Ecohydrological option analysis for New South Wales' coastal regional water strategies: Bega River

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Abstract: The NSW Department of Planning and Environment (NSW DPE) has been developing regional water strategies (RWS) to enhance the management of water for improved water security. The strategies develop a long list of water management options through community consultation that aim to determine future water demand, and to identify challenges, choices, and solutions in meeting those demands. The likely hydrological, economic and ecological effects of those options more focused on providing water security during drought is then assessed. This modelling approach is also described by Dutta et al. (2023) for the Murray and Murrumbidgee Rivers. RWS modelling includes the development of base case models, which can then be compared to options models, to inform hydrological, cost-benefit and ecological analysis. All these options are assessed using different long-term hydrological time series: (1) current river operational models (Instrumental), (2) modelled past climate data (Stochastic) and (3) drought impacts under more extreme climate change scenarios (NSW and ACT Regional Climate Modelling, or NARCliM). The South Coast RWS work includes an additional east coast low model (ECL).

This paper is focused on the ecological and coastal components of RWS ecohydrology work (NSW DPE 2022 a-c), with the Bega River as an example. The Bega River is within the South Coast region, which is a highly significant and diverse ecological area. The reach of the Bega River between Bega township and the Bega River estuary supports a small floodplain that includes paleochannels and wetlands, and areas that have been modified for irrigation. The lower Bega River estuary is in a relatively natural state, with extensive forest cover on the slopes of the immediate catchment, and areas of wetland (including lagoons) and saltmarsh.

The ecohydrology impacts of three water management options as compared to current conditions (base case) were assessed at representative locations along the river under Stochastic, NARCliM and ECL conditions. These were: Option 1. Increased on-farm water storage with low-flow bypasses and active water markets that increase opportunities for irrigators to access water that is not being used through trade. Option 2. As per Option 1, but also including a pumped hydro scheme and Option 3, which is as per Option 2, but with a larger on-farm water storage. Although the ecohydrology metrics used were generic measures, rather than catchment-specific measures the predicted ecohydrology impacts predicted were consistent with what is known of the Bega River and flow effects usually associated with increased flow regulation and abstraction. These methods were fit-for-purpose to aid an option prioritisation process but could need refining for different water management questions.

Keywords: *Ecohydrology, strategy, climate change, variability*

1. INTRODUCTION

The Bega River is within the South Coast region (Figure 1. Map of the Figure 1), which is a highly significant and diverse ecological area with connected river, estuarine and marine ecosystems, state- and nationally significant wetlands, and large areas of mangrove, saltmarsh and seagrasses that all require a range of flows (DECC 2010a, DECCW 2010b, EES 2022). These ecosystems require flow maintenance during low flow periods, larger flows for native fish species and plant recruitment and the dispersal of seeds, eggs, young fish, reproductive fish and nutrients, and connection from tributaries through to the estuaries, and then the sea (Morris *et al.* 2001, NSW DPI 2006). The Bega, Clyde and Shoalhaven rivers support the vulnerable-listed Australian grayling that spend their first six months at sea, and the adult spawning that starts this cycle is thought to be initiated by an increase in river flow from seasonal rains. Adult Cox's gudgeon require fast-flowing upland streams. Australian bass range from tributaries to the estuaries, and possibly need river freshes to recruit. Empire gudgeon prefer lowland habitat with aquatic plants; and spawn during spring to summer, and then their larvae drift down to estuaries.

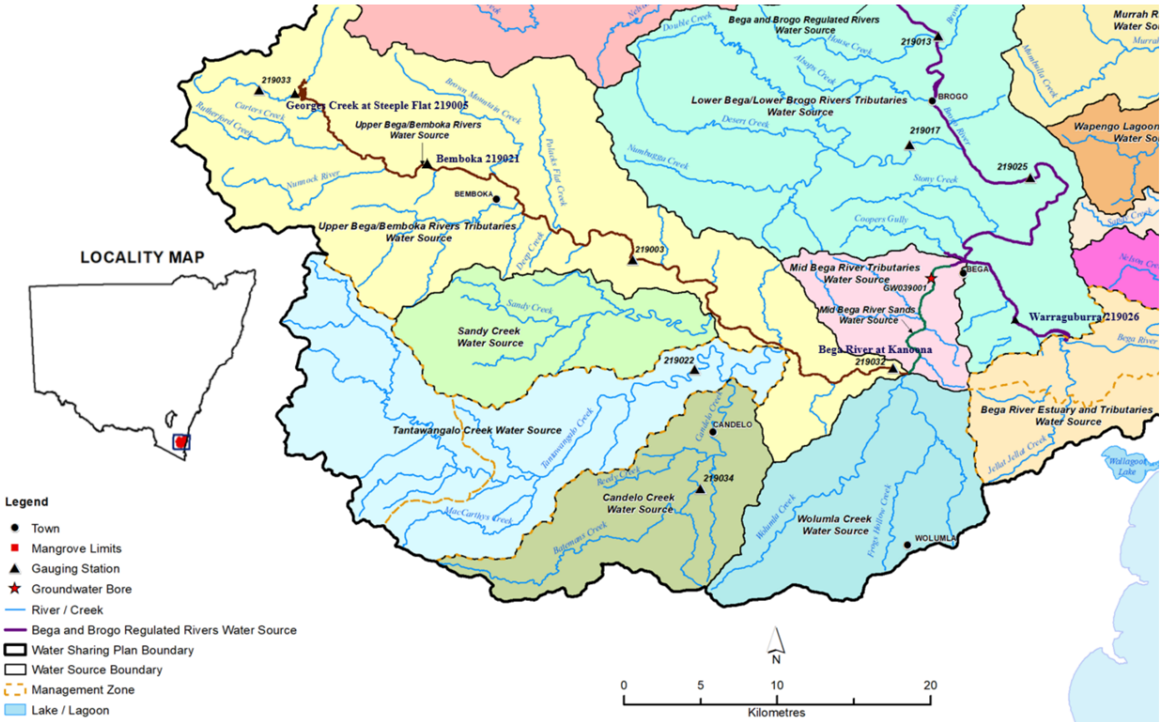

Figure 1. Map of the study area

As part of South Coast Regional Water Strategy work, three water management options that could affect the ecology of the Bega River were submitted for ecohydrological analysis as part of the modelling approach described above (NSW DPE., 2022a). These were:

- Option 1. Increased on-farm water storage (5.3 GL storage at Steeple Flat) with low-flow bypasses and active water markets that increase opportunities for irrigators to access water not being used through trade.
- Option 2. As above, but also including a pumped hydro scheme (Brown Mountain Water Project). The Brown Mountain Water Project is a 5.3 GL storage at Steeple Flat.
- Option 3. As above, but with a larger, 20 GL storage at Steeple Flat.

2. METHODS

2.1. Ecohydrological analysis

Ecological flow metric outputs as illustrated in Figure 2 and specified in Table 1 were coded in Python, NumPy, pandas and scipy libraries (Rossum 1995). Such flow classes are required by river and floodplain ecosystems over the long term (Bunn & Arthington 2002), and as such flow metrics represent the flow-river health conceptual model (as per Argent et al. 2016). Metrics from long term watering plans (e.g., for the Gwydir, NSW DPE 2022e) are not currently available for the coastal catchments. So, we used metrics that are typically applied when catchment-specific flow requirements are largely unknown, as used in other NSW and Australian government work (e.g., Alluvium 2010, DPI 2018).

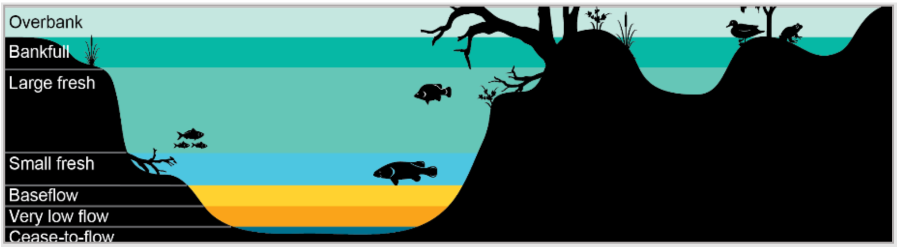

Figure 2. Conceptual model of the different flow regimes

Table 1. Ecological flow metrics used to compare the base case against each option

Ecological flow metric	Code	Beneficial % change
Number of years with greater or equal to 1 no-flow spell	NoFlowYears	Decrease
Average duration of no-flow spells (number of days)	NoFlowDays	Decrease
Number of no-flow events	NoFlowEvents	Decrease
Very low flow rate (ML/d), or the 95%ile.	VLF Q	Increase
Low-flow rate (ML/d), or 90%ile	LF Q	Increase
Median number of days below the low-flow threshold	Days < LF	Decrease
Base-flow rate (ML/d), or 80% percentile (80%ile).	BF Q	Increase
Mean annual discharge (ML/y)	Annual Q	Increase
Fresh flow rate (ML/d), or 20%ile	Fresh Q	Increase
Average number of freshes per year	Fresh Freq	Increase
Average duration of freshes (number of days)	Fresh Dur	Increase
'Overbank' - High flows—2.5-year Average Recurrence Interval flow rate (ARI, ML/d)	2.5 ARI	Increase
'Overbank' - High flows—5-year Average Recurrence Interval flow rate (ML/d)	5 ARI	Increase
'Overbank' - Very high flows—10-year Average Recurrence Interval flow rate (ML/d)	10 ARI	Increase

Each options' metric results were compared against the base case which, in this case, was the do-nothing, or current water sharing plan model (NSW Government 2011). These comparisons were conducted in R (version 4.1.1, R Core Team 2021) for three climatic scenarios. The climate scenarios were derived from 1. 13,000 years of long-term natural variability derived from paleoclimate data (stochastic), 2. climate change conditions and 3. modelled east coast low (ECL) conditions (NSW DPE 2000). The climate change models (NARCliM 1.0, Evans et al 2014, NSW DPE 2020, Dutta et al. 2023) provided for these analyses were derived from CSIRO Mk3 GCM (one of the four GCMs in NARCliM 1.0) that were re-modelled using three different Regional Climate Models (RCMs). The difference between 1990-2009 (baseline) and 2060-2079 were used to assess climate change impact. The ECL model, derived from Bureau of Meteorology and NARCliM data used the scenario from Kiem (2019) that removes one east coast low per year as this is closest to the lowest rainfall NARCliM 1.0 scenario.

Model runs measured impacts at 15 different gauges in the Bega River catchment to represent the breadth of river habitat types, with sites on Rutherford, Georges, Tantawangalo, Double, Sandy and Candelo Creeks, and on the Nunnock, Bemboka, Brogo and Bega Rivers (Figure 1). Results were classed using an 11-category effect ranking (Table 2). All results are from averaged effects over time for each site (NSW DPE 2022a). Mann-

Whitney U-tests (Bauer 1972) between the base case and the option were used to test the statistical significance (P < 0.01) of results considered to be of greater ecological significance.

Table 2. Effect categories used in the ecohydrology assessment

Code	Effect category	Estimated percentage change in hydrology/ecology
!!I	Extreme impact	More than 30% change in a negative direction (i.e. < –30%)
!I	Major impact	More than 20% change in a negative direction (i.e. < –20%)
"I	Moderate impact	More than 10% change in a negative direction (i.e. < –10%)
'I	Minor impact	More than 3% change in negative direction (i.e. < –3%)
N	Little impact	Less than 3% change in a negative direction (i.e. < 0%)
N	No change	0%, rounded to the nearest whole percentage point
N	Little gain	Less than 3% change in a positive direction (> 0% and < +3%)
'G	Minor gain	More than 3% change in a positive direction (i.e. > +3%)
"G	Moderate gain	More than 10% change in a positive direction (i.e. > +10%)
!G	Major gain	More than 20% change in a positive direction (i.e. > +20%)
!!G	Extreme gain	More than 30% change in a positive direction (i.e. > +30%)
Code	Additional effect category for result tables	
N	Median of no to little change	Range shows some potential impact without potential gain
N	Median of no to little change	Range shows some potential impact and potential gain
N	Median of no to little change	Range shows some potential gain without potential impact

3. RESULTS AND DISCUSSION

This section summarises the option effects under Stochastic, NARCliM and ECL modelling. Effects tested and significantly different under the Mann-Whitney U-test are notated with a ** in the text. The direction and extent of effect is indicated in the result tables using the codes in Table 2. All results are reported consistently in this order for the climate scenarios Stochastic, ECL and NARCliM, and is notated as S, E and N.

Option 1: Increase on-farm water storage and activate water markets

The number of days at or below low flows was impacted under Option 1 (Table 3), and this can reduce the amount of available river habitat for aquatic plants and animals, reduce long-term sediment control and can increase the likelihood of poor water quality. It can also inhibit fish movement and increase predation because of fewer refuge habitats. The median number of days below the low flow threshold (22, 18 and 18 ML/day under S, E and N base case) per year doubled for Bega River at Warraguburra (from 2-4, 7-13 & 6-12 days)**. The Warraguburra gauge (219026) is a proxy for the end-of-system as it is downstream of the Brogo / Bega rivers confluence, about one-third of the way along the Bega River from the Bega township to where the river discharges into the sea. It is also in the floodplain area where there is more obvious floodplain agricultural development, which explains the impacts on low flows. As these increases are not long periods of low flow, the greatest risk would be that the river is more prone to the risk of more frequent, short no-flow periods and at more risk under local extraction.

Table 3. Predicted ecological effects of options 1 and 2

	Option 1						Option 2					
	Stochastic		NARCliM		ECL		Stochastic		NARCliM		ECL	
	Av.	Range	Av.	Range	Av.	Range	Av.	Range	Av.	Range	Av.	Range
NoFlowYears	N	N	N	N	N	N	N	'G-'I	N	'G-N	N	'G-N
NoFlowDays	N	"G-N	N	"G-N	N	"G-N	'G	"G-N	N	"G-N	N	"G-N
NoFlowEvents	N	!G-"I	N	"G-"I	N	"G-"I	'G	!!G-"I	'G	!!G-"I	'G	!!G-"I
VLF Q	N	!I-'G	N	!I-"G	N	!I-"G	N	"I-"G	'G	!I-!G	'G	!I-!G
LF Q	N	'I-N	N	"I-N	N	"I-N	'G	N-!G	'G	N-!G	'G	N-!G

	Option 1						Option 2					
	Stochastic		NARCliM		ECL		Stochastic		NARCliM		ECL	
	Av.	Range	Av.	Range	Av.	Range	Av.	Range	Av.	Range	Av.	Range
Days < LF	'I	N-!!I	'I	N-!!I	'I	N-!!I	!!I	N-!!I	"I	N-!!I	"I	N-!!I
BF Q	N	N	N	N	N	N	'I	!I-'G	'I	!I-'G	'I	!I-'G
Annual Q	N	N	N	N	N	N	N	N-"G	'G	N-!!G	'G	N-!!G
Fresh Q	N	N	N	N	N	N	N	'I-N	N	'I-N	N	'I-N
Fresh Freq	N	N	N	N	N	N	N	N	N	N	N	N
Fresh Dur	N	N	N	N	N	N	'I	!I-N	'I	!I-N	'I	!I-N
2.5 ARI	N	N	N	N	N	N	'I	!I-N	'I	!I-N	'I	!I-N
5 ARI	N	N	N	N	N	N	N	N-!G	N	N-"G	N	N-"G
10 ARI	N	N	N	N	N	N	N	N-'G	N	N-"G	N	N-"G

Option 2. Increase on-farm, centralised water storage and activate water markets

Option 2 showed similar but more extreme impacts than option 1. Again, the impact was on the number of days at or below low (90%ile) flows. The number of low flow days generally doubled across the three climate scenarios. At Warraguburra the annual median of days at low flows increased from 2-5, 7-15, and 6-13 days under S, E and N. This option also increased low flows at Bemboka River at Bemboka, which is the closest gauge to, and downstream of Cochrane Dam. So, this river section is more subject to irrigation effects, such as more regular maintenance of low flows at the expense of larger flows like freshes. With low flows increasing from 1-7, 1-5 and 1-2 days, with proportionally large increases**. The duration and frequency of freshes was also reduced, especially at Bemboka River at Bemboka (5 km west of Bemboka, 219021)), Georges Creek at Steeple Flat (immediately downstream of Cochrane Dam, next to site 033 in Figure 1) and Bega River at Kanoona (site 032) which typically receive 73, 53 and 57 freshes/year under the base case S, E and N, but receive 24-25, 3-4 and 6-9% fewer freshes per year**. For these streams, freshes would last about 9-11, 13-16 and 17-21 days under the base case but would have 25-29, 3-4 and 8-9% shorter fresh durations respectively under option 2. These freshes are likely to be important for key ecological processes such as transferring river nutrients and stimulating movement and growth in native fish species.

Option 3: Increase on-farm, even more centralised water storage, and activate water markets

Several changes indicate a more modified flow regime under Option 3. The streams have 13-15% less frequent cease-to-flow events, but these are on average 63% longer events under ECL and NARCliM, and 76% longer events under Stochastic scenarios. The reduction in cease-to-flow event frequency is most pronounced at Bemboka at Moran's Crossing with about 100% reduction. Bega River at Kanoona and Warraguburra similarly shows 85-90% and 68-71% reductions. The duration and frequency of freshes under option 3 is even more reduced than observed under option 2, again especially at Bemboka River at Bemboka, Georges Creek at Steeple Flat (Cochrane Dam) and Bega River at Kanoona. These streams receive about 32-37, 8-9 and 8-9% fewer freshes per year across the three climate scenarios**. For these streams, freshes would last about 9-11, 13-16 and 17-21 days under the base case, but would have 34-40, 7-8 and 9-10% shorter fresh durations across all three climate scenarios under option 3. There is a general 12-18% decrease in the number of low flow days in a year. For Bega River at Warraguburra this was a 100% decrease in low flow day frequency across the three climate scenarios (from baselines of 2, 7 and 6 days/per 130 years under S, E and N) **. These results all suggest that while the stream flows are more protected from cease-to-flow and low flow events, they are also more actively managed. NSW, including coastal flow regimes with lower variability and maintained low flows provide refuge for invasive species such as carp (Driver *et al.* 1997, 2005) and disbenefit native fish species.

Table 4. Predicted ecological effects of option 3

Metric	Stochastic		NARCliM		East coast low	
	Average	Range	Average	Range	Average	Range
NoFlowYears	"G	!!G-NIL	"G	!!G-NIL	"G	!!G-NIL
NoFlowDays	!!I	"G-!!I	!!I	"G-!!I	!!I	"G-!!I
NoFlowEvents	!G	'I-!!G	!G	'I-!!G	!G	'I-!!G

Metric	Stochastic		NARCliM		East coast low	
	Average	Range	Average	Range	Average	Range
VLF Q	“G	‘I-!!G	“G	‘I-!!G	“G	‘I-!!G
LF Q	“G	!!G-”I	“G	!!G-”I	“G	!!G-”I
Days < LF	‘I	!!I-’G	‘I	!!I-’G	‘I	!!I-’G
BF Q	‘G	‘I-!!G	“G	‘I-!!G	“G	‘I-!!G
Annual Q	N	‘I-N	N	‘I-N	N	‘I-N
Fresh Q	N	N	N	N	N	N
Fresh Freq	‘I	!!I-N	‘I	!!I-N	‘I	!!I-N
Fresh Dur	‘I	!!I-N	‘I	!!I-N	‘I	!!I-N
2.5 ARI	N	‘I-N	N	‘I-N	N	‘I-N
5 ARI	N	“I-N	N	“I-N	N	“I-N
10 ARI	N	“I-N	N	“I-N	N	“I-N

4. CONCLUSIONS

The ecohydrology metrics used were generic flow metrics, rather than known thresholds for flow-dependent species or communities, but they achieved their purpose by showing option impacts. The analyses are intended to shorten the final list of options earmarked for more detailed assessment to help ensure that water management decisions better consider future climate impacts and variability (as per Prosser *et al.* 2021). However, any further analysis where the option is further elevated in priority, or other assessments such as local impacts on water trading might need to build in more detail. In particular, these results are based on time-averaged results at a site level, which means that some short-term flow sequences of great ecological significance could be hidden. This might indicate even greater impacts during generally drier flow periods (eg, 1997-2010, 2002-3, 2017-2019) were under-detected. Such low flow impacts caused by extraction that disrupt stream connectivity occurred during 2002-03 at Kanoona (Reinfelds et al. 2006, DPE 2022f).

The main option effects were on the river main stem where flow regulation and abstraction tend to impact the most, and not on the tributaries, except for those downstream of storages such as Cochrane Dam. The options had little effect on river flows larger than freshes. While Options 1 and 2 had greater impacts on low flows, especially for the Bega River at Warraguburra, Option 3 has the most effect on the flow regime. Option 3 showed moderate low flow increases, reductions in cease-to-flow events and fewer and shorter freshes. The impacts on freshes under option 2, and especially 3 could impact ecosystems function in various ways, including impacting fresh-dependent fish species such as the Australian grayling and Australian bass, and through benefitting invasive fish species.

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