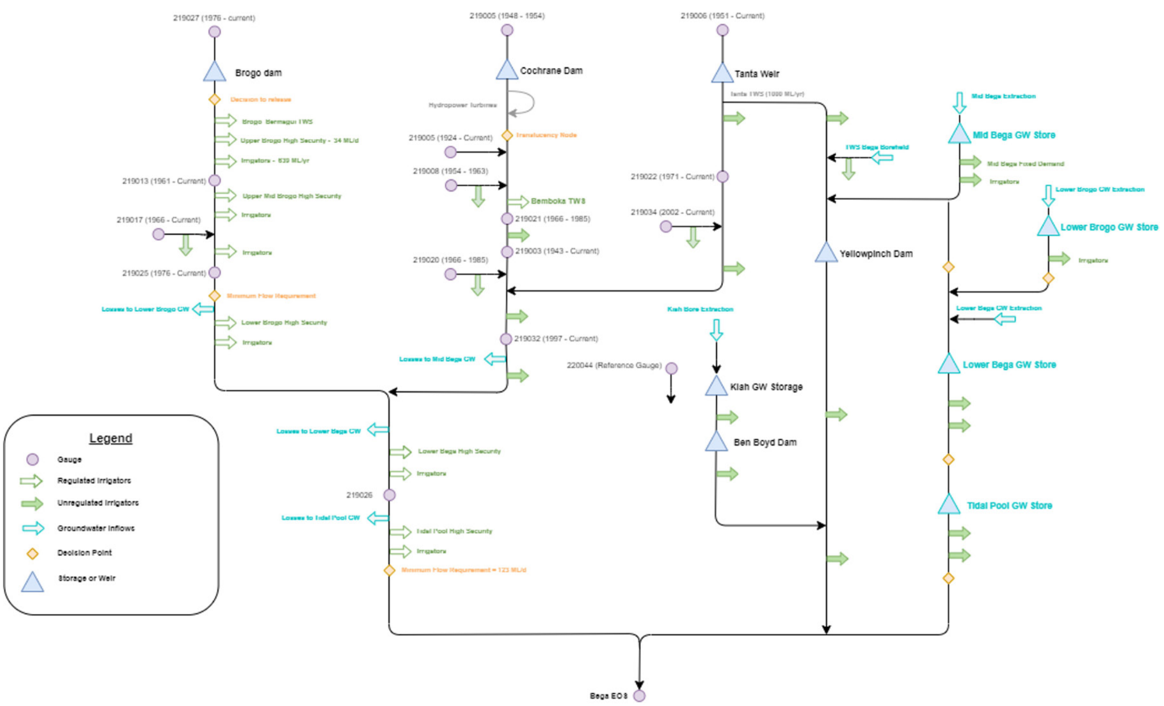

Figure 2. Bega-Brogo model conceptual model

7. Results and discussion

The model facilitates a comparative assessment of flow regimes and water resource availability under varying climate scenarios. Four key performance indicators were used to evaluate system response: Inflows to major dams, storage volumes, impacts to AWDs and town water supply shortfalls. Together, these metrics provide critical insights into how projected climate conditions may influence the reliability and resilience of the regional water supply systems and other water users.

Inflows to Brogo Dams are presented in Figure 3, showing monthly inflows and 95% confidence intervals for the stochastic, NARCliM, and -1_ECL scenarios. The median inflows produced by the stochastic model align closely with the instrumental (historical) record, confirming the validity of the stochastic approach in replicating past hydrological conditions. Under the NARCliM scenario, inflows are noticeably reduced during the winter months (May to July). A modest increase in early spring (September to October) can be identified. In contrast, the -1_ECL scenario exhibits a substantial decline in inflows across all months, reflecting the potential severity of prolonged dry climate extremes.

Reductions in inflow volumes have a direct impact on dam storage performance. Exceedance curves of daily effective storage volumes illustrate the resulting changes in system behaviour. At Brogo Dam (Figure 4), storage levels remain relatively stable 50% of the time under all scenarios. However, during dry periods, the effects of climate change and the -1_ECL scenario become more pronounced. The frequency of Brogo Dam's storage falling below 6,000 ML increases from 5.4% under the instrumental climate scenario to 7.0% under NARCliM and 9.1% under -1_ECL (Table 4) scenarios. Additionally, both the number and duration of events where storage drops to 30% of effective storage volume rise significantly under future scenarios, highlighting increasing vulnerability under climate stress (Figure 5).

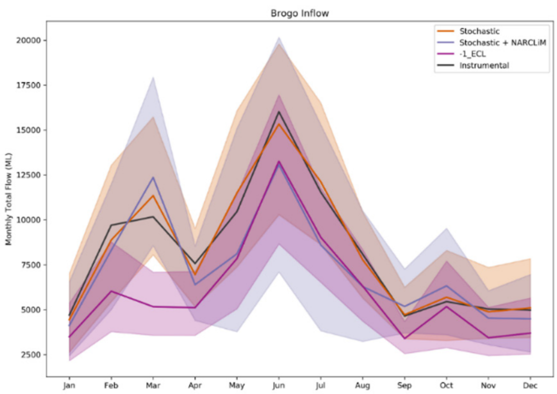

Figure 3. Monthly inflows to Brogo Dam under the instrumental, stochastic, NARCLiM and -1_ECL scenario

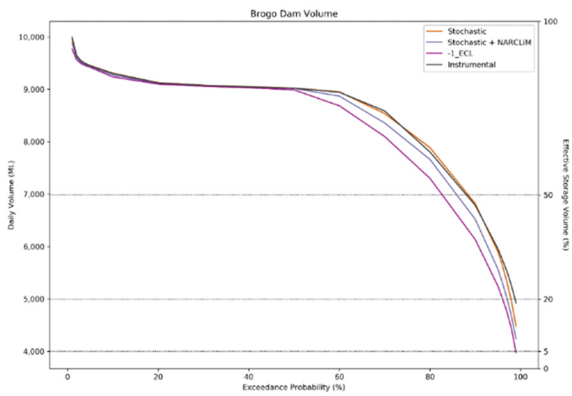

Figure 4. Brogo Dam under the instrumental, stochastic, NARCliM and -1_ECL scenario

Cochrane Dam exhibits a more substantial decline in storage across the full exceedance range (Figure 6). The proportion of time the dam's volume falls below 405 ML increases from 18% under the stochastic scenario to 21.6% in NARCliM and 26.7% in -1_ECL (Table 4). The frequency and duration of events where storage levels fall to 270 ML remain minor change between the NARCliM and -1_ECL scenarios (Figure 7).

Allocations have been plotted for the regulated system. Since allocations depend on Brogo Dam's volume, a decrease in Brogo volume leads to reduced allocations and water availability. General Security (GS) water users, being the lowest priority, were the most impacted. Figure 8 shows GS allocations across all scenarios. As evident from the graphs, dry periods reduce water availability, which negatively affect the system's water security.

The frequency and duration of TWS shortfalls under instrumental, stochastic climate data, and climate change scenarios are shown in Figure 9 and Figure 10 at Tathra and Bermagui system respectively for example.

Bega-Tathra and Tanta LWUs are located in unregulated systems and have been significantly impacted under both climate change and -1_ ECL scenarios. Shortfalls volumes range from 4.8% to 2.5% at Bega-Tathra and from 4.7% to 4.4% at Tanta. In contrast, the Brogo-Bermagui TWS, regulated by Brogo Dam, experiences minimal shortfalls-ranging from 0.7% under NARCliM to 0.9% under -1_ECL scenarios-due to its regulated nature. These results are summarised in Table 5. Bemboka TWS is supplied by groundwater, a stable source. The impacts of climate change and ECL have not been evaluated for this system; therefore, no shortfalls have been seen.

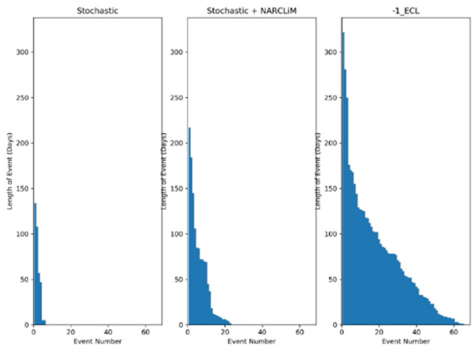

Figure 5. Brogo Dam drought events

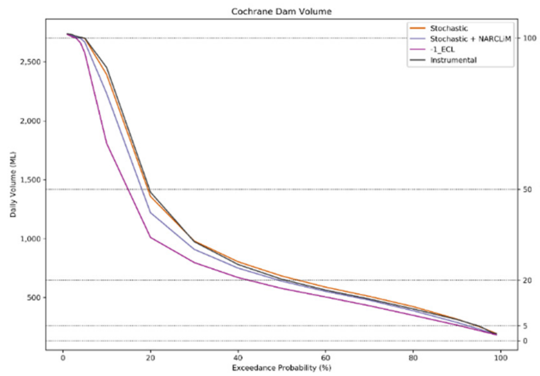

Figure 6. Cochrane Dam under the instrumental, stochastic, NARCliM and -1_ECL scenario

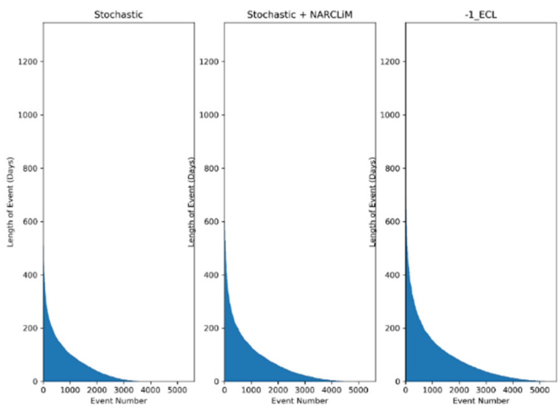

Figure 7. Cochrane Dam drought events

Table 4. Brogo and Cochrane dam volume at different quantiles

Volume (ML)	Percentage of days (%) lower than the volume				Volume (ML)	Percentage of days (%) lower than the volume			
	Instrumental	Stochastic	NARCliM	1_ECL		Instrumental	Stochastic	NARCliM	1_ECL
Brogo Dam					Cochrane Dam				
12000	99.9	99.9	99.9	100.0	2,700	94.8	95.1	96.1	96.9
10000	99.0	99.1	99.2	99.4	1,350	79.4	79.9	82.1	86.6
8000	22.0	21.4	24.2	28.5	675	51.7	49.2	53.4	60.4
6000	5.2	5.4	7.0	9.1	405	20.0	18.0	21.6	26.7
4000	0.1	0.4	0.6	1.0	270	5.8	6.1	8.1	10.3
2700	0.0	0.0	0.0	0.1	135	0.0	0.0	0.0	0.0

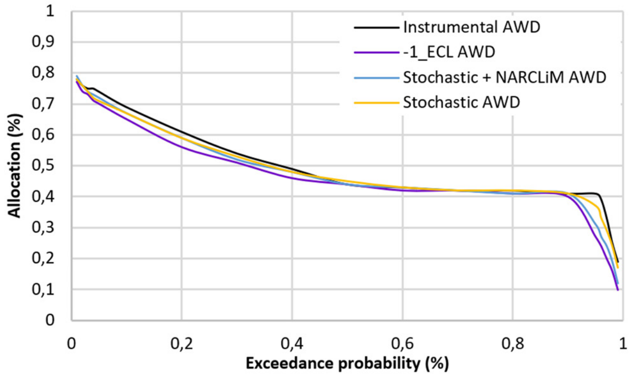

Figure 8. General Security allocation

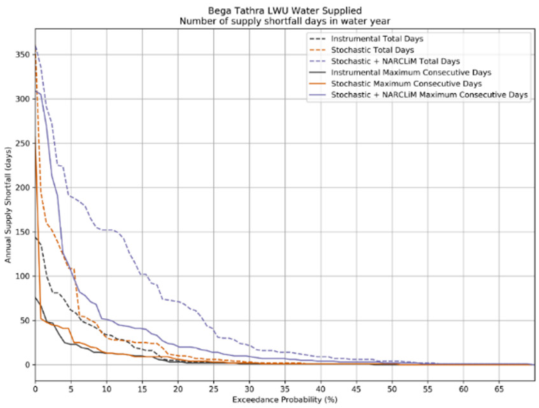

Figure 9. Shortfall at Tathra system

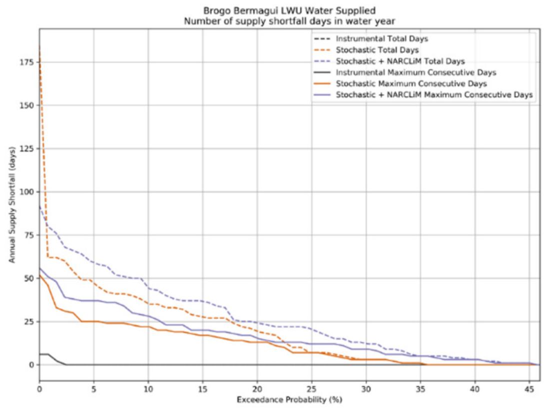

Figure 10. Shortfall at Bermagui system

Table 5. Annual Shortfall Volume (percentage)

Town	Instrumental	Stochastic	NARCliM	-1_ECL
Bega Tathra LWU Supplied Shortfall	0.7	1.5	4.8	2.5
Bemboka LWU Supplied Shortfall	0.0	0.0	0.0	0.0
Brogo Bermagui LWU Supplied Shortfall	0.0	0.6	0.7	0.9
Tanta LWU Supplied Shortfall	0.6	1.2	4.7	4.4

8. Conclusions

This paper summarised the key components of the WSP of the Bega-Brogo system and how those rules have been incorporated into the model for modelling scenarios under long-term climate. The impacts of climate change and extreme climatic events (ECLs) have been simulated to assess water security at the four Town Water Supplies Systems.

The model results indicate that shortfalls occur during dry periods at three out of four TWS locations. Bega Valley Shire Council considers this an unacceptable risk management strategy and recommends improvements to the current system.

Acknowledgments: *This research was supported by the Regional Water Strategies program, funded by the NSW Government.*

Conflict of Interest: *The authors declare no conflicts of interest relevant to this study.*

Author Contributions: *Conceptualisation, J. Simpson, D. Dutta, P. Cu; Software, J. Simpson; Investigation, P. Cu, J. Simpson; Writing-Original Draft, P. Cu; Review and Editing, J. Simpson, D. Dutta.*

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