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New South Wales Far North Coast Draft Regional Water Strategy Review

CSIRO Land and Water

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Document submission history

Date	Action	Reference
15 December	Final draft submitted to DPIE	Carmel Pollino
21 January	Revised draft incorporating first round of DPE comments	Neil Lazarow
14 February	Final report incorporating second round of DPE comments	Neil Lazarow

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Executive summary

Overview

To support finalisation of the Far North Coast Regional Water Strategy (RWS), the New South Wales Department of Planning and Environment (DPE) invited CSIRO to carry out a desktop study to analyse the options developed for the RWS to date, suitability and adequacy of the underpinning dataset used to develop the options, advise on options to achieve RWS objectives, and identify additional work to ensure that a systems view of water security, river health and flood risk is taken into account when considering options.

The draft RWS represents a significant step forward in planning for an integrated regional water management program for the region. The recommendations contained in this review are intended to support DPE to finalise and deliver a RWS that meets the needs of the region in a sustainable way into the future. Cognisant of growth in population and demand, climate change projections suggesting a rising probability of extreme floods and droughts, and a heavy reliance on unregulated water extractions and limited storages to buffer existing water supplies, the RWS is a welcome initiative to navigate future water resource challenges through sensible policy and infrastructure choices.

The Far North Coast (FNC) region is different to most other regions in New South Wales (NSW), as the mean annual rainfall and runoff are higher and regular flooding (and associated damages) needs to be considered together with water security when developing a RWS. Although flood risk is identified as a regional water strategy objective and is well-described in the RWS, there is only light consideration of flood management strategies across the options and no discussion or evaluation of the potential for water security investments to mitigate future flood risk (opportunity cost of saving future cost impacts). A system-wide view of the hydrological cycle will significantly improve delivery of the RWS, in particular where conjunctive management of water security and flood risk may be beneficial.

The review team recognises the complexities of water resource planning in the FNC, amplified by periodic but significant flood recovery efforts. The review team encourages ongoing consultation across a broad set of actors to support finalisation and delivery of the RWS, noting the important insights, cultural and local knowledge held by Indigenous communities. Where RWS objectives are being wholly or partially met by other agencies or actors, the review team recommends that these responsibilities are captured within the RWS. This will also improve the integration of the RWS with complementary strategies, policies and programs.

Challenges

The review team found that the DPE hydroclimate models had to be pushed to the extremes to stress test water security in the region – a consequence of high average annual rainfall. This process, however, exposed several limitations and uncertainties around the approaches and also the underpinning datasets for the hydrology and cost benefit analyses (CBA). For example, the use of annual averages for water availability masks the risk of intra-annual variability especially during drier years, which may result in pockets of water stress for both the consumptive pool and natural systems. Further, the performance of hydrological models outside of their calibration range has not been estimated by DPE. This raises the concern that the capacity of these models to simulate extreme dry or wet periods is unknown and the models may not be able to accurately stress test the system.

The review team found the short-listing process to be constrained by a lack of information (no environmental assessment, limited data on sensitivity, draft reports), opaque (lack of clarity on filtering process) and poorly mapped to the full suite of RWS objectives. For example, it was not clear to the review team which options had been set aside, rather than discarded, because they were viewed as being addressed by a different agency, program or level of government; integrated into other options; or identified as economically unviable. CSIRO is confident that these particular issues will be rapidly and successfully resolved as the principal and supporting documentation is finalised prior to public exhibition.

The review team acknowledges that the RWS is being developed at a time of change and uncertainty: in our understanding of the hydrology, hydroclimate, physical geography, socio-economic conditions and demographic change; and in the emerging requirements for how projects will be developed, assessed and financed in future. Although these latter considerations are not a barrier to finalising the RWS, they are likely to create extra challenges for implementation if not addressed in the planning process. Through the systems analysis, the review team identified several opportunities to improve the RWS and the underlying benefit-cost analyses of options to meet these emerging funding and financing requirements.

On the basis of the information presented to CSIRO and underscored by the significant gaps in knowledge as identified through the 27 actions proposed in the Consultation Paper, which are broadly supported by CSIRO, the review team believes that the current distillation of long-list to short-list options and combinations does not adequately capture the level of risk and uncertainty associated with option development nor does the CBA adequately reflect the benefits and trade-offs across options. Restriction of assessments to those options where there is available data, while practical, also raises the question of whether it is premature to cull individual or combinations of options at this stage.

Recommendations

The review team recommends that DPE finalise the RWS inclusive of the long-list of options and those generated during the community consultation phase. Where available, this should include clearer information about the options generation and selection process. This would enable a shift towards a more systems-oriented approach and a no or low regrets pathway. Several of the options described in the RWS are well-suited to this type of ‘options and pathways’ approach, and the focus on combining options where it is sensible is supported. Detailed studies should follow, including exploration of a broader set of options in the context of complementary strategies, to explore value creation and map a broader sets of benefits and beneficiaries. Such an approach may also enable DPE to construct options that are more likely to align with emerging project development, assessment and financing requirements at state and national level.

Chapter six of this report offers a consolidated set of forty-one recommendations to support DPE to finalise the RWS in the coming months, deliver the RWS over the next few years, and improve the regional water strategy program for NSW. The recommendations are summarised as high-level actions below and in Table 1.

Activities to support finalisation of the RWS over the coming months

A. **Identify and describe environmental assets in the region and identify associated assessment metrics**. Environmental preservation is one of the core objectives of the RWS and the FNC is recognised for its rich biodiversity and highly valued environmental assets. The RWS should incorporate greater emphasis on environmental objectives for water dependent systems, and report on environmental assets that are responsive to hydrological change. ***DPE completed the environmental assessment after delivery of this review. The review team supports a reconciliation by DPE of these outputs against CSIRO's recommendations and publication in the updated Consultation Paper.***

B. **Revise hydrological model performance assessment using cross-validation**. The RWS relies significantly on hydrological simulations to assess the current water resources of the region and the impact of proposed options. However, the review team identified that the performance of hydrological models outside of their calibration range has not been estimated by DPE, which limits their ability to accurately stress test the system.

C. **Clarify and update future climate data**. Clearly state that the patch point dataset has been used to represent climate for all the analysis undertaken to support development of the RWS. The review team has also identified that the use of monthly scaling factors to convert stochastic scenarios to future climate scenarios is likely to mask the impact of flooding, and this should be addressed.

D. **Start to build in elements of a broader systems approach**. Identify agencies with carriage of complementary strategies and plans, identify options that deliver multiple objectives / benefits, and clarify funding and financing requirements for potential future investments. This will provide a basis on which to move to a fuller systems approach, to meet the objective of affordability, build longer-term resilience, and meet emerging requirements of NSW and Australian government planning and financing requirements.

E. **Finalise supporting documentation**. Update and finalise all documentation to ensure consistency, including clarification of current level of knowledge and planning (where that is relevant) for each of the options under consideration. ***If DPE commits to a short-listing process prior to finalisation of the RWS then the updated Consultation Paper should include full coverage of short-listing, prioritisation and bundling assessments and all sensitivity analyses.***

The review team notes that the review and consolidation of methodologies could be completed within a few months, but revision of modelling methods may take six to 12 months, depending on resources.

Priority activities to support delivery of the RWS – up to five years from implementation

F. **Develop and test models that enable a combined assessment of flood and water security options.** Several options that address RWS objectives are likely to emerge through an investigation that jointly considers water security and flood risk. A detailed study for one of the basins in the region is recommended to enable development of a methodology capable of addressing water security, flood risk / mitigation and environmental flow (including water quality) options jointly. Such a study could serve as a template for other basins in the region and, potentially, for the Mid North Coast and South Coast regional water strategies.

G. **Detailed studies.** Several detailed studies are proposed to better inform the development of options to support the implementation of the RWS, including land capability assessment, agriculture viability assessment, alternative estimation of economic benefits, review of surface water storage options, characterisation of groundwater resources and a more coordinated approach to addressing declining river and catchment health through the RWS. Additionally, a focus on mapping and valuation of cultural assets and their associated water requirements is recommended. These recommendations are broadly supportive of the priorities identified in the Consultation Paper but also extend this in the areas of economic assessment and integrated flood and water security modelling.

H. **Develop and apply a systems approach.** Apply a systems approach to the implementation of the RWS, including use of systems approaches to elicit, prioritise and evaluate options in a manner consistent with creating resilience and meeting the emerging requirements of Infrastructure Australia, Infrastructure NSW, and numerous other funding sources.

I. **Distillation of long-list to short-list options.** Following completion of more detailed studies and revised modelling outputs (using updated modelling methods), including economic benefit analyses, a transparent framework should be used to ‘rapidly’ evaluate long-list options and create a meaningful short-list for more detailed assessment.

Guidance to improve regional water strategies at review

J. **Revision of RWS guidance.** Update guidance and templates to reflect a systems approach to the development of regional water strategies. This should include region or system specific advice depending on the risks, knowledge gaps and opportunities.

Table 1 CSIRO recommendations – review of NSW Far North Coast Regional Water Strategy

<table>
<tr><th>High level actions</th><th>Specific recommendation</th></tr>
<tr><td colspan="2">Activities to support finalisation of the RWS over the coming months</td></tr>
<tr><td>A. Identify and describe environmental assets in the region and identify associated assessment metrics</td><td>Recommendation 13 - Environmental assessment of proposed options should be included in the Consultation Paper to enable a robust options assessment process that meets the objectives of the RWS. This should extend to include a greater emphasis on environmental objectives for water dependent systems, and reporting on environmental assets and indicators that are responsive to hydrological change.
Recommendation 10 - Consider introducing evaluation metrics, which will be suitable to compare the impact of options on short dry and wet spells (water security and flood risk) within a given year instead of the currently used mean annual demand shortfall.
Recommendation 11 - Consider the adoption of low flow metrics to complement the water resource assessment such as the number of days during a year where shortfall is greater than, say, 10% of the total demand for the year.
Recommendation 12 - Consider introducing additional sub-annual metrics focusing on low flows within a year.
Recommendation 14 – Consider further investigation into the timing and severity of low flows and poor water quality (e.g. impact of nutrient loads and salinity) in the Richmond river and how this may be mitigated.</td></tr>
<tr><td>B. Revise hydrological model performance assessment using cross-validation</td><td>Recommendation 3 - Climate data and modelling methodologies should be consolidated into a single report for ease of access.
Recommendation 4 - Richmond and Tweed reports should be revised to include updated information on data quality such as the number of gauging stations and the amount of extrapolation beyond the maximum gauged flow.
Recommendation 6 - Richmond and Tweed reports should be revised to include updated information on rainfall–runoff model calibration methodology, calibration statistics and values of parameters obtained at the end of this process.
Recommendation 7 - Conduct a thorough review of rainfall–runoff model performance using a rigorous leave-out validation scheme when long streamflow records are available as is the case in the FNC.</td></tr>
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High level actions	Specific recommendation
	• Recommendation 8 - Richmond and Tweed conceptualisation reports should be updated to clarify river reach model calibration, particularly how transmission losses are setup, how they are calibrated and how much they amount to compared to inflows and outflows. Further clarification on how the hydrological models were calibrated to measure medium to low flows within the tidal zone is also recommended. • Recommendation 9 - Develop and use a rigorous leave-out validation scheme to evaluate the capacity of hydrological model performance in residual catchments in extrapolating beyond calibration conditions similarly to rainfall-runoff models in headwater catchments. • Recommendation 26 - Assesses hydrological model performance in both headwater and residual catchments using a well-established cross-validation approach. The performance metrics to be reported should include at least mean daily simulation bias, daily Nash-Sutcliffe efficiency and daily Nash-Sutcliffe efficiency computed from reciprocal transformed flows [see Chapter 6 for full recommendation].
C. Clarify and update future climate data	• Recommendation 1 - Provide a concise summary of baseline annual water availability in the region under both historical and future climate and combined with a current or no development scenario. • Recommendation 2 - Extend the climate projections beyond the driest scenario from the NARCliM analysis to include other most likely scenarios. • Recommendation 27 - Consider replacing static monthly scaling factors with more appropriate methods such as quantile–quantile mapping implemented for different time windows or potentially more advanced methods such as the Multivariate Recursive Nesting Bias Correction approach.
D. Start to build in elements of a broader systems approach	• Recommendation 25 - Highlight in RWS activities or complementary commitments that other agencies or actors are wholly or jointly undertaking. Parallel work that complements the objectives of the RWS should be documented in order to support a more integrated approach, noting that the extent to which this is undertaken is a negotiated process. • Recommendation 28 - Identify agencies for potential cooperation. Identify agencies with carriage of strategies and

High level actions	Specific recommendation
	plans with complementary visions and objectives, as pointers to cooperation in a broader place-based systems context in the longer term. Include in RWS. • Recommendation 29 - Include an activity to map options or combinations of options to multiple objectives / benefits. Building on the examples offered in the systems review, map out a broader suite of options connected to the water subsystem, including for example consideration of green infrastructure, that could have multiple benefits and help achieve improved cost-benefit ratios across multiple benefits to community and the environment. • Recommendation 30 - Map out longer-term pathways to project development, assessment and financing. There are many changes underway not only in the communities and places of the Far North Coast, but also in the context within which strategies might be implemented through projects over the next few years. Gaining a clearer line of sight over these changes and adjusting strategy development to align is an opportunity to manage risks and strengthen implementation pathways.
E. Finalise supporting documentation	• Recommendation 16 - Prior to finalisation, the strategy and supporting documents are updated to ensure consistency across the RWS. • Recommendation 17 - Update the Consultation Paper to include full coverage of short-listing, prioritisation and bundling assessments and all sensitivity analyses. • Recommendation 18 – Provide greater clarity on the current level of knowledge and planning (where that is relevant) for each of the options under consideration. • Recommendation 20 – Several in chapter recommendations are offered to improve readability and transparency of the RWS.
Priority activities to support delivery of the RWS – up to five years from implementation	
F. Develop and test models that enable a combined assessment of flood and water security options	• Recommendation 5 - Consider the inclusion of sub-daily hydrological models for modelling flood impact as part of future modelling work undertaken by DPE in the Far North Coast region. • Recommendation 15 - Undertake relevant flood risk assessments for small to moderate floods (<10% AEP) and

High level actions	Specific recommendation
	incorporate flood risk modelling into hydrological assessments. Options should be revisited in light of this new data. • Recommendation 31 - Consider investing in simplified flood models for the FNC region that can be combined with outputs from existing hydrological models to provide a rapid assessment of flooding impacts. The main benefit of these models will be to enable joint assessment of water security and flood mitigation options. A simplified hydrodynamic (flood risk) component should be able to estimate flooding extent in the region for a wide range of multi-year stochastic scenarios. This could be supported by more detailed 1D or 2D hydrodynamic models for specific high-risk areas such as Lismore. Ideally the model will extend to cover the Richmond and Tweed catchments to allow the setup of a fully dynamic connection between these areas [see Chapter 6 for full recommendation].
G. Detailed studies	• Recommendation 32 - Land capability assessment – The review team supports the current DPE three-year program to identify and map important agricultural lands. Depending on the extent of this work, more detailed investigations are recommended to be undertaken as part of land suitability assessment. The output, digital land suitability data and maps of the region, will identify areas that are more or less suitable under different combinations of land use and irrigation systems, as well as for aquaculture. • Recommendation 33 - Agriculture viability and socio-economics – The benefit assessment for the RWS assumes that agricultural production can be expanded if more water is secured over time. This assumption needs to be evaluated to better understand how agriculture within the FNC region may be expanded in response to water availability and efficiency of use. A study is recommended to model predicted land use change and impacts that could inform selection and development of options, which would be complemented with a spatial econometric study to evaluate direct benefits to the region as well as flow-on of benefits (including regional value added) to the region and state. • Recommendation 34 - Surface water storage options –More detailed analyses of surface water storages than that suggested in the Consultation Paper is recommended in order to provide a comprehensive overview of the different surface water storage

High level actions	Specific recommendation
	options in the region, including the potential to use existing storages more effectively (e.g. Toonumbar dam). This should extend to include pre-feasibility assessment of a range of instream and off-stream storages and the potential to locate these as distributed systems on public and / or private land. • Recommendation 35 - Groundwater – Further studies, as emphasised in the Consultation Paper, to characterise groundwater aquifers in the FNC region are supported in order to understand how: groundwater resources could support natural systems; may be used to buffer water supply; and better understand the potential for groundwater recharge using flood water during small to medium events [see Chapter 6 for full recommendation]. • Recommendation 36 - Water quality – Declining river and catchment health remains a challenge for the FNC. The focus for this review has been on the impact of low flows on the environment, and several recommendations are provided. The systems review identified the benefit of mapping options to complementary policies and programs, which then opens up the opportunity to address a range of practices that impact water quality in the Richmond river (focus of this review) and elsewhere. Beyond this, a coordinated approach should be adopted to better understand and address the health of rivers and ecosystems in the FNC region, identify environmental water needs and the impact of water infrastructure on ecosystem health and aquatic ecosystems is recommended.
H. Develop and apply a systems approach	• Recommendation 38 - Application of a systems approach including benefit cost analyses that account for the RWS objective of affordability and of multiple benefits across the broader system is recommended. A systems approach should also ensure that proposals meet the emerging requirements of Infrastructure Australia, Infrastructure NSW, and numerous other funding sources [see Chapter 6 for full recommendation].
I. Distillation of long-list to short-list options	• Recommendation 19 - All R&D, data and reports should be subjected to a peer review process and this process should be clearly described. • Recommendation 21 - Explore the performance of combination or bundled options, in particular how a combination of least-cost options performs in relation to a large investment.

<table>
<tr><th>High level actions</th><th>Specific recommendation</th></tr>
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Recommendation 22 - Short-listed options should be assessed against all objectives of the RWS to uncover potential tensions and maladaptive outcomes.
Recommendation 23 - Consider including a greater focus on the cost of investments as a means of differentiating options. An ‘impacts framework’ is suggested to complement quantitative and qualitative assessments of options or portfolios of options.
Recommendation 24 - Economic analysis of options should be extended to include the potential to mitigate future flood damages (i.e. the opportunity cost of saving future cost impacts), with a particular focus on small to moderate floods (<10% AEP).
Recommendation 37 - Documentation provided to and reviewed by CSIRO does not support a comprehensive distillation of long-list to short-list options and combinations at this stage. Following completion of more detailed studies and revised modelling outputs (using updated modelling methods) the review team recommends that DPE use a transparent framework to ‘rapidly’ evaluate long-list options and create a meaningful short-list that could be assessed. Several key steps are needed for this approach to be effective:

Resolution of key knowledge gaps:

Understanding and reporting on the impact to environmental assets from hydroclimate change and potential development options.
Update reporting of hydrological model outputs to show sub-annual statistics.
Update existing hydrological models to improve simulation of extreme wet and dry periods.
Development of an integrated (loosely coupled) flood and water security model.
Climate change scenario including assessment of impact on extremes wet (floods) and dry (drought) flow regimes at sub-annual level.

Development of options that are more likely to align with emerging project development, assessment and financing requirements at state and national level.

</td></tr>
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High level actions	Specific recommendation
	○ Map and value cultural assets and their associated water requirements. ○ Prioritise no or low regrets options until supporting studies improve critical knowledge gaps. ○ Adoption of a systems approach to options development that encourages the creation of options / combinations of options that realise multiple objectives and benefits. - Adoption of an evaluation process that more accurately accounts for costs and benefits, considers systemic risk and value creation / benefit flow opportunities.
Guidance to improve regional water strategies at review	
J. Revision of RWS guidance	• Recommendation 39 - Revision of guidance and production of templates to reflect a systems approach to the development of regional water strategies, aligned with the approaches being outlined by Infrastructure Australia (in collaboration with Infrastructure NSW), and across other areas of and levels of government in NSW. • Recommendation 40 - Distinguish 'regional water strategy' regions, where appropriate, to better differentiate system risks, knowledge gaps and opportunities. This process would identify where more attention needs to be given to certain objectives and would create transferability between regions across NSW with broadly similar challenges such as flood risk and sea level rise (e.g. Far North Coast, Mid North Coast and South Coast). • Recommendation 41 - Consider whether to rebalance current legislated priority to service basic landholder rights and essential town water supplies, towards also addressing the maintenance of essential ecosystem function / services that underpin regional systems and prosperity.

List of Acronyms

CBA	Cost benefit analysis
CPA	Common Planning Assumptions
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DPIE/DPE	Department of Planning, Industry and Environment / Department of Planning and Environment
FNC	Far North Coast
LGA	Local Government Area
NSW	New South Wales
RWS	Regional Water Strategy
SEQ	South East Queensland

1 Background

1.1 Development of Regional Water Strategies across New South Wales

The New South Wales Department of Planning and Environment (DPE) is developing 12 regional water strategies (RWS) across New South Wales (NSW). Regional water strategies are being developed to

> *Improve the security, reliability, quality and resilience of the State's water resources….. [They] look out over the next 20 to 40 years to understand how much water a region will need to meet future demand, the challenges and choices involved in meeting those needs, and the actions we can take to manage risks to water availability[1].*

A growing population, evolving industry, employment patterns, and a more variable future climate mean that NSW faces complex decisions to balance competing demands for limited water resources. This context calls for improved water management that combines efficacy and sustainability, and allows for uncertainties, over the coming decades. All twelve RWSs are required to be developed to support five key objectives:

1. **Deliver and manage water for local communities** – Improve town water security, water quality and flood management for regional towns and communities.
2. **Enable economic prosperity** – Improve water access reliability for regional industries.
3. **Recognise and protect Aboriginal water rights, interests and access to water** – Including Aboriginal heritage assets.
4. **Protect and enhance the environment** – Improve the health and integrity of environmental systems and assets, including by improving water quality.
5. **Affordability** – Identify least-cost policy and infrastructure options.

During extreme events priority is afforded to secure basic landholder rights and essential town water supplies[2].

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[1] NSW Government Department of Planning, Industry and Environment 2020 Regional water strategies–guide, September 2020 (nsw.gov.au) . Regional Water Strategies Guide 2020, p.4-5. Accessed 8 September 2021.

[2] Ibid. p.6.

1.2 Regional overview

The Far North Coast (FNC) region covers approximately 8,620 km^2 in the north-eastern part of NSW with a population of around 240,000 (in 2020) and includes the catchments of the Richmond River (7,026 km^2), the Tweed River (1,080 km^2) and the Brunswick River (512 km^2)[3]. The region encompasses six local government areas (LGAs): Ballina Shire, Byron Shire, Kyogle Council, City of Lismore, Richmond Valley Council and Tweed Shire.

Water is a significant feature of the Far North Coast region's environment, with its many interconnected systems of rivers, creeks, groundwater aquifers and wetlands. Water supports the region's population and its liveability, protects and conserves ecological assets and Aboriginal cultural heritage, and underpins key industries and local employment[4].

- The region has a strong but non-linear population growth and highly valued natural assets, which underpin industry development and the tourism market. Agriculture, manufacturing, health care and social services, education and training, and hospitality are the major industries in the region[5].
- A large portion of the region's elevated areas have world heritage status and are protected as part of the Border Ranges, Mount Warning and Nightcap National Parks[6].
- The region contains extremely high terrestrial and aquatic biodiversity and has many species that are endemic to the region[7]. The region supports species and habitats of local and international significance and forms crucial links between important conservation areas. The North Coast Bioregion is one of the most biologically diverse regions in Australia[8].
- While high rainfall has contributed to a robust agricultural sector, the impact of seasonal flooding has significantly impacted assets and communities. The City of Lismore is one of the most flood-affected towns in Australia[9]; since 1954, over 100 flooding events have been recorded in Lismore[10,11].

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[3] NSW Government Department of Planning, Industry and Environment 2020 Draft Regional Water Strategy. Far North Coast: Strategy. October 2020, p.11. Draft Regional Water Strategy: Far North Coast (nsw.gov.au). Accessed 10 October 2021.

[4] Ibid, p.13.

[5] Government of New South Wales Department of Premier and Cabinet. Northern Rivers Regional Economic Development Strategy 2018-2022. Northern Rivers Regional Economic Development Strategy 2018 -2022 (nsw.gov.au). Accessed 12 October 2021, p.14.

[6] NSW Government Department of Planning, Industry and Environment 2020 Draft Regional Water Strategy. Far North Coast: Strategy. October 2020, p.50. Draft Regional Water Strategy: Far North Coast (nsw.gov.au). Accessed 10 October 2021.

[7] NSW Government Department of Planning, Industry and Environment 2020 Draft Regional Water Strategy. Far North Coast: Strategy. October 2020, p.58. Draft Regional Water Strategy: Far North Coast (nsw.gov.au). Accessed 10 October 2021.

[8] Regional Development Australia—Northern Rivers, Northern Rivers Regional Profile 2013, RDA-Northern Rivers, 2013, p.67; and NSW Government Department of Planning, Industry and Environment. NSW North Coast bioregion. NSW North Coast bioregion | NSW Environment, Energy and Science. Accessed 15 October 2021.

[9] Gissing A, Langbein F 2019 What areas of Australia are most at risk from natural perils?, Risk Frontiers 18:4 1-3, newsletter_V18_Issue4_Oct_2019.pdf (riskfrontiers.com).

[10] http://australiasevereweather.com/floods/index.html Floods in Lismore NSW.

[11] https://lismore.nsw.gov.au/files/Lismore_Flood_Events_1870-2017.pdf.

The combination of high rainfall, internationally recognised natural assets, good quality soils, community and transport infrastructure, proximity to large markets, and population growth forecasts are suggestive of the significant economic growth potential for the region and greater demand on water assets and infrastructure into the future. However, development also carries the risk of greater (natural and built) assets exposure to climate extremes, including, flooding and water scarcity.

2 Objectives and approach

Development of the Far North Coast RWS is the first comprehensive effort to plan and manage for the region's water needs over the next 20 to 40 years, and covers a complex set of challenges, including secure provision of urban water supply, urban flooding and water quality in the context of a more variable and shifting climate.

The Department (DPE) is currently working through a process to short-list the options identified in the draft RWS or identified through the consultation process carried out following its release. The options are currently being assessed through a Cost Benefit Analysis (CBA) process, together with qualitative and quantitative assessments of environmental impact and cultural outcomes.

Community consultation that followed the release of the draft RWS highlighted major concerns around flood risk to towns and communities in the region.

To support finalisation of the RWS, the Department has invited CSIRO to carry out a desktop study that achieves the following objectives:

- Analysis of the options developed for the RWS to date (and the suitability and adequacy of the underpinning dataset used to develop the options).
- Assist the Department in the application of a systems thinking approach to the options identified and advise on development of portfolios of options which achieve the strategy objectives, with a particular focus on flood risk management, river health and water security.
- Identify whether there is other work required to ensure that the best overall systems view of water security, flood risk, land and river health is considered when assessing options.

This study will form part of the evidence base for the final Far North Coast RWS.

2.1 Area under investigation

1. Water security – Entire RWS study area.
2. Flood risk – City of Lismore and surrounding areas. This is for several reasons:
    - Floods in the Lismore region impact a broader area than that covered by the current Lismore Floodplain Risk Management Plan (2014).
    - The cost to the City and community of Lismore from flooding has been, and continues to be, significant. Flood risk to Lismore and surrounding areas was highlighted as a key issue of concern by the community.
    - Investigating the broader catchment is likely to elicit options for the conjunctive management of water security and flood risk. It also supports a systems-based approach (appropriate bounds for system) and addresses the key objectives of protecting and enhancing environmental and First Nations interests.

3. Water quality – Richmond River. The Richmond River has consistently recorded poor water quality outcomes and is in worse ecological health than most estuaries in NSW, as highlighted in the NSW Marine Estate Management Strategy (2018)[12].

2.2 Approach

CSIRO has interpreted the project tasks as follows:

1. Review the draft Regional Water Strategy for the FNC.
2. Review of the long-list and short-list of options developed for the draft Regional Water Strategy (including the datasets / models used to underpin the strategy).
3. Using a systems approach (see definition in 2.3 below) with a particular focus on flood risk management, river health and water security, identify and advise the Department on the development of portfolios of options to achieve the Regional Water Strategy.
4. Identify further work (studies, fieldwork), if any, required to support water security, flood risk, land and river health outcomes through delivery of the Regional Water Strategy.

A detailed description of the activities is provided in Appendix A

DPE has provided CSIRO with a series of documents to support this review. A list of all documents provided is shown in Appendix A Documentation covers the RWS[13], the FNC Long-list of options[14], the draft FNC Consultation Paper[15], supporting technical reports covering approach, climate, economic and hydrological modelling, and economic development and environmental strategies relevant to the region.

Several supporting documents in unconsolidated or draft format were only made available late into the review. In addition, a number of technical reports related to the development of hydrological models and environmental assessment were completed in parallel with the review and were not available to the reviewers. No comments are made in relation to this work.

2.3 Considering ‘systems approaches’

The review team has been tasked with guiding DPE to apply systems thinking approaches to the consideration of options identified in the RWS, with a particular focus on flood risk management, river health and water security. Taking a ‘systems approach’ explicitly recognises that all decision-makers are part of the system that they are trying to understand, influence and manage. It

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[12] NSW Marine Estate Management Strategy 2018-2028, https://www.marine.nsw.gov.au/__data/assets/pdf_file/0007/815596/Marine-Estate-Management-Strategy-2018-2028.pdf. Accessed 27 August 2021.

[13] NSW Government Department of Planning, Industry and Environment 2020 Draft Regional Water Strategy. Far North Coast: Strategy. October 2020. Draft Regional Water Strategy: Far North Coast (nsw.gov.au). Accessed 10 October 2021.

[14] NSW Government Department of Planning, Industry and Environment 2020 Draft Regional Water Strategy. Far North Coast: Long list of options. October 2020. https://www.industry.nsw.gov.au/__data/assets/pdf_file/0019/329014/draft-rws-fnc-options.pdf. Accessed 10 October 2021.

[15] NSW Government Department of Planning, Industry and Environment 2020 Draft Regional Water Strategy. Short-listed actions for the Far North Coast region: Consultation Paper.

provides tools to assess, analyse and discuss causes, influences and interactions, and identify barriers to and opportunities for change. It supports clear articulation of problem structures, expands the range of choices and possibilities available for solving the problems, and provides structure to document and test assumptions[16].

The term 'system' can describe an entity (organism, ecosystem, organisation) or a sector (for example the health system, education system, finance system) with interrelated and interdependent parts. It has defined boundaries and is more than the sum of its parts. Changing one part of the system affects other parts of the system and the system as a whole. Systems are in part constructed by the way people think about and perceive aspects of the system (subjective aspects) as well as the biophysical realities which are visible or tangible and can be measured and modelled (objective aspects)[17].

Systems thinking assesses possible points of intervention to create change and considers what the consequences of those interventions might be. An intervention may be a decision, a program, policy, investment, infrastructure, or a set of behaviours[18].

Socio-economic and biophysical systems are in a time of rapid change and novel disruptions, which fundamentally changes the dynamics of a system. There are systemic causes of change and disruption that are not adequately dealt with by standard risk assessment processes (e.g. ISO 31000 series) due to high uncertainty, ambiguity and novelty. Managing compound stresses and systemic risks are beyond the existing assessment capabilities and control of any single organisation, level of government, economic sector, or community. Emerging statements of requirements in Australia for infrastructure planning and investment[19], for instance, show that systems approaches take account of these factors, especially with respect to climate and disaster resilience, and will increasingly be necessary in order to access funding – whether they are government or private capital[20].

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[16] Adapted from Australian Government, Department of Home Affairs. 2019. Climate and Disaster Risk: What they are, why they matter and how to consider them in decision making. 3 Guidance on Vulnerability. This guidance was prepared by CSIRO.

[17] Ibid.

[18] Ibid.

[19] For example Infrastructure Australia 2021 A Pathway to Infrastructure Resilience: Advisory Paper 1: Opportunities for Systemic Change https://www.infrastructureaustralia.gov.au/sites/default/files/2021-08/Advisory%20Paper%201%20-%20A%20pathway%20to%20Infrastructure%20Resilience%20FINAL.pdf

[20] There are many examples of this such as:

Recommendations of the Task Force on Climate related Financial Disclosures: Final Report. In Task Force on Climate related Financial Disclosures. Report available at: https://assets.bbhub.io/company/sites/60/2020/10/FINAL-2017-TCFD-Report-11052018.pdf 2017.

AASB, AUASB. Climate-related and other emerging risks disclosures: assessing financial statement materiality using AASB/IASB Practice Statement 2. In Australian Accounting Standards Board (AASB) and Auditing and Assurance Standards Board (AUASB). Report available at: https://www.aasb.gov.au/admin/file/content102/c3/AASB_AUASB_Joint_Bulletin_Finished.pdf 2019.

APRA. Prudential practice guide. Draft CPG 229 Climate Change Financial Risks. In. Australian Prudential Regulation Authority (APRA). Available at: https://www.apra.gov.au/sites/default/files/2021-04/Draft%20CPG%20229%20Climate%20Change%20Financial%20Risks_1.pdf 2021.

Climate Bonds Initiative. Australia Green Finance State of the Market: 2019 update. In Climate Bonds Initiative. Available at: https://www.climatebonds.net/files/reports/australia_greenbonds_sotm-2019-update_august_270819_final_v1_.pdf 2019.

Mortimer G, Whelan B, Lee C. Adaptation Finance: Emerging approaches to solve the climate adaptation finance gap. In Climate-KIC Australia. Available for download at: www.climate-kic.org.au/our-projects/adaptation-finance 2020.

In a systems approach, systemic constraints need to be addressed by coordinating and collaborating efforts (conversations, analysis) across three inter-dependent levels of decision making: (1) high level strategy development (e.g. State level infrastructure strategies, regional/sectoral level strategies), (2) policy choices and planning (e.g. state land use planning, regional planning), and (3) project delivery (e.g. technical and feasibility assessments for specific projects identified by the other levels, and for which specific public or private sector funding is sought). Such coordination and collaboration efforts are depicted in Figure 1. When these three levels are well-aligned, the high-level strategies can have a robust problem and opportunity identification to define appropriate visions, goals and objectives to address them. This then flows through to a more constrained and coordinated set of policy and planning options, so the programs and projects that are designed can be better targeted to addressing the problems identified at the higher levels.

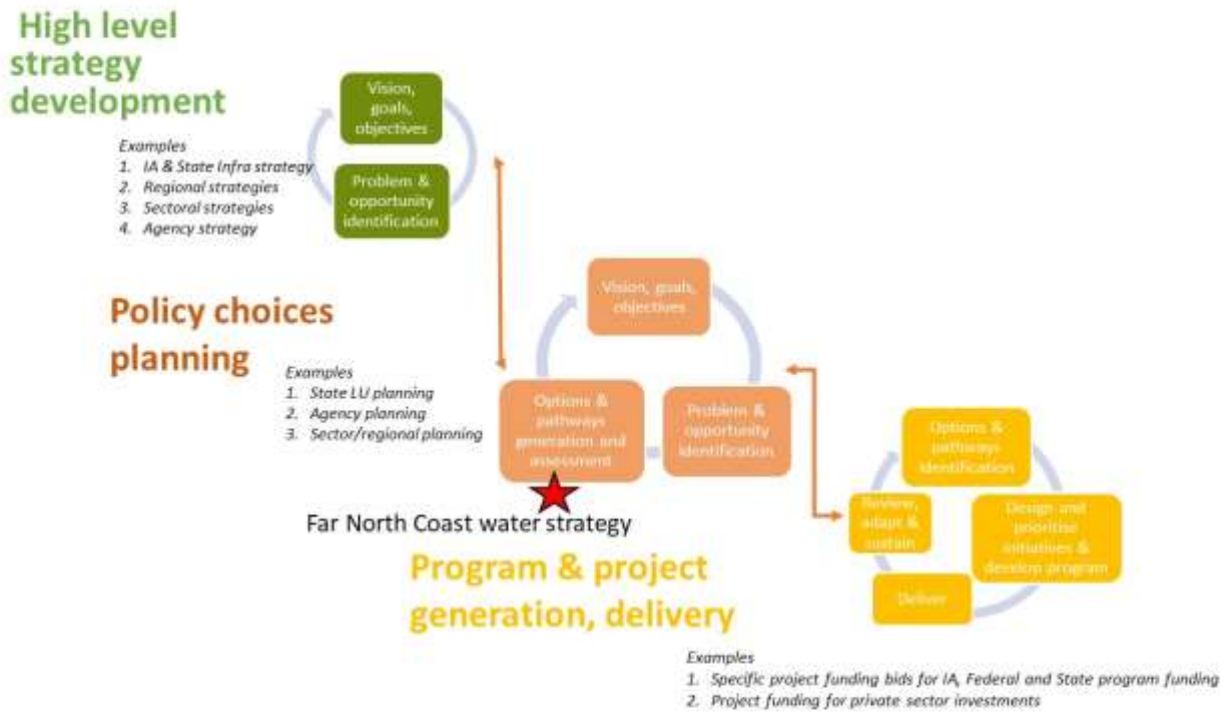

Figure 1. Taking a systems approach requires working across three interdependent levels of decision-making (modified from Wise et al, Guidance, in review)[21].

2.3.1 Applying systems approaches to the RWS

Applied to the RWS, systems approaches are helpful in five distinctive and important ways.

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[21] Wise R, Marinopoulos J, O'Connell D, Mesic N, Tieman G, Gorddard R, Chan J, Flett D, Lee A, Meharg S, Helfgott A 2021 Enabling Resilience Investment Guidance version 1. Report prepared by CSIRO, Value Advisory Partners, University of Adelaide. CSIRO, Canberra, Australia. Available from https://research.csiro.au/enabling-resilience-investment/.

1. Identify hierarchies and dependencies between objectives, which can reveal synergies or complementarities across objectives, but also whether particular strategies may result in unintended consequences.
2. Identify whether the RWS could potentially meet a broader range of objectives for the region and state, and in doing so generate a broader range of benefits to a wider set of beneficiaries.
3. Improve decision-making under uncertainty, so that actions and investments are sequenced to take low-regrets decisions along a pathway that keeps options open for the future as more information becomes available.
4. Ensure that climate and disaster risks are adequately addressed, which reduces chance of loss and damage in extreme events.
5. Identify whether the methodology and options proposed will be considered robust and legitimate by the time the RWS is in place, specific project proposals are developed, and more detailed technical and economic feasibility studies are completed. The review team notes that the RWS is being produced during a time of rapidly changing context for funding. For example, the review team notes the development of Infrastructure Australia and Infrastructure NSW guidelines[22] regarding assessment of resilience.

In the case of the FNC RWS, the 'focal scale' of the system is at the mid-level – policy choices and planning (Figure 1). A systems approach takes account of the levels above (high level strategy development) because it provides the context for the RWS. The lower levels (program and project generation and delivery) must also be considered – because this is the scale at which specific interventions to operationalise or implement regional strategy are usually realised.

[22] https://www.infrastructureaustralia.gov.au/sites/default/files/2021-07/Assessment%20Framework%202021%20Overview.pdf.

3 Detailed review comments

The following chapters focus on a review of three principal documents: the RWS[23], the FNC Long list of options[24] and the draft FNC Consultation Paper, which contains the short-list of options[25]; and additional supporting documentation provided by DPE and sourced by CSIRO directly. A full list of documentation reviewed is provided in Appendix A The principal documents are well-linked, and it is appropriate to review them concurrently rather than in sequence.

This chapter is complemented by a more detailed review of the biophysical aspects of the RWS in Appendix D .

The FNC Region exhibits a different hydro-climate regime than most other regions in NSW, with significantly higher mean annual rainfall and runoff and pronounced spatial variability. Damaging floods are also a frequent occurrence, which requires flooding issues to be considered together with water security when developing a regional water strategy. Most of the rivers and creeks in the Far North Coast region are unregulated and have no major dams for water storage / supply or instream structures. Unregulated rivers are the most important water resources in the region for towns, industry, and water-dependent ecosystems. Groundwater from alluvial aquifers, coastal sands aquifers and from porous and fractured rock aquifers are also important water resources.

3.1 Water security

Chapter One of the RWS provides a clear overview of how much water the region will need to meet future demand given projected population increase and future climate, including identification of challenges and choices required to meet these needs and to manage risks to water security and reliability. Linkages to relevant state-wide water reforms and new investments in water infrastructure are stated, as is the integration with strategic and local land use planning.

Data on annual water availability in the region under both historical and future climate, and combined with current or no development scenario, is presented at various points in the documentation. However, as it is currently set out, comparisons between scenarios and options are difficult. For example, the RWS states that *“on average, about 3,000,000 ML water runs through the Richmond River each year”* (RWS p. 52). Later in the chapter, the strategy indicates that *“our modelling shows the total volume of water flowing each year in these sections of the catchment may reduce by 4% to 16%”.* It would be useful to consolidate these numbers in a single table for the reader to easily quantify the volumes to support a more informed view on options.

[23] NSW Government Department of Planning, Industry and Environment 2020 Draft Regional Water Strategy. Far North Coast: Strategy. October 2020. Draft Regional Water Strategy: Far North Coast (nsw.gov.au). Accessed 10 October 2021.

[24] NSW Government Department of Planning, Industry and Environment 2020 Draft Regional Water Strategy. Far North Coast: Long list of options. October 2020. https://www.industry.nsw.gov.au/__data/assets/pdf_file/0019/329014/draft-rws-fnc-options.pdf. Accessed 10 October 2021.

[25] NSW Government Regional Water Strategies Program 2021 Discussion Paper on short-listed actions for the Far North Coast region: Consultation Paper. Nov. 2021, Appendix 2.

An illustrative example of such a table is available in the Murray Darling Sustainable Yield report, where different modelling and assessment methods are used[26].

Recommendation 1 - The review team recommends that DPE provide a concise summary of annual water availability in the region under both historical and future climate and combined with current or no development scenario.

3.2 Historical and future climate

Chapter Two of the RWS summarises information about the region's climate (historical and projected future), its landscapes and river systems, water availability, people and industry. The chapter describes existing pressure on water resources in the region (especially during droughts), which is expected to increase under climate change and a growing population. The review team congratulate DPE for summarising complex scientific information in such an accessible format.

3.3 Review of model assumptions and approaches

1. **Future climate scenario**. There is large uncertainty in rainfall projections for the region highlighted in the "North Coast Climate change snapshot"[27], which suggests that the worst-case scenario has a very low likelihood of occurrence. The review team recognises the logic of using the most conservative / extreme dry scenario to 'pressure test' the effectiveness of potential strategies in a worst-case scenario. However, there is a risk that using this approach may encourage elimination of some options based on a high-level consideration of costs and benefits. Further, the driest future scenarios may not be the most appropriate for assessing the impact of flooding across the region as it may give a false sense of security with reduced flood magnitude. This is discussed further in the report in more detail. **Recommendation 2 - The review team recommends that DPE extend the climate projections beyond the driest scenario from the NARCliM analysis to include other most likely scenarios.**
2. **Downscaling of future climate data**. The approach used by DPE is different to that used in most other similar studies[28], especially the extension of observed records using stochastic modelling. The review team acknowledges that the climate modelling method has been

[26] CSIRO Water for Healthy Country Flagship 2008 Water Availability in the Murray Darling Basin. A report from the CSIRO to the Australian Government (Issue October). www.csiro.au/mdbsy. See page 30.

[27] NSW Government 2014 North Coast Climate change snapshot Overview of North Coast Region climate change. https://climatechange.environment.nsw.gov.au/Climate-projections-for-NSW/Climate-projections-for-your-region/NSW-Climate-Change-Downloads

[28] Examples include:

CSIRO Water for Healthy Country Flagship 2008 Water Availability in the Murray Darling Basin. A report from the CSIRO to the Australian Government (Issue October). www.csiro.au/mdbsy.

Petheram C, Chilcott C, Watson I, Bruce C 2018 Water resource assessment for the Darwin catchments A report to the Australian Government from the CSIRO Northern Australia Water Resource Assessment, part of the National Water Infrastructure Development Fund: Water Resource Assessments.

Petheram C, Watson I, Stone P 2013 Agricultural resource assessment for the Flinders catchment. Report (CSIRO), December.

reviewed by an Independent Expert Panel[29] and such a review is not repeated here. However, the review team has found that despite a recommendation by the Expert Panel to use daily scaling factors, the information provided in the RWS suggests that DPE has used constant monthly scaling factors based on the bias corrected NARCliM future climate projections in this analysis. The choice of monthly factors raises two issues for representing future extreme flood events:

- The monthly scaling factors remains constant in time whereas climate trends modelled by Global Climate Models clearly show progressive change over time suggesting an intensification in future flood risk over the course of the century[30].
- Flood events in the region are much shorter than a month (less than 10 days) as indicated in Figure 2, which shows the number of days above minor flood level in Lismore between 2005 and 2021. Consequently, the use of monthly scaling factors for predicting future extreme flood events smears out future extreme events by not capturing their full extent and severity.

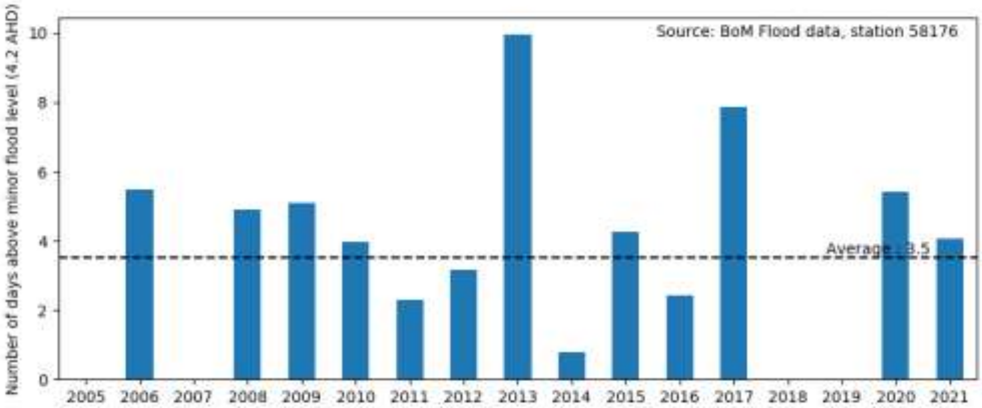

Figure 2. Number of days above minor flood level in Lismore[31]

3.4 Review of hydrological model simulations

The review team investigated the suitability and adequacy of the foundational datasets used by DPE to analyse and short-list the options in the RWS. Three datasets are used extensively to support the development of the RWS:

1. Historical climate data over the past 130 years supplemented by stochastically generated climate data underpins water resources assessment.
2. Future climate data are used to extend the assessment to the next century.

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[29] Independent Expert Panel 2020 Independent review of the climate risk method for the NSW Regional Water Strategies Program.

[30] AR6 Climate Change 2021: The Physical Science Basis, https://www.ipcc.ch/report/sixth-assessment-report-working-group-i/.

[31] Bureau of Meteorology, Australian River and Rainfall conditions, http://www.bom.gov.au/australia/flood/. Accessed on the 2021-12-10.

3. Hydrological model outputs form the core of the option selection process undertaken by DPE.

Flood modelling was not used to assess the options, but considering the importance of flooding issues in the region, the review team considered it important to provide a brief summary of data availability that could support development of a more integrated and sustainable RWS.

In addition to the RWS, the review team was provided with four separate technical reports presenting the hydrological modelling methods. These reports contain a considerable amount of hydrologic analysis. A wide range of options have been considered by DPE and integrated into both Richmond and Tweed hydrological models, including a connection between the Tweed and Richmond systems related to the upgrade of Clarrie Hall dam. The review team was impressed with the number of variants tested by DPE, which suggests a strong expertise and familiarity with this kind of analysis.

Notwithstanding that these reports were provided in draft form only and further work may yet be undertaken, the review team found several missing elements to the work that was presented, which has limited our ability to fully review the modelling outputs.

- *Overview of climate data availability and quality*: **Recommendation 3 - The review team recommends that climate data and modelling methodologies and results be consolidated into a single document for ease of access.**

- *Streamflow data availability and quality*: **Recommendation 4 - The review team recommends that the Richmond and Tweed reports be revised to include updated information on data quality such as the number of gauging stations and the amount of extrapolation beyond the maximum gauged flow**.

- *Hydrological model time intervals:* Most catchments in the Far North Coast Region react extremely quickly during floods compared to other parts of NSW. This behaviour suggests that hydrological models operating at daily time step may not be appropriate to characterise hydrological flow regime during flood events in the Far North Coast region. While this is not of significant concern for the analysis of water security options alone, it is problematic if water security and flooding issues were to be analysed jointly. Consequently, (**Recommendation 5**) **the review team recommends considering sub-daily hydrological models for modelling flood impact as part of future modelling work undertaken by DPE in the Far North Coast region**.

- *Calibration approach for rainfall-runoff models in headwater catchments*: **Recommendation 6 - The review team recommends that the Richmond and Tweed reports be revised to include updated information on rainfall-runoff model calibration methodology, calibration statistics and values of parameters obtained at the end of this process.**

- *Validation of rainfall-runoff models performance in headwater catchment*: **Recommendation 7 - The review team recommends a thorough review of rainfall-runoff**

model performance using a rigorous leave-out validation scheme where some part of the data is used for calibration and another part is left for validation following the recommendation of the eWater guidelines for rainfall-runoff modelling[32] when long streamflow records are available as is the case in the FNC. The review team noted a statement in the Tweed conceptualisation report indicating that *"it was chosen not to perform a validation for the headwater flows."* (section 4.10). The review team does not support the use of rainfall-runoff model outside of their calibration range without proper performance evaluation on both low and high flows and suggests that the performance assessment should be reviewed as a matter of urgency. The review team stresses that once such a performance evaluation using a split-sample approach has been completed and reported, it is acceptable to recalibrate hydrological models using all data available.

- *Calibration approach for hydrological models in residual catchments:* **Recommendation 8 - The review team recommends the Richmond and Tweed conceptualisation reports are updated to clarify how transmission losses are set up, how they are calibrated and how much they amount to when compared to inflows and outflows. Further clarification on how the hydrological models were calibrated to measure medium to low flows within the tidal zone is also recommended.**
- *Validation of hydrological model performance in residual catchments*: **Recommendation 9 - The review team recommends the use of a rigorous leave-out validation scheme to evaluate their capacity in extrapolating beyond calibration conditions similarly to rainfall-runoff models in headwater catchments.**
- *Performance evaluation metrics:* **Recommendation 10 - The review team recommends use of appropriate evaluation metrics, which will be suitable to compare the impact of options on short dry and wet spells (water security and flood risk) within a given year instead of the currently used mean annual demand shortfall.** The hydrological models developed by DPE operate at a daily time step which allows the computation of such metrics from existing model runs without any model changes.

3.5 Estimating demand shortfall

Appendix 2 of the Consultation Paper suggests that the demand shortfall estimates used to support the detailed CBA are low (less than 1% of the total demand) in most climate and infrastructure scenarios. This would suggest, on the basis of net water security only, that large infrastructure investments may be inappropriate. For example, the Consultation Paper states that model results

> *suggests that there is plenty of water available in the system, except under extreme outcomes (p.6).*

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[32] Vaze, J., Jordan, P., Beecham, R., Frost, A., Summerell, G., (eWater Cooperative Research Centre 2011), Guidelines for rainfall-runoff modelling: Towards best practice model application.

This is accurate if one focuses on total annual flow, which offers an estimate of the mean annual demand shortfall. However, as described above, the FNC region may experience short periods of low or very high (flooding) flows that can potentially be difficult to manage for certain users and harmful for the environment. For example, Figure 3 compares the total annual flow against the minimum daily flow during the same year for the Richmond River at Wiangaree. At this site, certain years such as 1977, 1995 and 2007 are above average in terms of total flow but significantly lower than average in terms of minimal daily flow.

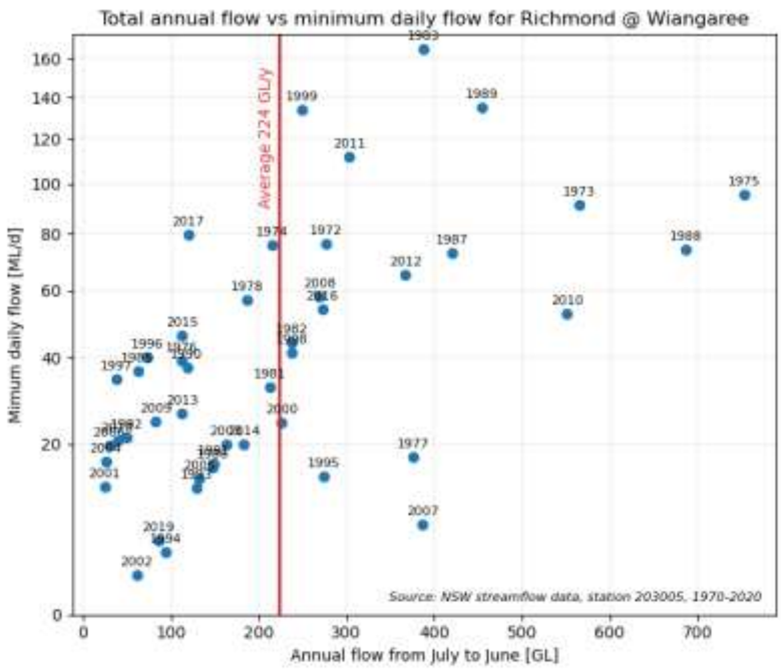

Figure 3. Comparison of annual flow with minimum daily flow for the Richmond river at Casino[33]. The years are defined with a start in July and end in June to avoid splitting the high flow seasons. The y-axis is transformed using square root to magnify low flows.

Recommendation 11 - The review team recommends that DPI consider the adoption of low flow metrics to complement the water resource assessment such as the number of days during a year where shortfall is greater than, say, 10% of the total demand of the year.

3.5.1 Groundwater resources

There is limited knowledge of groundwater resources in the FNC region. The Consultation Paper recognises this, and several options are proposed to improve the characterisation of groundwater systems. Considering the limited knowledge currently available about groundwater resources, it appears premature to include potential groundwater resources in future water storage and supply options. The review team supports DPE's emphasis on prioritising groundwater activities that focus on knowledge acquisition at this stage and recommends a detailed study is undertaken to characterise groundwater aquifers in the FNC region.

[33] Water NSW, real-time data, station 203005, https://realtimedata.waternsw.com.au/. Accessed 2021-12-10.

3.6 Impact of low flows on the environment

There is limited characterisation of water dependent ecosystems in the RWS and only one assessment of the environmental impact of options on flow regimes (Clarrie Hall low flow behaviour), although the Consultation Paper notes that these studies are ongoing. The use of yearly averages masks the impact on low flows because of the predominance of high and medium flows in the computation of annual averages.

Environmental health will depend on the establishment of sustainable extraction limits (option 20 in the Consultation Paper). An improved understanding of the risks to natural systems from over-extraction is therefore foundational to the development of options to support delivery of the RWS.

The review team notes that there are several important actions identified in the Consultation Paper to better address the health of the region's rivers and ecosystems, identify environmental water needs and the impact of water infrastructure on ecosystem health and aquatic ecosystems. These are supported.

Recommendation 12 - The review team recommends introducing additional sub-annual metrics focusing on low flows within a year.

Recommendation 13 - The review team recommends that the environmental assessment of proposed options be included in the Consultation Paper to enable a robust options assessment process that meets the objectives of the RWS. This should extend to include a greater emphasis on environmental objectives for water dependent systems, and reporting on environmental assets and indicators that are responsive to hydrological change.

Recommendation 14 - The review team recommends investigation into the timing and severity of low flows and poor water quality (e.g. impact of nutrient loads and salinity) in the Richmond river and how this may be mitigated.

3.7 Flood risk

Floods are an important feature of the Far North Coast hydrologic water cycle and occur in alternance with large flood events every three to five years on average, as highlighted in Figure 4. This has had a profound impact on the community in Lismore for the last 150 years (see Figure 5). Local government authorities are responsible for developing flood risk assessment and management plans such as the ones developed for all major towns in the region such as the Lismore Floodplain Risk Management Plan (2014)[34]. The review team noted that a considerable amount of flood modelling has been undertaken in the region as highlighted by Caddis et al[35] and summarised in Table 2. It is beyond the scope of this review to analyse these flood models and

[34] Lismore Floodplain Risk Management Plan 2014, https://lismore.nsw.gov.au/files/Lismore_Floodplain_Risk_Management_Plan.pdf (accessed 10 June 2021).

[35] Caddis B, Chin T, Wood M, Eggins B 2012 Towards a Catchment based model after two decades of modelling in the Richmond. Floodplain Management National Conference, 1–10.

governance arrangements responsible for the assessment and mitigation of flood risk in the region.

The Consultation Paper does not review flood data or report on the performance of options in response to flood impact or flood mitigation. The review team found that just one option addressed flooding. The review team notes that flooding is only implicitly represented in the objectives framing (within the '***deliver and manage water for local communities***' objective), highlighting the separation of governance and management of water security and flood risk. This separation of governance is a function of water management in NSW and not isolated to the FNC RWS.

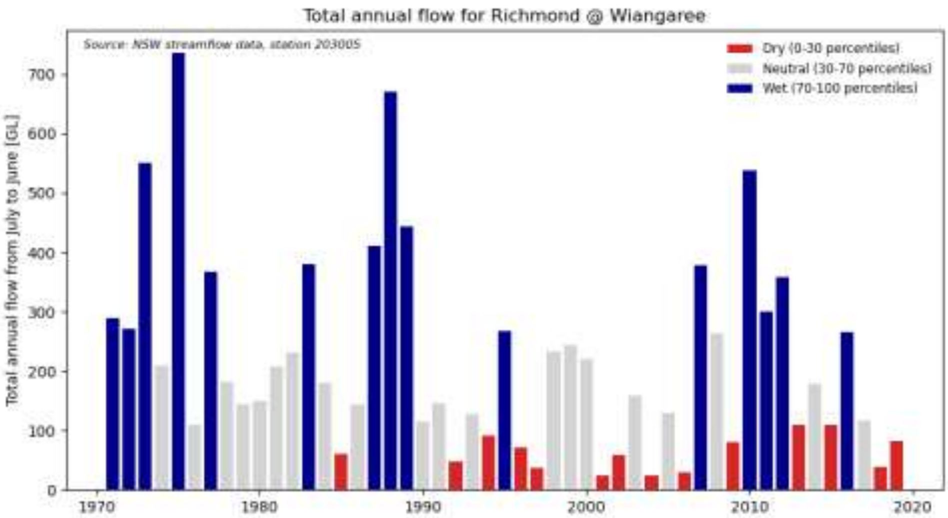

Figure 4: Alternance of dry and wet years for Richmond River at Wiangaree[36]

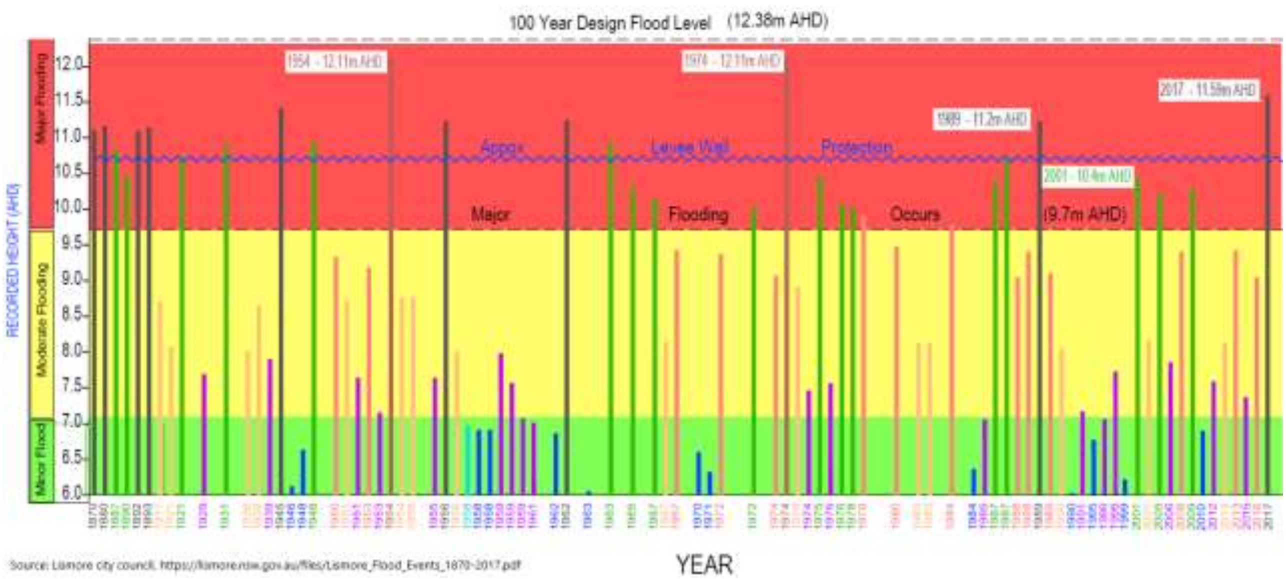

Figure 5. Flood history in Lismore. Source: Lismore City Council.

[36] Water NSW, real-time data, station 203005, https://realtimedata.waternsw.com.au/ (accessed 2021-12-10).

Table 2 Overview of flood modelling in the Richmond catchment, Far North Coast NS[35]

Year Completed	Location	Purpose	Software	Modelling Method
1993	Lismore	FS	Mike 11	1D
1997	Ballina	FS	Estry	1D
1998	Casino	FS	Mike 11	1D
1999	Mid-Richmond	FS	Mike 11	1D
2000	Deep Creek	FIA (Summerland Way)	Tuflow	1D/2D
2002	Casino	FRMS	Tuflow	1D/2D
2002	Lismore	FRMS	RMA2	2D
2003	Mid-Richmond	FRMS	Estry	1D
2004	Kyogle	FS	Tuflow	1D/2D
2004	Tuckombil Canal	FS	Tuflow	1D/2D
2006	Woodburn	FIA (Pacific Hwy)	Sobek	1D/2D
2006	Newrybar Swamp	FIA (Pacific Hwy)	Tuflow	1D/2D
2008	Ballina	FS Upgrade	Tuflow	1D/2D
2009	Kyogle	FRMS	Tuflow	1D/2D
2009	Wardell and Cabbage Tree Island	FRMS	RMA2	2D
2009	Ballina	FIA (Ballina Bypass)	Tuflow	1D/2D
2010	Mid-Richmond	FMS	Tuflow	1D/2D
2011	Ballina	FRMS	Tuflow	1D/2D
2012	Newrybar Swamp	FRMS	Tuflow	1D/2D

However, the review team is concerned that the current problem framing and identification of options in the RWS doesn't explicitly recognise that water security and management of flood risk are intrinsically linked in this region. For example, partial harvesting and storage of water from the 2017 flood event may have helped to reduce the impact of the severe drought in 2018–2020.

DPE identified council and community interest in the need for a proactive approach to managing extreme events (RWS, p.29). Consideration of options to conjunctively manage water security and flood risk is recommended, noting the need for a much broader set of development and mitigation (preparation) strategies (e.g. improved development control planning) to significantly reduce flood risk in established centres such as Lismore.

The review team noted that Caddis et al. (2012)[37] recommended the building of a unified flood model covering the whole Richmond catchment (including the Wilsons River). This is supported, however, the review team points out that Caddis et al. focus on event based hydrological and hydrodynamic models only, which cannot provide long simulations covering the full instrumental period (130 years) or future climate scenario. Noting these complexities, the review team suggests that it may be useful to initially focus on simplified flood models, such as the one proposed by Teng et al.[38], which can be run in sequence following hydrological models in order to assess flood and water security options simultaneously. An example of this type of approach is presented in Figure 6. This Figure shows the extent of the 2017 flood simulated at different times by projecting Australian Bureau of Meteorology water levels data on a LIDAR digital elevation model of the area. The flooded area compares favourably with remotely sensed data from the SENTINEL1 satellite

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[37] Caddis, B., Chin, T., Wood, M., & Eggins, B. (2012). Towards a Catchment based model after two decades of modelling in the Richmond. Floodplain Management National Conference, 1–10.

[38] Teng J, Vaze J, Dutta D, Marvanek S 2015 Rapid Inundation Modelling in Large Floodplains Using LiDAR DEM. Water Resources Management, 29(8), 2619–2636.

sensor[39] shown in Figure 6.c. Based on these encouraging results the review team recommends exploring combined hydrological / hydrodynamic models in the development and assessment of options for the RWS.

The review team recognises that flood volumes for rare events (e.g. 1% AEP) are much larger than volumes of future or planned storage infrastructures. However, critically placed off-stream infrastructure could improve water security and mitigate the impact of minor floods (e.g. <10% AEP). Beyond this, more detailed hydrodynamic models ought to be developed for higher-risk locations in the region, such as Lismore.

Recommendation 15 - The review team recommends that DPE undertake relevant flood risk assessments for small to moderate floods (<10% AEP) and incorporate flood risk modelling into hydrological assessments. Options should be revisited in light of this new data.

[39] Ticehurst, C., Zhou, Z.-S., Lehmann, E., Yuan, F., Thankappan, M., Rosenqvist, A., Lewis, B., & Paget, M. (2019). Building a SAR-Enabled Data Cube Capability in Australia Using SAR Analysis Ready Data. In Data (Vol. 4, Issue 3). https://doi.org/10.3390/data4030100

(a) 31st March 2017 at 4AM (b) 1st April 2017 at 10AM (c) 3rd April 2017 at 4AM

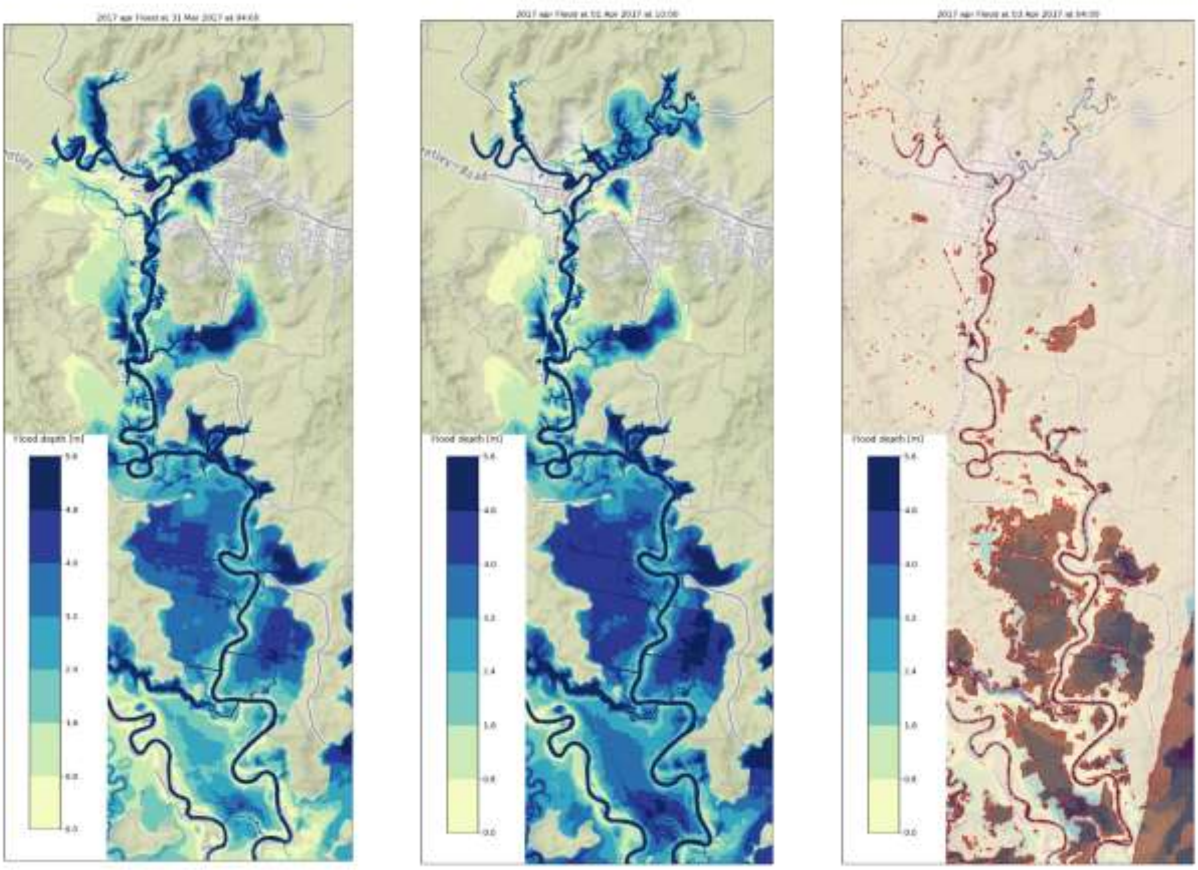

Figure 6. Example of rapid flood mapping showing the 2017 flood depth between Lismore and Coraki using interpolation of Australian Bureau of Meteorology water level (a, b, c) and SENTINEL1 remotely sensed data (c)[39].

3.8 Population, economic growth and demand

The impact of population growth on water security is emphasised at several points in the RWS. For example, the RWS (p.87) states

> *Town water supplies in the region are not capable of managing the extended dry periods that our new modelling shows are possible, particularly when expected population growth is taken into account*.

Estimating future water demand is a central element to the RWS and underpins the development of water security options, more so because the majority of future climate scenarios indicate reliable annual supply. Population projections released in 2019 by DPE under the ‘Common

Planning Assumptions' (CPA) were used to estimate future demand[40]. For the LGAs covered by the RWS, population is projected to grow from 246,626 in 2016 to 270,430 by 2041, an increase of 9.5%, reflected as 10% in the current RWS. DPE has extrapolated population growth to 2061 and estimates a potential FNC regional population of 285,000. Several alternative population projections have also been produced, including the North Coast Regional Strategy, Rous County Council one offered by Regional Development Australia (see Table 3), which suggests that the CPA projections are towards the lower bounds of current estimates.

Table 3. Far North Coast region population estimates.

Population projection	2041	2061
NSW DPE	270,000	285,614 (DPE extrapolation) 295,000 (simple extrapolated on 2041 curve by CSIRO)
North Coast Regional Plan 2036[41]	286,100 (2036)	325,574 (extrapolated on same curve by CSIRO)
Regional Development Australia[42]	Low 262,599 Medium 272,243 High 291,350	Low 287,502 Medium 302,274 High 331,896
Rous County Council[43]	Not available at time of writing	Not available at time of writing

The differences in population projections are highlighted in Appendix 2 of the Consultation Paper on short-listed options. In this appendix, two population forecasts are used to assess selected combinations of options through a cost-benefit analysis, as described in Table 4 below.

Table 4. Far North Coast population projections: Common planning assumptions and local government forecast growth 2020–2060[44].

LGA	CPA forecast increase	Local government forecast increase
Rous (Richmond Valley, Ballina, Byron and Lismore)	8%	31%
Tweed and Murwillumbah	24%	83%

[40] Ticehurst, C., Zhou, Z.-S., Lehmann, E., Yuan, F., Thankappan, M., Rosenqvist, A., Lewis, B., & Paget, M. (2019). Building a SAR-Enabled Data Cube Capability in Australia Using SAR Analysis Ready Data. In Data (Vol. 4, Issue 3). https://doi.org/10.3390/data4030100

NSW Government Department of Planning, Industry and Environment, population projections. Population projections - (nsw.gov.au). Accessed 17 November 2021. Population projections were released in 2019 and will be updated in 2022.

[41] NSW Government 2017 North Coast Regional Plan.

[42] Source DataAU (AEC). https://dataau.com.au/. Accessed via Regional Development Australia Northern Rivers on 12 November 2021.

[43] Water demand is drawn from Hydrosphere Consulting 2021 Rous Regional Supply: Future Water Project 2060. Integrated Water Cycle Management Strategy. Draft for Public Exhibition. March 2021.

[44] Reproduced from NSW Government Regional Water Strategies Program 2021 Discussion Paper on short-listed actions for the Far North Coast region: Consultation Paper. Nov. 2021, Appendix 2, p.2.

DPE also provides a useful comparison of projected demand based on NSW CPA predicted demand and Rous LGA predicted demand, illustrated in Table 5. This predicts a difference in demand for the region of approximately 3GL/y by 2060.

Table 5. Differences in projections of water demand in the Richmond valley[45].

Year	Rous LGA Predicted Demand (ML/y)[46]	NSW CPA Predicted Demand (ML/y)
2020	12,247	12,175
2030	13,595	12,430
2040	14,500	12,684
2050	15,286	12,939
2060	16,054*	13,194

**This is the lower bound estimate. The upper bound estimate is 16,667 ML/y and assumes no action is taken to remedy water losses,*

DPE is correct to draw on the CPAs to reflect potential population growth and to extrapolate demand out to 2061, as this better aligns projected demand with the expected life of any significant water infrastructure investments.

Several population projections are produced in Table 3, reflecting a range of assumptions. There are several reasons why the CPA projections are likely to be at the lower end of this spread. In the case of Rous County Council, estimates were drawn from a more current study and are also likely to reflect current and granular planning and development assumptions from relevant LGAs. For Tweed Shire Council, the data provided to CSIRO is from 2014, so it is unclear as to the basis for the difference in population forecasts, which also exceed those provided by Regional Development Australia[47].

Given uncertainty around population projections 40 years into the future, the review team finds that the two population estimates provide a useful set of boundaries against which to assess water security investment options to meet population demand.

However, it is worth noting that in the demand estimates produced for Rous County Council, household consumption is estimated at approximately 50% of demand (see Figure 7), with the remainder delivered to bulk supply and retail customers. This roughly 50/50 split in demand has been extrapolated through to 2060, however, it might be considered a bold assumption.

[45] Hydrologic Analysis of Options for Regional Water Strategies, Richmond Valley, DPIE, Table 17 page 49).

[46] Scenario 2A: Revised forecast dry year demand (estimated Ballina lot yield, reduced water losses).

[47] Source DataAU (AEC). https://dataau.com.au/. Accessed via Regional Development Australia Northern Rivers on 12 November 2021.

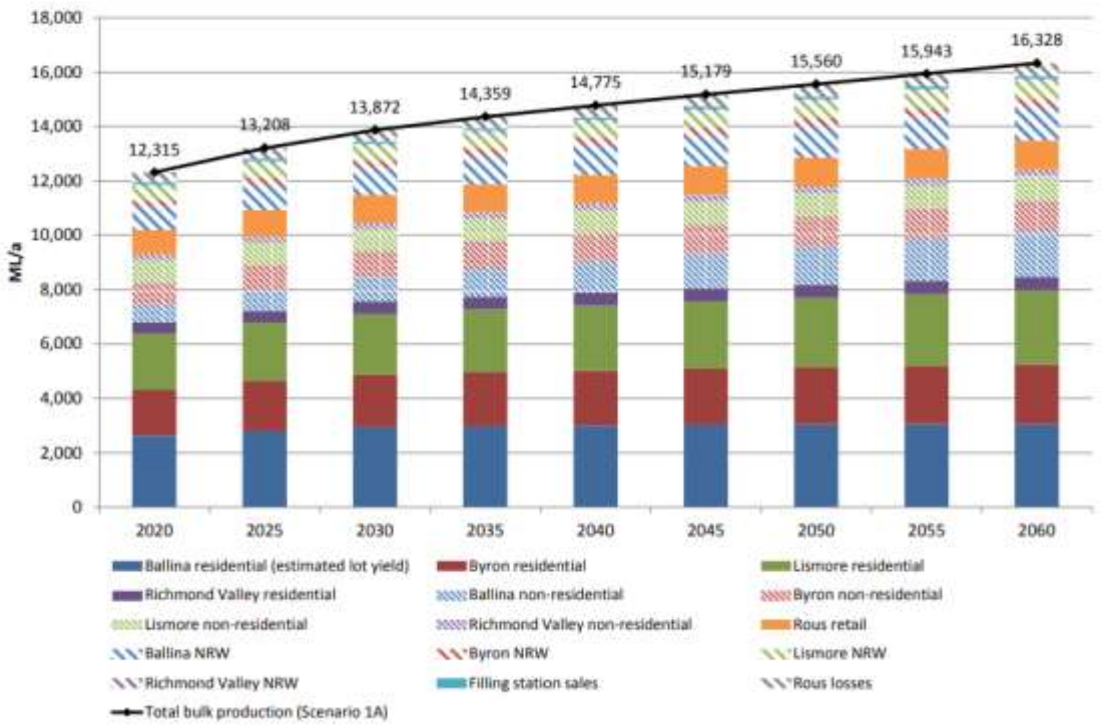

Figure 7. Forecast demand (bulk production): Scenario 1A – Rous bulk supply area[48].

A number of considerations are noted:

- Rous' forecast demand is approximately 3GL/y greater than that produced by DPE and would be higher again once demand for Tweed and Kyogle are incorporated (see Figure 7).
- The review team notes the substantial but non-linear growth of population in the region over the past one to two decades, which has also been accompanied by an increase in housing unaffordability. Anecdotally, there continue to be reports of families who are being priced out of long-term rental holdings adjacent or close to the coast and having to seek alternative accommodation further inland. It is possible that through a combination of internal-region migration, proximity to regional growth centres in South East Queensland and affordability issues, Lismore and surrounding villages may experience much faster population growth over the next two decades than is currently forecast.

If and when new industries emerge or existing industries expand (such as high value irrigated agriculture, ag-tech or energy), a scenario may emerge where bulk demand exceeds growth proportional to household demand. Emphasis in the 20-year Economic Vision for Regional NSW[49] on the sustainable supply of long-term energy and water resources and the provision of an 'attractive environment for business to establish and invest' suggests that these possibilities should be more clearly articulated in the RWS. In the absence of more detailed information, the review team thinks that DPE's approach to reflect population growth and potential future water

[48] Hydrosphere Consulting 2020 Rous County Council Bulk Water Supply. Demand Forecast: 2020 – 2060. Draft Final Report. Prepared for Rous County Council.

[49] As identified in the NSW Government 20-year Economic Vision for Regional NSW (2021), p.25. https://www.nsw.gov.au/sites/default/files/2021-02/20%20Year%20Vision%20for%20RNSW_0.pdf.

demand is robust. However, a more granular understanding of residential and retail / bulk demand will be required to fully assess the costs and benefits of future water infrastructure. For example, the RWS briefly describes a three-year program undertaken by DPE to identify and map important agricultural lands. Land capability mapping, extending beyond agriculture, is a valuable tool to support the assessment of agricultural opportunities as well as the suitability of land for instream and off-stream storages. This is discussed in more detail in Chapter Six.

3.9 Cost benefit analyses

3.9.1 Review of model assumptions and approaches

A total of 39 options were proposed for consideration in Chapter 3 of the RWS. Further details were provided in a separate document, the FNC Long-list. Thirteen additional options were included, based on feedback through the stakeholder engagement process. Of these, 12 options were given a rapid assessment for hydrologic and economic impact and benefit[50] and a detailed CBA and ecological assessment was performed for five combined actions[51].

Cost benefit analyses of options was undertaken using a three-stage process.

- Stage 1 – filtering process based on whether or not an option addresses an identified problem or helps to realise an identified opportunity.
- Stage 2 – 'rapid cost benefit analyses' of the long-list of options. Rapid CBA supports the decision whether or not to short-list an option.
- Stage 3 – short-listed options are evaluated using a more detailed CBA.

The review team thinks that the use of such three-stage process approach is robust as it has the potential to offer a transparent comparison and prioritisation process. However, the review team has identified several areas that deserve more attention or clarification.

- There are several expressions of challenges (seven), priorities (three) and objectives (five) across the three principal documents. The review team found it difficult to link the Consultation Paper with the RWS because of inconsistencies in priorities across these various elements. The review team understands that these various articulations have arisen as a result of the planning process not being smoothly linear as the state-wide RWS guidance was developed after the RWS had been drafted. These tensions are discussed in more detail in the Chapter 4 and Appendix A , which discuss the systems review.

Recommendation 16 - The review team recommends updating the principal RWS documents with content from supporting documents to ensure consistency across the RWS.

[50] NSW Government Regional Water Strategies Program 2021 Discussion Paper on short-listed actions for the Far North Coast region: Consultation Paper. Nov. 2021, Appendix 2.

[51] Ibid.

- No detail is provided in the Consultation Paper on the process to filter and prioritise the long-list options to produce the short-list of options. Through the workshop process, the review team learnt that several filters were applied, including: a) the need to stay within organisational remit for water management; b) bundling of options that are tightly linked; c) selecting based on tractability for modelling and analysis within the required timelines; and d) capacity of the option to secure reliability of water supply to towns and communities.
- Not all options are equally mature in terms of consideration. This could be more clearly reflected in the Consultation Paper. For example, the upgrade to Clarrie Hall dam is more advanced than other options (noting this has been developed by Tweed Shire Council, not DPE).
- The ‘rapid CBA’ for the long-list of options does not provide meaningful outcomes to take forward for more detailed analysis. Out of the 39 options available in the long-list, 12 are not supported by the rapid CBA and the rest were not assessed. Of the additional 13 options included after community consultation, none were assessed with the ‘rapid’ CBA.
- The final short-list includes 29 options (options identified as ‘Yes’ in the short-listed column of the options assessment table of the Consultation Paper) that were evaluated through combined or ‘bundled’ options. While the review team supports such an approach where it makes sense, no evidence is provided as to why certain combinations were preferred over others.
- Limited information is provided to support the rapid environmental assessment so this cannot be reviewed.
- There are significant uncertainties for data and potential variation in trends for future climate, as well as for potential structural and demographic changes. DPE has utilised eight separate sensitivity analyses to capture these uncertainties (four were not completed at the time of writing). However, it is not clear to the review team how these sensitivity analyses are being used to support decision making.

At the stage of analysis reviewed by CSIRO, and to the extent that documentation and data were made available, the review team supports DPE’s findings that none of the options that were evaluated by DPE are economically viable and that investment is not justified. This is illustrated by the difficulty in identifying and estimating the direct and indirect benefits (in a ‘rapid’ way) across different options.

Recommendation 17 - The review team recommends that DPE update the Consultation Paper to include full coverage of short-listing, prioritisation and bundling assessments and all sensitivity analyses.

Recommendation 18 - The review team recommends that DPE provide greater clarity on the current level of knowledge and planning (where that is relevant) for each of the options under consideration.

3.9.2 Review of datasets and modelling

The economic evaluation (the CBA analysis) draws in data generated from the outputs of three different components:

1. The costing of options – based on engineering and accounting analyses performed by the engineering consultancy firm ARUP[52].
2. Outputs from the hydrological models for the Richmond and Tweed valleys.
3. A 'regional value function' – developed by the consultancy firm Marsden Jacob Associates[53].

The review team assumes that contracted work has included a peer review process. However, this was not explicit, and (**Recommendation 19**) **the review team recommends that all data and reports are subjected to peer review (where appropriate, external review) and that this process is clearly described.** While no specific concerns are raised by CSIRO, we recognise the value of the peer review process for its potential to detect oversights.

The estimation of benefits in any CBA can be a complex task involving multiple dimensions and non-market values. This complexity was constrained by DPE so far only focusing on the estimation of the direct economic benefit (benefit to society) that RWS options can provide based on the amount of water that a particular option can secure in the catchment. This is translated in dollar values considering a) the capacity to secure water for consumption in townships; and b) the value of agricultural production (estimated as producer surplus) that it is possible to secure with the water provided by a particular option.

Hydrological model outputs are used to estimate the volume of water that an option can secure in the future. The rapid CBA uses outputs from the 130-year instrumental record to assess options and the detailed CBA uses the stochastic climate/hydrologic model (which is derived from the paleoclimatic model). The low variability in model results means that there is little in the way of differentiation across options that might enable a more detailed exploration of alternative investment/economic benefit pathways. For example, the worst-case scenario predicts a 1.3% shortfall of total water supply in 2060 (Rous Bulk under NARCliM). This also limited our capacity to provide 'back-of-the-envelope' estimates, as data used for the estimation of benefits are directly linked to the inconclusive outputs of the hydrological models.

The review team understands that DPE had limited time to work on the CBA prior to sharing the results with CSIRO. The following specific suggestions are offered to improve readability prior to finalisation:

- The charts provided on page 4 in Appendix 2 of the Consultation Paper appear to be intended to show 'cumulative' effect. However, they highlight shocks at a point in time as a result of

[52] Memorandum from ARUP to Nathan Taylor and Sarah Horne (May 6th, 2021) and accompanying cost model Excel file.

[53] Regional water value functions – values for inclusion in the cost-benefit analysis to support NSW Regional Water Strategies. Marsden Jacob Associates, February 2nd, 2021.

water shortfall in townships and could provide clearer insights into 'predicted economic outcomes' if the distribution of impacts shown were included.

- Consider whether it may be useful to provide a series of charts that enable a direct comparison between outcomes, including economic implications, for two locations.

The following comments are offered in relation to the use of data from the 'regional value functions' to support the CBA:

- The producer surplus estimated for irrigators with annual crops assumes that additional water will translate into additional areas planted. However, while suitable for high-level analyses, this assumption is unlikely to hold true in all circumstances. For example, in some areas soils and geographic conditions would not allow much more planting than current levels. Land may also be retired, for example through conservation covenants or because of poor productive capacity, which will reduce the amount of land in production.
- Economic assumptions about commodities need to be clarified. For example, in the MJA report[54] blueberries are considered a key commodity produced in the FNC region. To estimate the producer surplus of this activity an output price of $20/kg is assumed in the MJA report. This assumption may be questioned by producers, who have seen lower farm-gate prices in recent seasons (e.g., 2020-21). Thus, adjustments of producer surplus parameters can be considered for the regional water value functions, as local costs and prices can vary. For instance, larger areas planted with a commodity can increase inputs costs (e.g. higher labour costs from increasing labour demand) affecting surplus.

Recommendation 20 - The review team has offered several suggestions to improve readability and transparency of datasets and modelling.

3.9.3 Introducing a systems approach to CBA

Systems approaches highlight that distilling options from long to short-lists too early potentially misses the opportunity to explore options in the context of complementarity to broader strategies, or to explore value creation and map a broader set of benefits and beneficiaries that might be possible through assessing a wider set of options.

Additionally, when dealing with high levels of uncertainty about population, economic settings and data inadequacies in analysis, it may be helpful to conduct an 'options and pathways' analysis. This approach allows for the sequencing of bundles of options to address foundational, near-term options while maintaining options for further investment in interventions as future trajectories in uncertain parameters become clearer[55]. Beyond the review of the CBA and CBA process, the

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[54] Regional water value functions – values for inclusion in the cost-benefit analysis to support NSW Regional Water Strategies. Marsden Jacob Associates, February 2nd, 2021.

[55] Several relevant references are suggested as follows:

Wise R, Fazey I, Stafford Smith M, Park SE, Eakin HC, Archer Van Garderen ERM & Campbell B 2014 Reconceptualising adaptation to climate change as part of pathways of change and response, Global Environmental Change, pp. 28, 325 - 336.

systems review described in Chapter Four highlights the potential for cooperation with other agencies in the wider FNC place-based system to achieve multiple benefit outcomes, and co-investment towards options that address complementary objectives of both the RWS and the visions of other plans and strategies. This may include the potential to cooperate with agencies leading regional development and economic strategies, and conservation or land management strategies at regional or state levels. We note that several aspects of this extend beyond what is expected of a traditional CBA.

Recommendation 21 - The review team recommends that DPE further explore the performance of combination or bundled options, in particular how a combination of least-cost options performs in relation to a large investment.

Recommendation 22 - The review team recommends that short-listed options be assessed against all objectives of the RWS collectively, to uncover potential tensions and maladaptive outcomes (discussed in more detail in Chapter Four).

3.9.4 Extending the economic analysis by focusing more on costs and cumulative benefits

To support the economic analysis for the prioritisation of options the review team suggests that DPE might consider several other ways of differentiating options. One may be to put a greater emphasis on costs as a means of differentiating options. Although available in detail only for 15 options, costs in the ARUP report[56] are well described and do present a high variability across cases, as shown in Figure 8. Given these detailed data 'cost effectiveness analysis' or 'break-even analysis' approaches may also be adapted to the RWS in order to explore the variability that the costs data provides, which can support a more robust prioritisation process.

A second approach may be to attempt to depict growth projections for key economic sectors, including growth within existing and new industries, in the region over time to attempt to illustrate where and when, within the region, additional demand is likely to emerge, so that water investments can be planned. An alternative but less expansive approach to express this could be as an expression of the willingness to pay to avoid restrictions. An illustrated example of how this may be presented in a time series is shown in Figure 9. For the FNC, this level of detail has been

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Haasnoot M, Kwakkel JH, Walker WE, Ter Maat J 2013 Dynamic adaptive policy pathways: a method for crafting robust decisions for a deeply uncertain world J. Glob. Environ. Change, 23 (2) pp. 485-498.

O'Connell D, Maru Y, Grigg N, Walker B, Abel N, Wise R, Cowie A, Butler J, Stone-Jovicich S, Stafford-Smith M, Ruhweza A, Belay M, Duron G, Pearson L, and Meharg S 2019, Resilience, Adaptation Pathways and Transformation Approach. A guide for designing, implementing and assessing interventions for sustainable futures (version 2), CSIRO.

Hallegatte S, Maruyama Rentschler JE, Rozenberg J, The Adaptation Principles: A Guide for Designing Strategies for Climate Change Adaptation and Resilience (English). Washington, D.C. World Bank Group. http://documents.worldbank.org/curated/en/546611605298449211/The-Adaptation-Principles-A-Guide-for-Designing-Strategies-for-Climate-Change-Adaptation-and-Resilience.

Wise R, Marinopoulos J, O'Connell D, Mesic N, Tieman G, Gorddard R, Chan J, Flett D, Lee A, Meharg S, Helfgott A 2021 Enabling Resilience Investment Guidance version 1. Report prepared by CSIRO, Value Advisory Partners, University of Adelaide. CSIRO, Canberra, Australia. Available from https://research.csiro.au/enabling-resilience-investment/.

[56] Memorandum from ARUP to Nathan Taylor and Sarah Horne (May 6th, 2021) and accompanying cost model Excel file.

summarised at a high level for Rous County Council by Hydrosphere Consulting[57]. The benefit of extending this approach to cover second order benefits is that it can be translated into an assessment of economic benefits by projecting growth in the number of jobs, changes in sectors' value added, and estimation of impacts on household incomes.

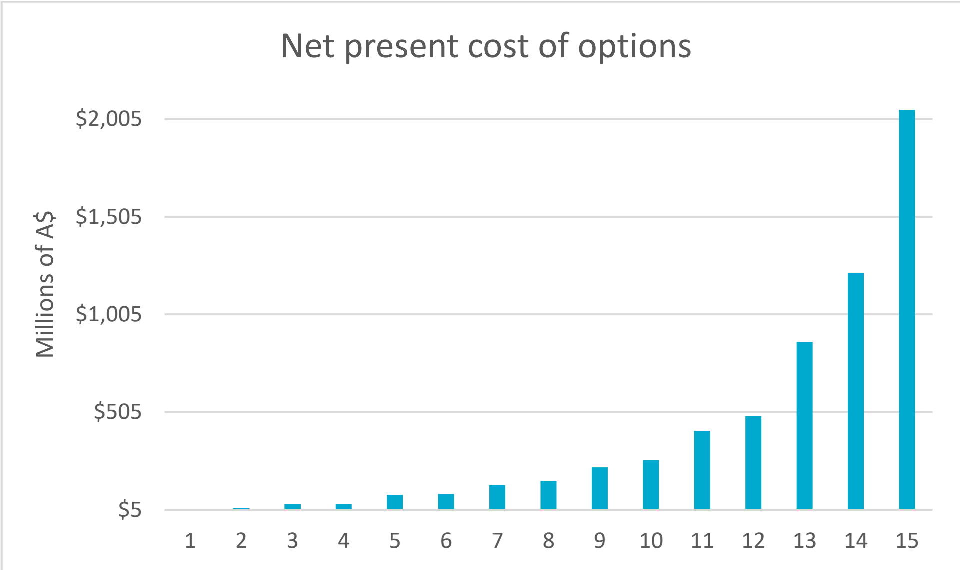

Figure 8. Costs for 15 different options considered in the Far North Coast Regional Water Strategy.
Note: Numbering of options does not coincide with DPE options IDs. *Source*: Authors, with data from ARUP (2021)

[57] Hydrosphere Consulting 2021 Rous Regional Supply: Future Water Project 2060. Integrated Water Cycle Management Strategy. Draft for Public Exhibition. March 2021.

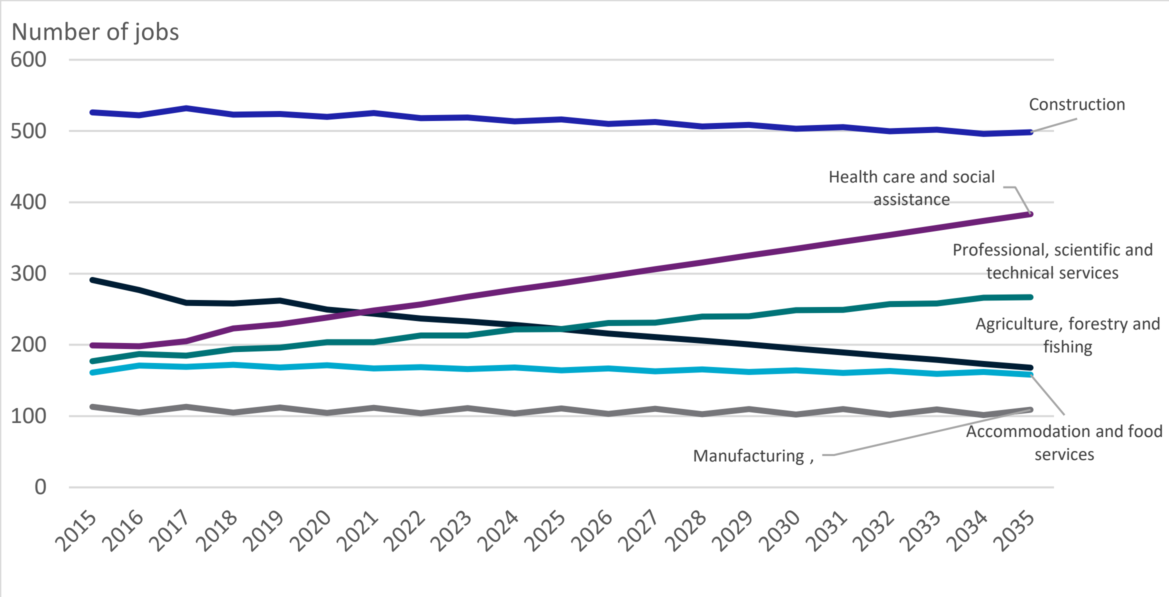

Figure 9. Economic data at Local Government Area level. Source: Adapted from Measham et al. (2021)[58].

Future water infrastructure investment business cases will need to provide more detailed analyses of costs and benefits for options. The review team acknowledges that this is beyond the scope of the RWS, however, the RWS should identify the range of potential benefits, costs and impacts of water infrastructure investments under consideration such as the benefits from an expansion in agricultural activity to the region. For example, different portfolios of options are likely to support water use in diverse types of agricultural activity (e.g. MJA report[59] identifies blueberry, avocados, macadamia, dairy, hay and sorghum production) across the catchment, also depending on land use suitability. Such expansion of agricultural activity will not only increase producer surplus but will generate direct benefits to the supply chain and other impacts to the community as a whole.

The review team suggests the inclusion of an 'impacts framework' to support future economic analyses to identify direct and indirect impacts (benefits and costs) from the expansion of (different types of) agriculture. Figure 10 shows an example of such a framework. Note that not all impacts can and need to be quantified, but qualitative analysis of their occurrence can greatly contribute to the economic evaluation of an option.

This type of 'impacts framework' can also be deployed to evaluate the cost, benefits and trade-offs of responding to flood risk by identifying actors and sectors likely to be adversely impacted. The potential socio-economic impacts of costs and the economic benefits of policies and investments to enhance preparedness and resilience are discussed further in 2.3, Chapter Four and Appendix C.

[58] Measham T, Walton A, Poruschi L, Fleming-Muñoz D 2021 Renewable energy transition to 2035 for the Great South Coast: Report prepared for the Victorian Department of Jobs, Precincts and Regions. CSIRO, Australia.

[59] Regional water value functions – values for inclusion in the cost-benefit analysis to support NSW Regional Water Strategies. Marsden Jacob Associates, February 2nd, 2021.

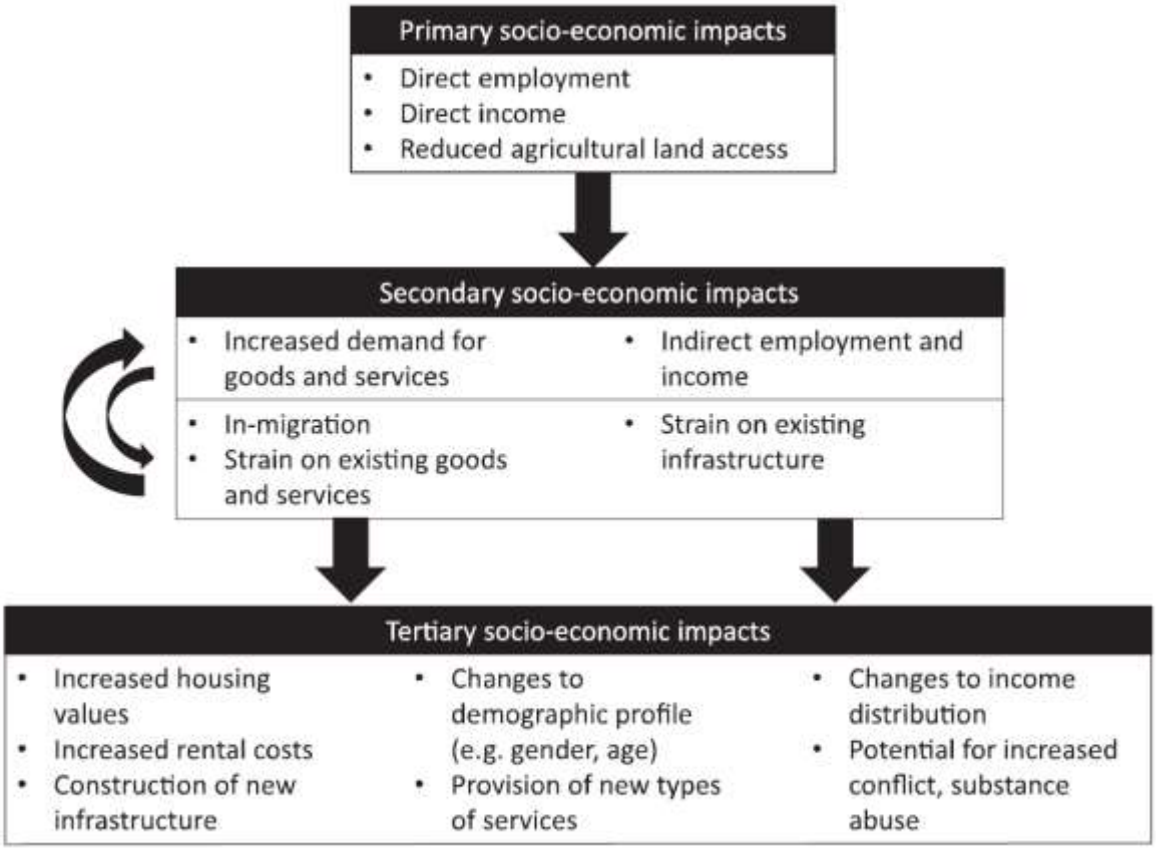

Figure 10. An 'Impacts framework' to expand the analysis of benefits and costs[60].

Note: The primary impact of 'Reduced agricultural land access' refers to the potential loss of other type of agricultural activity in detriment of the expansion of a particular set of commodities that is benefiting from the development of a particular RWS option.

Recommendation 23 - The review team recommends the use of a broader set of approaches to estimate broader benefits from interventions, including a greater focus on the costs of options as a differentiator. An 'impacts framework' is suggested to complement quantitative and qualitative assessments of options or portfolios of options to support regional development.

3.9.5 Flood economic modelling

Estimates of the cost of flood damage to the SEQ / Northern Rivers region are reported widely but not consistently. Roche et al. (2013) suggest that the impact of the 1954 flood in 2011 dollars would have been in excess of $7.5B for the broader region[61] – or $9B in 2021. The estimated total damage to infrastructure and agriculture in the Lismore LGA from the March 2017 flood is

[60] Measham T, Fleming D, Schandl H 2016 A conceptual model of the socioeconomic impacts of unconventional fossil fuel extraction. *Global Environmental Change*, 36, 101-110.

[61] Roche KM, McAneney J, Chen K, Crompton RP 2013 The Australian Great Flood of 1954: Estimating the cost of a similar event in 2011 American Meteorological Society DOI: 10.1175/WCAS-D-12-00018.1.

estimated at almost $40M[62] and $20M from the December 2020 flood[63]. The review team notes the Productivity Commission's concern that as of 2014 mitigation spending was only three percent of what had been spent on post-disaster recovery efforts in recent years[64].

It is beyond the scope of this report to conduct a detailed analysis of pre-flooding (preparedness) expenditure in Lismore compared to post-disaster (recovery) expenditure. The review team also acknowledges that economic modelling to understand the benefits of flood mitigation options would require an extension of DPE's current mandate for the development of regional water strategies. Nevertheless, flood risk management is an important element of regional water resource management for the FNC and greater attention to the benefits and costs of flood risk in the RWS is recommended. This is consistent with community feedback on the RWS, which highlighted expectations that the RWS should consider flood risk management. When considering conjunctive management and multiple benefits, options that demonstrate outcomes for both water security and flood risk reduction are likely to be preferable to options that address just one in isolation. For example, if on balance, two options are equivalent from a water security perspective, and one can also demonstrate flood risk reduction benefit, it is likely to be preferable.

To further support the recommendation in 3.7 to include flood risk modelling in hydrological assessment, (**Recommendation 24) the review team recommends that assessments of options to deliver the RWS should also be extended to include an economic analysis of the potential to mitigate future flood damages (i.e. the opportunity cost of saving future cost impacts), with a particular focus on small to moderate floods (<10% AEP).**

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[62] Nelson S 2017 Counting the cost and facing the future. Report on the 31 March 2017 natural disaster for the Lismore Business Flood Recovery Taskforce. Counting the Cost and Facing the Future Report (nsw.gov.au). Accessed 10 November 2021.

[63] Channel 9 news report. https://www.9news.com.au/national/floods-storms-leave-massive-cleanup-nsw-queensland-weather/106a2e36-879e-4375-8167-200a616d1804. Accessed 10 November 2021.

[64] Productivity Commission 2014 Natural Disaster Funding Arrangements, Inquiry Report no. 74, Canberra. JEL code: H77, H84, p.9.

4 Systems review of the RWS

As described in 2.3, systems approaches can add significant value to strategy development and implementation. The approach adopted by the review team was to initially map out elements of the problem and the system, first going wide to gather multiple perspectives, and then moving through a process of conversation, exploration and analysis to distil and converge on key findings. This contributes insights to support a process of identifying options or a portfolio of options for the RWS, in a systems context.

A detailed description of the approach and findings is provided in Appendix A

4.1 Applying the systems lens

This approach places an emphasis on a broader analysis of benefits that could include synergies with other public and private objectives and the socio-economic impacts that particular options could generate across townships and economic sectors with the FNC region. The review team carried out preliminary systems analysis work, which was twice tested and iterated with DPE to identify gaps and missing pieces of information, explore incongruities and dependencies, and expose critical framings, constraints and priorities. This iteration supported distillation and convergence to generate advice within a systems context.

The systems analysis focused on the following areas:

1. Resolving internal consistency in the articulation of the problem space and overarching goals (expressed as challenges and objectives) across the planning process and identifying the central framing for the remainder of the systems analysis.
2. Identifying dependencies between RWS objectives, including identifying the foundational objectives relied upon to achieve others. Mapping CSIRO review focus areas to RWS objectives to reveal constraints on the review's ability to assess whether the strategy will meet its full objectives.
3. Assessing to what extent and how sufficiently the RWS objectives are covered by the short-list option areas.
4. Revealing potential tensions and the possibility for unintended consequences of actions targeting one objective, on other objectives in the RWS.
5. Exploring potential lower cost (or higher benefit-cost ratio) pathways to implementation through cooperation by examining whether RWS objectives could link to the visions of other regional or state level strategies and plans.
6. Options selection process to distil from a long-list to a short-list of options.

4.2 Meeting policy objectives

As discussed in 3.9, the review team found it difficult to link the Consultation Paper with the draft Regional Water Strategy dated October 2020 because of inconsistencies across various challenges and objectives. Through consultation with DPE it was revealed that RWS objectives are considered the central organising framework when considering the RWS ability to meet policy goals, as the objectives have a basis in legislation and are standard across all regional water strategies in NSW. Through consultation with DPE, the review team determined that a ‘nested’ view of the objectives is applicable as follows:

- Two objectives, ‘enhance the environment’ and ‘Aboriginal rights and interests’, are considered foundational.
- Two objectives, ‘deliver and manage water for local communities’ and ‘enable economic prosperity’, depend on the achievement of other objectives.
- One objective, ‘affordability’, is interpreted as ‘least-cost’ and considered by DPE as a lens against which to consider investment options.

The review team mapped short-list options to RWS objectives to gain a picture of the proportionate attention paid to each objective and to consider whether foundational objectives (those upon which the achievement of other objectives depends) where supported.

This provided insights into whether policy goals have been adequately considered in the higher-level framing of the RWS. Beyond the analysis in this review, additional work would be required to ascertain whether the relationships mapped here hold at the level of the specific actions under each of the options areas, and their interconnections. Findings from this analysis include:

- There are a strong suite of options areas (13) addressing the ‘***enhance the environment***’ objective, which is one of two foundational objectives. Options or combined / bundled options supporting the environment objective include those targeted specifically at protecting ecosystems, river health and fish, and those that aim to manage water extraction sustainably. The review team notes that there is also a list of actions identified in the Consultation Paper to support the delivery of this objective.
- The ‘***deliver and manage water for local communities*'** objective is also well served by the short-list of options areas (12), and supporting options broadly include those addressing better information, those aimed at improving water governance and management, and those identifying infrastructure or supply options.
- A modest but specific and targeted suite of short-list option areas (3) address the objective related to ‘***Aboriginal rights and interests’***. These are aimed at collaboration and supporting business opportunities and place-based initiatives for cultural outcomes. The review team notes that there is a commitment to, and several actions identified in the Consultation Paper to support deliver of this objective. Preliminary mapping, the sufficiency of options, and the potential for other options to also consider this objective would need to be tested with Aboriginal groups.
- A smaller suite of options map to the ‘***enable economic prosperity***’ objective, consistent with dependency relationships between objectives and the achievement of outcomes related to environmental, community water and Aboriginal rights and interest being foundational to achieving economic outcomes.
- The ‘***affordability***’ objective is not addressed by short-list option areas per se and can be considered a lens through which to pass options. The review team suggest that this objective

will be well-supported by a systems-based approach that considers opportunities for multiple benefits and cooperative action across complementary plans and strategies.

4.3 Insights

Focusing on the <u>three priorities</u> for this review, the review team found a strong emphasis on the options related to water security, a modest focus on water quality, and a very weak focus (just one action area) on flooding.

RWS objectives provide a useful organising framework for assessing the sufficiency of options. The contextualisation of these in the FNC context (via challenges) places emphasis on economic and then environmental aspects[65]. However, there is potential for options designed to '***deliver and manage water for local communities***' to be in tension with options designed to '***enhance the environment***' in situations where water is scarce. Adopting a systems approach offers an opportunity to frame the prioritisation of short-list action areas in the context of RWS objective dependencies, highlighting the dependency of long-term sustainable community and economic outcomes on meeting environmental and Aboriginal objectives (e.g. valuing and mapping cultural assets and water requirements) and exploring options that might achieve synergies.

Overall the RWS objectives are generally well serviced by the short-list option areas, however, and specific options to address flooding are weak. The review team notes that flooding is only implicitly represented in the objectives framing (within the '***deliver and manage water for local communities***' objective). Further, '***affordability***' is not specifically addressed, although the review team understands that affordability is considered to be implicitly addressed through the selection of options that generate economic value.

A broader analysis of other actors and objectives (beyond the RWS) in the system revealed many potential entry points for considering complementarity of options under the RWS with objectives and outcomes sought in related place-based regional development and environmental strategies and plans. Examples may include, but not be limited to, for example, combining green infrastructure solutions with re-zoning to address flood risk, providing multiple benefits to biodiversity, water quality, local recreation, amenity, tourism potential, as well as mitigating property damage and reducing emergency and disaster response impacts. A broader systems approach is likely to help identify suites of options that provide a better overall benefit to cost ratio when multiple benefits are considered, noting that appropriate CBA and evaluation methodologies that can account for qualitative and quantitative assessment of benefits, and ensure internal consistency (e.g. no double-counting of benefits etc.) will be required for this (see 3.9 for more detail).

As discussed in 3.9, the distillation of long-list to short-list too early on in a process potentially misses the opportunity to explore the options in the context of the complementarity to broader

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[65] However, the review team notes that during extreme events priority is to secure basic landholder rights and essential town water supplies. Source: NSW Government Department of Planning, Industry and Environment 2020 Regional water strategies–guide, September 2020 (nsw.gov.au) . Regional Water Strategies Guide 2020, p.4- Accessed 8 September 2021.

strategies, or to explore value creation and map broader sets of benefits and beneficiaries that might be possible through assessing a wider set of options. The use of 'options and pathways' analyses that focuses on 'low-regrets' investments provides a framework to make policy and investment decisions when dealing with high levels of uncertainty about population, economic settings, and inadequate data for some of the analyses, as is the case in the RWS[66]. Rather than risking the unintended consequences of a large but potentially unnecessary investment decision this type of approach enables actors to keep options broad for as long as possible, revealing potential interconnections that could deliver multiple benefits and reduce cost benefit ratios.

The systems analysis undertaken in this review addressed consistency, dependencies, sufficiency, tensions and cooperation at the regional scale, as well as higher level system considerations for pathways to implementation of strategy. It provides a framework to support the application of a systems approach to delivery of the draft RWS objectives and offers a template for the incorporation of systems approaches in regional water strategies in NSW.

Finally, while community engagement was not a focus of this review, meeting the objectives for the RWS requires ongoing consultation across a broad set of actors to support finalisation and delivery of the RWS, noting the important insights, cultural and local knowledge held by Indigenous communities and local stakeholders.

[66] See Footnote 38 for relevant references.

5 Scenarios and options

As discussed in the previous chapter, to the extent that documentation was made available at the time of review, CSIRO found it challenging to interpret and understand the full extent of DPE's option development and review process. It was also unclear which options had been set aside, rather than discarded, because they were viewed as being addressed by a different agency, program or level of government; or integrated into other options. Finally, the review team notes that review and assessment of options was limited to those options where there is sufficient data to support a CBA or ecological assessment. While this is understandable, it is important to recognise that several potential options were eliminated on this basis, for example groundwater recharge.

Recommendation 25 - The review team recommends that the RWS highlight activities or commitments that other agencies or actors wholly or jointly undertaking work that complements the objectives of the RWS, noting that the extent to which this is undertaken is a negotiated process. Guidance is offered through the systems approach discussed in Chapter Four.

The review team found that DPE's hydrological models needed to be pushed to extremes to generate water scarce outcomes and this has meant that investment in the five combinations of options that impact supply, demand or allocation of water (i.e. those options that underwent a detail CBA) is not justified.

This doesn't mean that the FNC is without water security challenges. Existing storages are able to supply the region for most of the years, so it is in the event of inter-annual shortfalls that regional water security is likely to be threatened. However, current climate projections don't indicate a significant drying trend of this nature over the next few decades. This suggests a focus on low-regrets decision pathways that keeps option open for the future as more information becomes available.

The FNC region regularly experiences high levels of intra-annual variability, which is well-described in existing hydrological models and the lived experience. These events can impact communities, businesses and natural systems. To support the extension of scenarios and options, the review team has developed three hypothetical scenarios to illustrate how the risks of intra-annual variability may be mitigated to some extent. These scenarios focus on the use of smaller and lower cost infrastructure.

5.1 Mitigation of intra-annual water security risk

1. **Intense shortfall of 7 - 10 days affecting Lismore.** The response to this scenario focuses on water security for Lismore. Construction of one or several dedicated ring tanks to capture and hold high security water above Lismore and effective use of managed aquifer recharge in the vicinity of Lismore (subject to characterisation and suitability of the underlying aquifers) are proposed in order to provide sufficient water to buffer Lismore through periods of acute water scarcity. This scenario effectively bundles longlist options or elements therein of Option 17 'increased on-farm storage', Option 18 'off-stream storages, and Options 37-39, which focus

on the use of groundwater resources. This type of analysis may also be extended to other urban centres within the FNC region.

2. **Less intense but longer shortfall of 30 - 60 days affecting Lismore and surrounding settlements.** The response to this scenario deploys the investment described in scenario 1 and Option 1 of the RWS ‘interconnection of independent water supplies in the region to the Rous County Council network’. This type of analysis may also be extended to other urban centres within the FNC region.
3. **Mitigation of low-water flow events.** The response to this scenario encourages more effective use of water releases from Toonumbar Dam to flush the system, with a focus on achieving improved environmental and water quality outcomes. Toonumbar Dam is currently identified as an option (Option 3) in the long-list to augment town water supplies, whereas this scenario reorientates the focus to water quality and management of environmental outcomes.

5.2 Conjunctive management of water security and flood risk

As discussed in Section 3.7, flood volumes for rare events (e.g. 1% AEP) are much larger than volumes of future or planned storage infrastructures. Strategies that combine green infrastructure solutions with well thought through development controls to reduce risk (e.g. limits on new development in flood prone areas, strengthening of critical assets, relocation of critical services from at risk zones) must be at the forefront of planning to manage for such events. Nevertheless, several interventions may be effective in helping to ‘shave the top’ off small to moderate flood events, potentially reducing damage and also improving water security.

The following examples illustrate how the RWS may conjunctively address the issues of water security and flood mitigation:

1. Together, Option 18 ‘development of a grid of off-stream storages in the FNC region’ and Option 15 ‘increased harvestable rights’, raise the prospect of creating targeted instream or off-stream storages to capture the surplus water available during wet periods in order to increase water security during extended dry periods. Such an intervention may also perform a small but important role to reduce peak flood impact in specific areas.
2. Option 9, targeted ‘managed aquifer recharge’ also creates the possibility of harvesting flood water for use in drier periods.

6 Recommendations

This review has been undertaken on the understanding that DPE intends to finalise the RWS in early 2022. DPE has asked CSIRO to frame recommendations as follows:

1. Activities that could be undertaken within a few months to support finalisation of the strategy.
2. Priority activities to support delivery of the RWS over the next 3–5 years, once approved and implemented.
3. Guidance to improve regional water strategies when they are reviewed.

The review team recognises that the process to develop the RWS has not been straightforward and acknowledges the value provided by detailed analyses in support of the production of the draft RWS, Long-list, Consultation Paper and relevant supporting documents. The process for developing the RWS is consistent with current policy and process requirements and meets those immediate needs – and has done so in a very short timeline.

The review team also acknowledges that the RWS is being developed at a time of change and uncertainty: in our understanding of the hydrology, hydroclimate, physical geography, socio-economic conditions and demographic change; and in the emerging expectations / requirements for how projects will be developed, assessed and financed in future. Although these latter considerations are not a barrier to finalising the RWS, they are likely to be challenges to implementation of many of the options – especially those requiring financing for infrastructure. Through the systems analysis, the review team has therefore considered whether there are opportunities to improve the RWS and option development to meet these emerging funding and financing requirements (outlined and exemplified in section 2.3.1).

The Far North Coast Region is different to most other regions in regional NSW where the mean annual rainfall and runoff are higher and regular flooding (and associated damages) need to be considered together with water security when developing a RWS. Flood management is identified as a regional water strategy objective and is well-described in the RWS, however, there is only basic consideration in the Long-list and Consultation Paper. This may be an artefact of having a state-wide regional water strategy guidance/template, where (in most years) flood risk is not a significant concern. A system-wide view of the hydrological system is important for the RWS, in particular where conjunctive management of water security and flood risk may be beneficial.

The FNC region has high annual rainfall and hydroclimate projections suggesting that it is only under extreme conditions that water security in the region is likely to be stressed (for short periods – weeks to months). This is not adequately expressed in the RWS, which is currently restricted to the reporting of mean annual metrics in the modelling despite the fact that underlying models are running at short (daily) time steps. This masks the risk of intra-annual variability especially during drier years, which may result in pockets of water stress for both the consumptive pool and natural systems. The review team found that the DPE hydroclimate models had to be pushed to the extremes to stress test water security in the region – a consequence of high average annual rainfall. This process, however, exposed several limitations and uncertainties around the approaches and also the underpinning datasets for the hydrology and CBA assessments. This was further complicated by a constrained and opaque short-listing process that did not map well to the full suite of RWS objectives. In the documentation provided to CSIRO it is not clear which options had been set aside, rather than discarded, because they were viewed as being addressed by a different agency, program or level of government; integrated into other options; or identified as economically unviable. Restriction of assessments to those options where there is available data, while practical, also raises the question of whether it is premature to cull individual or combinations of options at this stage.

On the basis of the review team's assessment of hydroclimate conditions and projections, and drawing attention to the significant gaps in knowledge as identified through the 27 investigations proposed in the Consultation Paper, the review team believes that it is premature to distil long-list to short-list options and combinations. It is likely to be more beneficial to proceed on no or low regrets pathways, which hold open the opportunity to explore options (and packages of options) in the context of the complementarity to broader strategies, or to explore value creation and map broader sets of benefits and beneficiaries. Such an approach may also enable DPE to develop options that are more likely to align with emerging project development, assessment and financing requirements at state and national level.

6.1 Activities to support finalisation of the RWS in the coming months

6.1.1 Identify and describe environmental assets in the region and identify associated assessment metrics

Post review note: after delivery of this review DPE completed the environmental assessment. The review team supports a reconciliation by DPE of these outputs against CSIRO's recommendations.

Environmental preservation is one of the core objectives of the strategy. This is important in the Far North Coast region which is recognised for its rich biodiversity and highly valued environmental assets. Numerous options reveal the importance of positive environmental outcomes, however, it appears this is more *ad hoc* than by design.

Recommendation 13 - The review team recommends that the environmental assessment of proposed options be included in the Consultation Paper to enable a robust options assessment process that meets the objectives of the RWS. This should extend to include a greater emphasis on environmental objectives for water dependent systems, and reporting on environmental assets and indicators that are responsive to hydrological change. If a short-listing process occurs prior to finalisation of the RWS then the environmental impacts should also be reported on in the updated Consultation Paper. Two examples are offered that may assist DPE to extend the environmental evaluation process:

- *Environmental assets description:* The review panel suggests performing a study aimed at identifying, characterising, and prioritising environmental assets in the region. An example of a similar study is provided by Pollino et al. for the Fitzroy catchment in Northern Australia[67].

- *Environmental metric selection:* Metrics targeting key environmental assets may be based on hydrological or hydrodynamic simulations (e.g. inundation depth, duration, frequency). Examples of such metrics can be found in Pollino et al. (see Table 3.1).

Specific in-chapter recommendations are repeated here for ease of access:

- Recommendation 10 - Consider introducing evaluation metrics, which will be suitable to compare the impact of options on short dry and wet spells (water security and flood risk) within a given year instead of the currently used mean annual demand shortfall.
- Recommendation 11 - Consider the adoption of low flow metrics to complement the water resource assessment such as the number of days during a year where shortfall is greater than, say, 10% of the total demand of the year.
- Recommendation 12 - The review team recommends introducing additional sub-annual metrics focusing on low flows within a year.
- Recommendation 14 - The review team recommends investigation into the timing and severity of low flows and poor water quality (e.g. impact of nutrient loads and salinity) in the Richmond river and how this may be mitigated.

6.1.2 Hydrological model performance assessment using cross-validation

The draft RWS relies significantly on hydrological simulations to assess the present water resources of the region and the impact of proposed options. However, the review team identified that the performance of hydrological models outside of their calibration range has not been estimated by DPE. This raises the concern that the capacity of these models to simulate extreme dry or wet periods remains unknown and the models may not be able to accurately stress test the system.

- Recommendation 26 - Considering that streamflow records longer than 20 years are available for many stations in FNC[68], the review team, following the eWater Guidelines for rainfall-runoff modelling[32], recommends that DPE conducts an assessment of hydrological model performance in both headwater and residual catchments using a well-established cross-validation approach. The performance metrics to be reported should include at least mean daily simulation bias, daily Nash-Sutcliffe efficiency[69] and daily Nash-Sutcliffe

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[67] Pollino C, Barber E, Buckworth R, Cadiegues M, Cook G, Roy A, Deng, Ebner B, Kenyon R, Liedloff A, Merrin L, Moeseneder C, Morgan D, Nielsen, D, O'Sullivan J, Reyes RP, Robson, B, Stratford D, Stewart-Koster B, Turschwell M 2018 Synthesis of knowledge to support the assessment of impacts of water resource development to ecological assets in northern Australia: asset analysis. A technical report to the Australian Government from the CSIRO Northern Australia Water Resource Assessment.

[68] Real time streamflow data, Water NSW, https://realtimedata.waternsw.com.au/, accessed on 18/01/2022.

[69] Nash JE, Sutcliffe JV 1970 River flow forecasting through conceptual models part I - A discussion of principles. Journal of Hydrology, 10(3), 282–290. https://doi.org/10.1016/0022-1694(70)90255-6

efficiency computed from reciprocal transformed flows[70]. Other metrics could be reported as well, such as bias on certain portions of the flow duration curve[71].

Specific in-chapter recommendations are repeated here for ease of access:

- Recommendation 3 - Climate data and modelling methodologies should be consolidated into a single report for ease of access.
- Recommendation 4 - Richmond and Tweed reports be revised to include updated information on data quality such as the number of gauging stations and the amount of extrapolation beyond the maximum gauged flow.
- Recommendation 6 - Richmond and Tweed reports be revised to include updated information on rainfall–runoff model calibration methodology, calibration statistics and values of parameters obtained at the end of this process.
- Recommendation 7 - Conduct a thorough review of rainfall–runoff model performance using a rigorous leave-out validation scheme when long streamflow records are available as is the case in the FNC.
- Recommendation 8 - Richmond and Tweed conceptualisation reports are updated to clarify river reach model calibration, particularly how transmission losses are setup, how they are calibrated and how much they amount to compared to inflows and outflows. Further clarification on how the hydrological models were calibrated to measure medium to low flows within the tidal zone is also recommended.
- Recommendation 9 - Develop and use a rigorous leave-out validation scheme to evaluate the capacity of hydrological model performance in residual catchments in extrapolating beyond calibration conditions similarly to rainfall-runoff models in headwater catchments.

The review team notes that with appropriate resourcing this task may take up to six months.

6.1.3 Clarify and update future climate data

As indicated in this review, there is a need to clearly state that the patch point dataset has been used to represent climate for all the analysis undertaken to support development of the RWS. The review team has also identified that the use of monthly scaling factors to convert stochastic scenario to future climate scenario is likely to mask the impact of flooding. The review team recommends that:

- Recommendation 27 - Consider replacing static monthly scaling factors with more appropriate methods such as quantile–quantile mapping implemented for different time

[70] Pushpalatha R, Perrin C, Moine N Le, Andréassian V 2012 A review of efficiency criteria suitable for evaluating low-flow simulations. Journal of Hydrology, 420–421, 171–182. https://doi.org/10.1016/j.jhydrol.2011.11.055

[71] Lerat J, Thyer M, McInerney D, Kavetski D, Woldemeskel F, Pickett-Heaps C, Shin D, Feikema P 2020 A robust approach for calibrating a daily rainfall-runoff model to monthly streamflow data. Journal of Hydrology, 591. https://doi.org/10.1016/j.jhydrol.2020.125129

windows[72] or potentially more advanced methods such as the Multivariate Recursive Nesting Bias Correction approach[73].

Specific in-chapter recommendations are repeated here for ease of access:

- Recommendation 1 - Provide a concise summary of baseline annual water availability in the region under both historical and future climate and combined with a current or no development scenario.
- Recommendation 2 - Extend the climate projections beyond the driest scenario from the NARCliM analysis to include other most likely scenarios.
- Recommendation 5 - Consider the inclusion of sub-daily hydrological models for modelling flood impact as part of future modelling work undertaken by DPE in the Far North Coast region.

The review team notes that the activity to review and consolidate the methodology could be completed within a few months, but model revision may take six to 12 months depending on resources. DPE will need to evaluate the benefit of finalising the RWS sooner rather than later, noting that underpinning results may change.

6.1.4 Early steps and signposts to a broader systems approach

The review team has identified the benefits of adopting a systems approach at various points in this review. As stated by Infrastructure Australia, in their collaboration with Infrastructure NSW

> *The infrastructure planning phase offers the most significant opportunity to plan for and achieve resilience. The decisions made at this stage establish the trajectory for the remaining phases of the infrastructure lifecycle. It is the stage when key decisions like location, design and management of assets are made, and interdependencies between assets are identified. There are also opportunities to build shared responsibility for outcomes between all stakeholders, including governments, infrastructure asset owners and operators, the community, Aboriginal and Torres Strait Islander people, and emergency services[74].*

Where possible, a systems approach is best adopted early in the process as this supports activities such as identifying opportunities for multiple-benefits, avoiding perverse outcomes, identifying the most effective levers and intervention points and developing cost-sharing arrangements. This thinking then needs to flow on into the implementation stage. Several activities are recommended over the next few months to enable the RWS to move towards a broader systems approach in the future, as may be necessary as indicated by emerging national and state planning and finance requirements (section 2.3.1).

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[72] Wilby RL, Charles SP, Zorita E, Timbal B, Whetton P, Mearns LO 2004 Guidelines for Use of Climate Scenarios Developed from Statistical Downscaling Methods. Analysis, 27(August), 1–27. http://www.ctn.etsmtl.ca/cours/mgc921/dgm_no2_v1_09_2004.pdf.

[73] Mehrotra R, Sharma A 2015 Correcting for systematic biases in multiple raw GCM variables across a range of timescales. Journal of Hydrology, 520, 214–223. https://doi.org/10.1016/j.jhydrol.2014.11.037.

[74] Infrastructure Australia 2021 A Pathway to Infrastructure Resilience - Advisory Paper 1: Opportunities for systemic change.

- Recommendation 25 - Highlight in RWS complementary activities or commitments that other agencies or actors are wholly or jointly undertaking. Parallel work that complements the objectives of the RWS should be documented in order to support a more integrated approach, noting that the extent to which this is undertaken is a negotiated process.
- Recommendation 28 - Identify agencies for potential cooperation. Identify agencies with carriage of strategies and plans with complementary visions and objectives, as pointers to cooperation in a broader place-based systems context in the longer term. Include in RWS.
- Recommendation 29 - Include an activity to map options or combinations of options to multiple objectives / benefits. Building on the examples offered in the systems review, map out a broader suite of options connected to the water subsystem, including for example consideration of green infrastructure, that could have multiple benefits and help achieve improved cost-benefit ratios across multiple benefits to community and the environment.
- Recommendation 30 - Map out longer-term pathways to project development, assessment and financing. There are many changes underway not only in the communities and places of the Far North Coast, but also in the context within which strategies might be implemented through projects over the next few years. Gaining a clearer line of sight over these changes and adjusting strategy development to align is an opportunity to manage risks and strengthen implementation pathways.

6.1.5 Finalise supporting documentation

Several supporting documents and reports were provided to the review team in a draft form. In some cases this meant it was not possible to fully review methods and outputs. The review team anticipates that these contributions will be finalised prior to publication of the RWS.

Specific in-chapter recommendations are repeated here for ease of access:

- Recommendation 16 - Prior to finalisation, the strategy and supporting documents are updated to ensure consistency across the RWS.
- Recommendation 17 - Update the Consultation Paper to the report to include full coverage of short-listing, prioritisation and bundling assessments and all sensitivity analyses.
- Recommendation 18 - Greater clarity is provided on the current level of knowledge and planning (where that is relevant) for each of the options under consideration.
- Recommendation 20 - Several specific recommendations are offered to improve readability and transparency of the RWS.

6.2 Activities to support delivery of the RWS – up to five years from implementation

The seven challenges identified in the Consultation Paper are well thought through and proposed actions are supported by the review team. To complement this, several additional studies are recommended.

6.2.1 Develop and test models allowing a combined assessment of flood and water security options

Several options that address RWS objectives are likely to emerge through an investigation that jointly considers water security and flood risk mitigation for small to moderate floods (<10% AEP). For example, investigation into the harvesting and storage potential of flood water through off stream storages or groundwater recharge may offer the required buffer to communities and for natural systems during drier periods.

- Recommendation 31 - The review team recommends that DPE invests in simplified flood models for the FNC region that can be combined with outputs from existing hydrological models to provide a rapid assessment of flooding impacts. The main benefit of these models will be to enable joint assessment of water security and flood mitigation options. A simplified hydrodynamic (flood risk) component should be able to estimate flooding extent in the region for a wide range of multi-year stochastic scenarios. This could be supported by more detailed 1D or 2D hydrodynamic models for specific high-risk areas such as Lismore. Ideally the model will extend to cover the Richmond and Tweed catchments to allow the setup of a fully dynamic connection between these areas.

  A detailed study for one of the basins in the region (e.g. the Wilsons catchment as initially flagged by CSIRO) is recommended to enable development of a methodology capable of addressing water security, flood risk / mitigation and environmental flow (and water quality) options jointly. Such a study could serve as a template for other basins in the region and, potentially, for the Mid North Coast and South Coast regional water strategies.

Specific in-chapter recommendations are repeated here for ease of access:

- Recommendation 15 - Undertake relevant flood risk assessments for small to moderate floods (<10% AEP) and incorporate flood risk modelling into hydrological assessments. Options should be revisited in light of this new data.

6.2.2 Detailed studies

This review has identified the need for several studies to be undertaken to better inform the development of options to support the implementation of the RWS. These are now briefly described, aligned to the objectives of the RWS.

- Recommendation 32 - Land capability assessment – The review team supports the current DPE three-year program to identify and map important agricultural lands. Depending on the extent of this work, more detailed investigations are recommended to be undertaken as part of land suitability assessment. The output, digital land suitability data and maps of the region, will identify areas that are more or less suitable under different combinations of land use and irrigation systems, as well as for aquaculture.
- Recommendation 33 - Agriculture viability and socio-economics – The benefit assessment for the RWS assumes that agricultural production can be expanded if more water is secured over time. This assumption needs to be evaluated to better understand how

agriculture within the FNC region may be expanded in response to water availability and efficiency of use. The review team recommends a study to model predicted land use change and impacts that could inform selection and development of options, which would be complemented with a spatial econometric study to evaluate direct benefits to the region as well as flow-on of benefits (including regional value added) to the region and state.

- Recommendation 34 - Surface water storage options – The review team recommends more detailed analyses of surface water storages than that suggested in the Consultation Paper to provide a comprehensive overview of the different surface water storage options in the region, including the potential to use existing storages more effectively (e.g. Toonumbar dam). This should extend to include pre-feasibility assessment of a range of instream and off-stream storages and the potential to locate these as distributed systems on public and / or private land.
- Recommendation 35 - Groundwater – The review team notes and supports the recommendations in the Consultation Paper to undertake detailed studies to characterise groundwater aquifers in the FNC region in order to understand how groundwater resources could support natural systems and may be used to buffer water supply. The review team has also highlighted the potential for groundwater recharge using flood water during small to medium events. In the absence of these detailed studies, it is premature to consider potential groundwater resources as options to support future storage, supply and natural resource management solutions.
- Recommendation 36 - Water quality – Declining river and catchment health remains a challenge for the FNC. The systems review identified environmental objectives as foundational to the success of the RWS, and multiple options are identified to support work towards this goal. The focus for this review has been on the impact of low flows on the environment, and several recommendations are provided. The systems review identified the benefit of mapping options to complementary policies and programs, which then opens up the opportunity to address a range of practices that impact water quality in the Richmond river (focus of this review) and elsewhere. Beyond this, the review team recommends a coordinated approach be adopted to better understand and address the health of rivers and ecosystems in the FNC region, identify environmental water needs and the impact of water infrastructure on ecosystem health and aquatic ecosystems.

6.2.3 Short-listing of options

Post review note: after delivery of this review DPE has made the review team aware of a series of technical analyses and filters that collectively might describe the framework against which options are assessed. The review team supports the publication of a consolidated version of this framework.

Recommendation 37 - Documentation provided to and reviewed by CSIRO does not support a comprehensive distillation of long-list to short-list options and combinations at this stage. Following completion of more detailed studies and revised modelling outputs (using updated modelling methods) the review team recommends that DPE use a transparent framework to 'rapidly' evaluate long-list options and create a meaningful short-list that could be assessed. Several key steps are needed for this approach to be effective:

- Resolution of key knowledge gaps:
    - Understanding and reporting on the impact to environmental assets from hydroclimate change and potential development options.
    - Update reporting of hydrological model outputs to show sub-annual statistics.
    - Update existing hydrological models to improve simulation of extreme wet and dry periods.
    - Development of an integrated (loosely coupled) flood and water security model.
    - Climate change scenario including assessment of impact on extremes wet (floods) and dry (drought) flow regimes at sub-annual level.
- Development of options that are more likely to align with emerging project development, assessment and financing requirements at state and national level.
- Map and value cultural assets and their associated water requirements.
- Prioritise no or low regrets options until supporting studies improve critical knowledge gaps.
- Adoption of a systems approach to options development that encourages the creation of options / combinations of options that realise multiple objectives and benefits.
    - Adoption of an evaluation process that more accurately accounts for costs and benefits, considers systemic risk and value creation / benefit flow opportunities.

Specific in-chapter recommendations are repeated here for ease of access:

- Recommendation 19 - all data and reports are subjected to peer review (where appropriate, external review) and this process is clearly described.
- Recommendation 20 - The review team has offered several suggestions to improve readability and transparency of datasets and modelling of the RWS.
- Recommendation 21 - Explore the performance of combination or bundled options, in particular how a combination of least-cost options performs in relation to a large investment.
- Recommendation 22 - Short-listed options should be assessed against all objectives of the RWS to uncover potential tensions and maladaptive outcomes.
- Recommendation 23 - Consider including a greater focus on the cost of investments as a means of differentiating options. An 'impacts framework' is suggested to complement quantitative and qualitative assessments of options or portfolios of options.

- Recommendation 24 - Economic analysis of options should be extended to include the potential to mitigate future flood damages (i.e. the opportunity cost of saving future cost impacts), with a particular focus on small to moderate floods (<10% AEP).

6.2.4 Develop and apply a systems approach

Recommendation 38 - Consistent with scoping and early activities conducted as part of recommendations outlined in section 6.1.4, the review team recommends the application of a systems approach including the BCA consistent with meeting the RWS objective of affordability, inclusive of multiple benefits across the broader system, and meeting the emerging requirements of Infrastructure Australia, Infrastructure NSW, and numerous other funding sources. According to Infrastructure Australia taking a systems view requires defining the outcomes and actions needed across all systems levels, including governance and coordination, place, assets and community[75]. They outline 10 directions for system change across these system levels. Clearly, this will require broad engagement across government, business and community – and a staged approach will be needed consistent with whatever broader approach is taken by the NSW Government in the coming months and years.

6.3 Guidance to improve regional water strategies at review

The review team has identified several recommendations for consideration that may support the long-term delivery of regional water strategies in NSW.

- Recommendation 39 - Revision of guidance and production of templates to reflect a systems approach to the development of regional water strategies, aligned with the approaches being outlined by Infrastructure Australia (in collaboration with Infrastructure NSW)[76], and across other areas of and levels of government in NSW.
- Recommendation 40 - Distinguish ‘regional water strategy’ regions, where appropriate, to better differentiate system risks, knowledge gaps and opportunities. This process would identify where more attention needs to be given to certain objectives and would create transferability between regions across NSW with broadly similar challenges such as flood risk and sea level rise (e.g. Far North Coast, Mid North Coast and South Coast).
- Recommendation 41 - Consider whether to rebalance current legislated priority to service basic landholder rights and essential town water supplies, towards also addressing the maintenance of essential ecosystem function / services that underpin regional systems and prosperity.

[75] Infrastructure Australia 2021 A Pathway to Infrastructure Resilience Advisory Paper 1: Opportunities for systemic change.

[76] Infrastructure Australia 2021 A Pathway to Infrastructure Resilience Advisory Paper 1: Opportunities for systemic change.

Appendix A Documents reviewed

Table 6 Documents provided to CSIRO

Document type	Title	File name	Authors
Regional Water Strategy			
Report	Regional Water Strategies guidelines	rws-guide.pdf	NSW Government
Report	Draft Regional Water Strategy Far North Coast: Strategy	REP_Kit2_Draft-rws-fnc-strategy.pdf	NSW Government
Report	Draft Regional Water Strategy October 2020 Far North Coast: Long list of options	REP_Kit3_Draft-rws-fnc-longlistoptions.pdf	NSW Government
Report	Short-listed actions for the Far North Coast region: Consultation Paper	DRAFT Far North Coast RWS for Pub Ex 2_Shortlist Actions_20211014.docx	NSW Government
Report	Regional water strategy – Far north coast region: Regional context and water security options 2019	REP_DoIWater_Far North Coast RWS Interim Report_V2_20190711_DH_DR	NSW Government
Program Logic Mapping			
RWS supporting documentation	Far North Coast Regional Logic Map	PLM_FarNorthCoastRegionalLogicMap_V2_20210803.xlsx	NSW Government
RWS supporting documentation	Far North Coast Problem Statement Industries	SUM_FNC_Problem_Statement_Industries (reg and unreg systems)_V4_20210716.docx	NSW Government
RWS supporting documentation	Far North Coast Problem Statement Environment	SUM_Problem statements_Far North Coast RWS_for IAP Environment reps.docx	NSW Government
RWS supporting documentation	Far North Coast Problem Statement Town Water Security	SUM_Problem statements_Far North Coast RWS_TownWaterSecurity_V3_20210813_DH.docx	NSW Government
Climate modelling			
Report	New climate analysis informs	nsw-climate-model-report.pdf	NSW Government

Document type	Title	File name	**Authors**
	NSW's regional water strategies		
Report	Independent review of the climate risk method for the NSW Regional Water Strategies Program	REP_ChiefScientist&Engineer_IndependentReviewClimateRiskMethodsForRWS_20200402.pdf	NSW Government
Report	Multisite Rainfall and Evaporation Data Generation for the Macquarie Water Infrastructure Project	MacquarieRiver_StochasticGeneration_FinalReport_20190115.pdf (and appendices)	NSW Government
Report	Multisite Rainfall and Evaporation Data Generation for the Macquarie Water Infrastructure ProjectAddendum – Updated Simulation with Additional Sites	MacquarieRiver_StochasticGeneration_Addendum_20190619.pdf	NSW Government
Report	Far North Coast Region Stochastic Evaluation	REP_UniverstyOfAdelaide_StochasticClimateGeneration_AnnexD_FarNorthCoast_20200422.pdf	University of Adelaide
Hydrologic modelling			
Report	Source Model Conceptualisation - Tweed Valley *(referred to in this review as "Tweed conceptualisation report")*	REP_ModelConceptulisation_Tweed_v0.4_20190904_DR_JK.docx	NSW Government
Report	Hydrologic analysis of options for the Tweed River System *(referred to in this review as "Tweed analysis report")*	REP_OptionsModelling-Tweed_draft-30Sep21.docx	NSW Government
Report	Source Model Conceptualisation - Richmond Valley *(referred to in this review as "Richmond conceptualisation report")*	REP_Model_Conceptulisation_Richmond_Draft-v0.8.docx	NSW Government
Report	Hydrologic Analysis of Options for Regional Water Strategies	REP_OptionsModelling-Richmond_draft_V3_20210828.docx	NSW Government

Document type	Title	File name	**Authors**
	Richmond Valley *(referred to in this review as "Richmond analysis report")*		
Presentation	Rocky Ck Dam Storage Volume Analysis	PRE_RICH-model-outputs -for-FNC-RWS_includingForecastDemand_20200626.pptx	NSW Government
Presentation	Hydrological Modelling of Richmond Basin	PRE_RICH-model-outputs-for-RWS_Kit2-questions-v2-_20200428_DD.pptx	
Presentation	Tweed Model Outputs for RWS	TWEED-model-outputs-for-RWS_Kit2-questions-v6.pptx	NSW Government
RWS supporting documentation	ANNEX A Richmond Site−by−Site Annual Rainfall Totals (mm) 129 Year Period 1−, 2−, 5−, 10−Year Accumulations 90%Confidence Interval from 77 Replicates	Richmond_Annex.pdf	NSW Government
RWS supporting documentation	ANNEX A Tweed Site−by−Site Annual Rainfall Totals (mm) 129 Year Period 1−, 2−, 5−, 10−Year Accumulations 90%Confidence Interval from 77 Replicates	Tweed_Annex.pdf (and appendices)	NSW Government
Economic Analysis			
Presentation	Far North Coast Rapid CBA Results Preliminary Results August 2021	OUTPUTS_FNC_RapidCBA.pdf	NSW Government
Presentation	Far North Coast Portfolio/Detailed CBA Results Preliminary Results August 2021	OUTPUTS_FNC_Portfolio-DetailedCBA.pdf	NSW Government
Presentation	Far North Coast Economic Base Case Preliminary Results August 2021	OUTPUTS_FNC_EconomicBaseCase.pdf	NSW Government

Document type	Title	File name	Authors
Presentation	Department of Planning, Industry and Environment Options Assessment Process Overview November 2021	GOVP1557_DPIE_WATER_OPTIONS ASSESSMENT METHODOLOGY_GENERIC V1A.pdf	NSW Government
Report	Memo DPIE Regional Water Strategy Infrastructure Costings: Updated assumptions and cost basis for cost model (based on feedback from Gwydir, Macquarie and Lachlan regions)	Assumptions_Cost basis_Memo_Updated 07.05.2021.pdf	Arup
Supporting documentation	DPIE Cost Model First six regions UPDATED	DPIE Cost Model_First six regions_UPDATED_30042021.xlsx	Arup
Report	Regional water value functions. Values for inclusion in the cost-benefit analysis to support NSW Regional Water Strategies 2 February 2021	210202 Regional Water Value Functions - Final Report.docx	Marsden Jacob Associates
Supporting documentation	Margin analysis - permanent crops	210202 Margin analysis - permanent crops.xlsm	Marsden Jacob Associates
Supporting documentation	Town water supply shortfall costs	210202 Town water supply shortfall costs.xlsx	Marsden Jacob Associates
Supporting documentation	Margin analysis - annual crops	2102002 Margin analysis - annual crops.xlsm	Marsden Jacob Associates
Additional documentation supplied by DPE			
Strategy	NSW Marine Estate Management Strategy	REP_MEMA_NSWMarineEstateManagementStrategy2018-2028_2018.pdf	NSW Government
Report	Rous County Council Bulk Water Supply. Demand Forecast: 2020 – 2060. Draft Final Report. 2020	REP_RousCountyCouncil_Hydrosphere_RousCountyCouncilBulkWaterDemandForecast2020-2060_V1_20200414 (1).pdf	Hydrosphere Consulting
Report	Tweed Shire Council. Tweed District, Uki and Tyalgum Water Supplies: Demand Forecasts. 2014	REP_TweedShireCouncil_Hydrosphere_TweedShireDemandForecasts_2014 (1).pdf	Hydrosphere Consulting
Supporting documentation		RAW_RWS Data Sources - LGA population forecasts	NSW Government

Document type	Title	File name	Authors
Supporting documentation		STA_population_projections	NSW Government

Table 7 Additional documents reviewed

Document type	Title	File name	Authors
Report	Rous Regional Supply: Future Water Project 2060. Integrated Water Cycle Management Strategy. Draft for Public Exhibition. March 2021.	Rous-CC-future water project 2060.pdf	Hydrosphere Consulting
Strategy	A 20-Year Economic Vision for Regional NSW (February 2021)	20 Year Vision for RNSW_0.pdf	NSW Government
Plan	2036 North Coast Regional Plan	north-coast-regional-plan-2017.pdf	NSW Government
Strategy	Northern Rivers Regional Economic Development Strategy	Northern-Rivers-Regional-Economic-Development-Strategy-1.pdf	NSW Government
Policy	Greener Places Policy	Greener places 2020 06 02.pdf	NSW Government
Plan	Strategic Conservation Planning	https://www.planning.nsw.gov.au/Policy-and-Legislation/Strategic-conservation-planning	NSW Government
Plan	Northern Rivers Regional Biodiversity Management Plan 2010	northern-rivers regional biodiv management plan.pdf	NSW Government
Plan	Far North Coast Regional Conservation Plan	FNC Regional Conservation Plan.pdf	NSW Government
Strategy	Australia's Strategy for Nature	Australias-strategy-for-nature.pdf	Commonwealth Government
Framework	Infrastructure Australia Assessment Framework	https://www.infrastructureaustralia.gov.au/publications/assessment-framework	Commonwealth Government
Plan	Lismore Floodplain Risk Management Plan 2014	Lismore_floodplain_Risk_Management_Plan.pdf	Lismore City Council
Manual	Floodplain Development Manual. The management of flood liable land. April 2005	floodplain-development-manual.pdf	NSW Government

Appendix B Description and reconciliation of project activities against workplan

Table 8 Reconciliation of activities with workplan

Activity	Completed	Notes
Activity 1 – Review of the short-list of options developed for the draft Regional Water Strategy		
1. Met with the key members of DPE, including members of the Environment, Energy and Science Group, to understand work that has been undertaken since the draft Far North Coast RWS was released, and secure access to all relevant documentation, data and model documentation.	Yes	Meeting on 4 November

2. Reviewed draft Regional Water Strategy taking into consideration:
• Existing climate (historical and future), biophysical (landscape and river systems) and flood modelling that has been done to underpin the strategy, and the interpretation of the biophysical modelling results that were used to formulate the strategy. DPE compiled a document register and provided CSIRO with a comprehensive set of relevant references for review. More specifically, this aspect of the review:
  • Identified potential interactions between options in the draft Regional Water Strategy and flood management projects undertaken by local authorities
  • Defined knowledge gaps in the draft Regional Water Strategy in relation to climate change and flood mitigation.
	Yes	Relevant report section – Chapter Three

Activity	Completed	Notes
• Documented existing and projected water demand from industry / agriculture, environment and communities, inclusive of water quality considerations. This included consideration of current and future uses for water identified in economic development and regional growth strategies at state and local level.		
3. Reviewed of related documents and data (technical reports, scientific publications, observation networks) supporting the draft strategy and more recent documents where relevant – as directed by DPE and identified through CSIRO's own investigations. Focused on the adoption of a partial systems approach to understand water linkages to broader policy and program directions and how these relate to the RWS.	Yes	Relevant report sections Chapters Three and Four
4. Repeated review with a focus on the proposed short-list of options developed for the draft RWS.	Yes	Relevant report sections Chapters Three and Four
5. Led a virtual workshop process with DPE personnel to enable CSIRO to share thinking around the application of systems approaches to the RWS. This workshop explored several themes: setting and prioritising objectives; reviewing complementarities, potential tensions and trade-offs to meet RWS objectives; and an exploration of the linkages between the 'water system' and broader strategic outcomes. The session concluded with a short presentation and discussion that illustrated how the adoption of systems approaches may benefit the implementation of the RWS.	Yes	Workshop on 24 November

Activity	Completed	Notes
Activity 2 – Using a systems approach with a particular focus on flood risk management, river health and water security, identified and advised the Department on the development of portfolios of actions to achieve the Regional Water Strategy		
1. Reviewed RWS objectives, inclusive of impacts or outcomes for water quality, with a specific focus on the potential for conjunctive management of water security and flood risk. A key aspect of this analysis included the review of systemic risk and cumulative benefits rather than consideration of individual elements of the water system. Defined what we mean by 'systems approach'. A particular focus of the review was on the government approaches (policies, programs) to the management of flood risk.	Yes	Relevant report sections – Chapters Three and Four
2. Provided a broad overview of the nature, frequency and extent of flood risk (past flooding events) to the area under investigation. This was based on existing datasets and technical documents, including single-event and cumulative socio-economic and environmental impacts. The overview briefly summarised the key characteristics of the study area, including recent significant flood events, and highlighted how this physical setup may affect the definition of options for the RWS. The review focused on opportunities to improve methodological approaches to understanding flood risk and identification of future modelling and analyses. Estimates of the socio-economic costs of floods were considered in light of lost or restricted opportunities (for example, efforts focused on flood recovery rather than economic development).	Yes	Relevant report section – Chapter Three Specifically, the broad overview of recent flood events was illustrated via Figures 2 and 4 in this report, including an analysis of streamflow data for selected gauging stations in the catchment, a consultation of past flood risk mapping studies and a proof-of-concept flood mapping tool for Lismore area.
3. Reviewed Cost Benefit analyses provided by the Department and approaches to support a systems-based representation. Focused on	Yes	Relevant report section – Chapter Three

Activity	Completed	Notes
suggesting approaches that span water security, flood risk and water quality elements in a cost benefit analysis or trade-off framework in order to highlight additional costs and benefits. Review team recognised that existing limitations, if any, may be the result of methodological choices and/or limited datasets.		Review team did not perform back-of-the-envelope estimations of additional costs and benefits of options because it risked extending the limitations and uncertainties in the DPE modelling process. Instead, the review focused on discussing potential additional benefits to assess in future evaluations and on advice to support options development using a systems approach.
4. Identified options or portfolios of options to support delivery of the draft Regional Water Strategy objectives with a focus on options that conjunctively improve water security, reduce flood risk in the upper Wilsons catchment and improve river system health.	Yes	Relevant report sections – Chapters Three, Four and Five Review team identified a limited set of potential options due to risk of extending limitations and uncertainties in the DPE modelling process. In addition, the review proposes several specific areas of research that could support the selection of future options.
5. Identify and qualitatively describe potential economic, social and environmental benefits and costs to the region of options, including but not limited to: mitigation of the impact of future floods; social and economic outcomes for communities and assets at risk; and environmental outcomes. Worked with DPE to refine an approach that highlights options and investments that may be delivered primarily through RWS guidance and investments, as well as those that may require a more devolved	Partial	Relevant report sections – Chapters Three, Four, Five, Six, Appendix C Given the challenges of linking the Consultation Paper with the RWS, the review focused more on advice related to benefit of systems analysis to identify connections and benefits.

Activity	Completed	Notes
or broader set of actors. This included options that are most likely to deliver improved financial outcomes, support community and economic resilience, and contribute towards sustainable environmental outcomes (i.e. partial systems approach).		In addition, discussion of potential economic and social benefits were provided in an aggregated level (with a framework), but not for individual options.
6. Development of a framework to support the application of a systems approach appropriate to delivery of the draft Regional Water Strategy objectives. This will include a virtual workshop with relevant DPE staff to demonstrate and refine framework. This activity will focus on developing material to complement or potentially be included in existing guidance for the preparation of Regional Water Strategies.	Yes	Relevant report section – Appendix C Systems approach framework addressing consistency, dependencies, sufficiency, tensions and cooperation at regional scale, as well as higher level system considerations for pathways to implementation of strategy. See sections 2.3, 4 and 5 of report.
Activity 3 – Identify further work (studies, fieldwork), if any, required to support water security, flood risk, land and river health outcomes through delivery of the Regional Water Strategy		
1. Highlighted and described sections of the draft Regional Water Strategy that might need to be refined prior to finalisation. Recommended tasks that can be reasonably undertaken with limited resources and time (i.e. within 1–2 months).	Yes	Relevant report sections – Executive Summary, Chapters Three and Five
2. Reviewed the suitability of the biophysical and socio-economic input datasets, modelling methodologies used to generate future climate and water balance components, future demand scenarios, and interpretation of the modelling results that underpin the RWS. Identified additional socio-economic inputs and further analyses of salient hydrological processes to support delivery of a robust strategy for the region.	Yes	Relevant report sections – Chapter Three

Activity	Completed	Notes
3. Identified and prioritised further work to be undertaken to support ongoing delivery of the Regional Water Strategy Program. Recommendations considered what might be achieved at different timescales to support delivery of Regional Water Strategies (~5–6 months) and the review of existing Regional Water Strategies (3–5 years). This included but was not limited to: • Knowledge acquisition (e.g. data collection). • Knowledge generation (e.g. flood modelling; socio-economic and regional economic development scenarios; and coupling of flood modelling with water security to optimise improved overall outcomes across built and natural assets, for business and for the community). • Guidance on the inclusion of appropriate / relevant systems approaches in Regional Water Strategies with a focus on supporting community resilience and adaptive capacity. • Relevant community and key stakeholder engagement and governance approaches.	Yes	Relevant report sections – Executive Summary, Chapters Three, Five, Six, Appendix C

Appendix C Systems approach

C.1 Background

The project was tasked with considering the specific challenges of flooding, water security, and water quality and providing advice to help finalise a short-list of options for the FNC RWS, for the relatively near-term. Alongside that, the project was asked to include a systems component to consider interactions and linkages relevant to the water context. A systems approach is helpful for providing a broader place-based perspective as context for decisions related to water management actions, and to understand the linkages of the water system to broader policy and program directions. A systems approach can help to realise least-cost (or any other criteria) pathways to water objectives, drawing on complementarity within water strategies and on elements outside the water system. It can help to realise multiple benefits from selecting options that achieve not only the water objective, but also other goals, for example in the community or for the environment. It can also help to avoid perverse outcomes on the goals of other sectors from actions selected to address a water problem, or unintended adverse impacts between objectives within the water sector. Importantly, it is also an emerging requirement for many of the planning and financing mechanisms for infrastructure – at national and international levels, and within government and private sectors.

C.2 Approach

A partial systems approach was taken to reviewing the FNC RWS. Our approach to developing the systems context was to map out elements of the problem and the system, first going wide to gather multiple perspectives, and then moving through a process of conversation, exploration and analysis to distil and converge on key findings. These findings can guide DPE in the process of identifying options or a portfolio of options for the RWS, in a systems context.

Inputs to our systems analysis included information about the remit, challenges, objectives, visions and goals for the FNC RWS and associated program logic planning documentation; information about the structural and institutional arrangements for managing water in the region; the FNC RWS long-list of options including potential actions, projects, reforms and investments; the FNC RWS short-list of option areas aligned under the three regional priorities identified; and information from strategies and plans about state-wide economic, regional development, infrastructure, water, environment, marine estate, green infrastructure and biodiversity objectives, goals and visions (see Appendix A).

The research team carried out preliminary systems analysis work, which was twice tested and iterated with the DPE team to identify gaps and missing pieces of information, explore incongruities and dependencies, and expose critical framings, constraints and priorities. This iteration supported distillation and convergence to generate advice within a systems context.

The (partial) systems analysis focussed on the following areas:

1. Resolving internal consistency in the articulation of the problem space and overarching goals (expressed as challenges and objectives) across the planning process and identifying the central framing for the remainder of the systems analysis.
2. Identifying dependencies between RWS objectives, including identifying the foundational objectives relied upon to achieve others. Mapping CSIRO review focus areas to RWS objectives to reveal constraints on the review's ability to assess whether the strategy will meet its full objectives.
3. Assessing to what extent and how sufficiently the RWS objectives are covered by the short-list option areas.
4. Revealing potential tensions and the possibility for unintended consequences of actions targeting one objective, on other objectives in the RWS.
5. Exploring potential lower cost (or higher benefit-cost ratio) pathways to implementation through cooperation by examining whether RWS objectives could link to the visions of other regional or state level strategies and plans.
6. Options selection process to distil from a long-list to a short-list of options.

The systems approach taken in this review was structured around a high-level analysis of consistency, dependencies, sufficiency, tensions and cooperation at regional scale, and included higher level system considerations for pathways to implementation of strategy. These elements provide a framework to support the application of more comprehensive systems approaches to delivery of Regional Water Strategy objectives in the future.

C.3 Resolving internal consistency and a central framing for the systems analysis

In order to apply the systems analysis, it was necessary to resolve internal inconsistencies, to clearly understand which central organising framework to focus on. The problems and outcomes sought under the FNC RWS were articulated slightly differently across planning documents. They were expressed as challenges and objectives, with challenges articulated differently between documents, reflecting the progress and development of thinking over time.

RWS objectives were used as the central organising framework, having their basis in legislation and being standard across all RWS in New South Wales. Consultation with the DPE team indicated that the challenges can be considered the expression of RWS objectives within the place-based context of the FNC region. These consultations revealed that the challenges in the short-list options paper were robustly developed, while those expressed in the draft FNC RWS strategy and program logic table were intermediate planning artefacts. It became apparent that the various articulations arose as a result of the planning process not being smoothly linear, for example state-wide RWS guidance was developed after the FNC RWS had been drafted, so some retro-fitting of objectives was required.

In resolving internal consistencies, we mapped challenges to one another and challenges to objectives (see Figure 11). This revealed that the objectives of 'enable economic prosperity' was expressed via four challenges; 'enhance 'water for local communities' through three (and tenuously by a fourth); 'enhance the environment' through three; and 'Aboriginal water rights and interests' through one. The objective of 'affordability' was not expressed via any of the challenges.

Importantly, the flood challenge links only weakly (and assumed implicitly) to one objective (community water). It is not explicitly expressed in any objective. This means that this significant challenge is poorly represented in the strategy framing and is relying on implicit assumptions for proper consideration.

Subsequent systems analysis was based on the objectives framework.

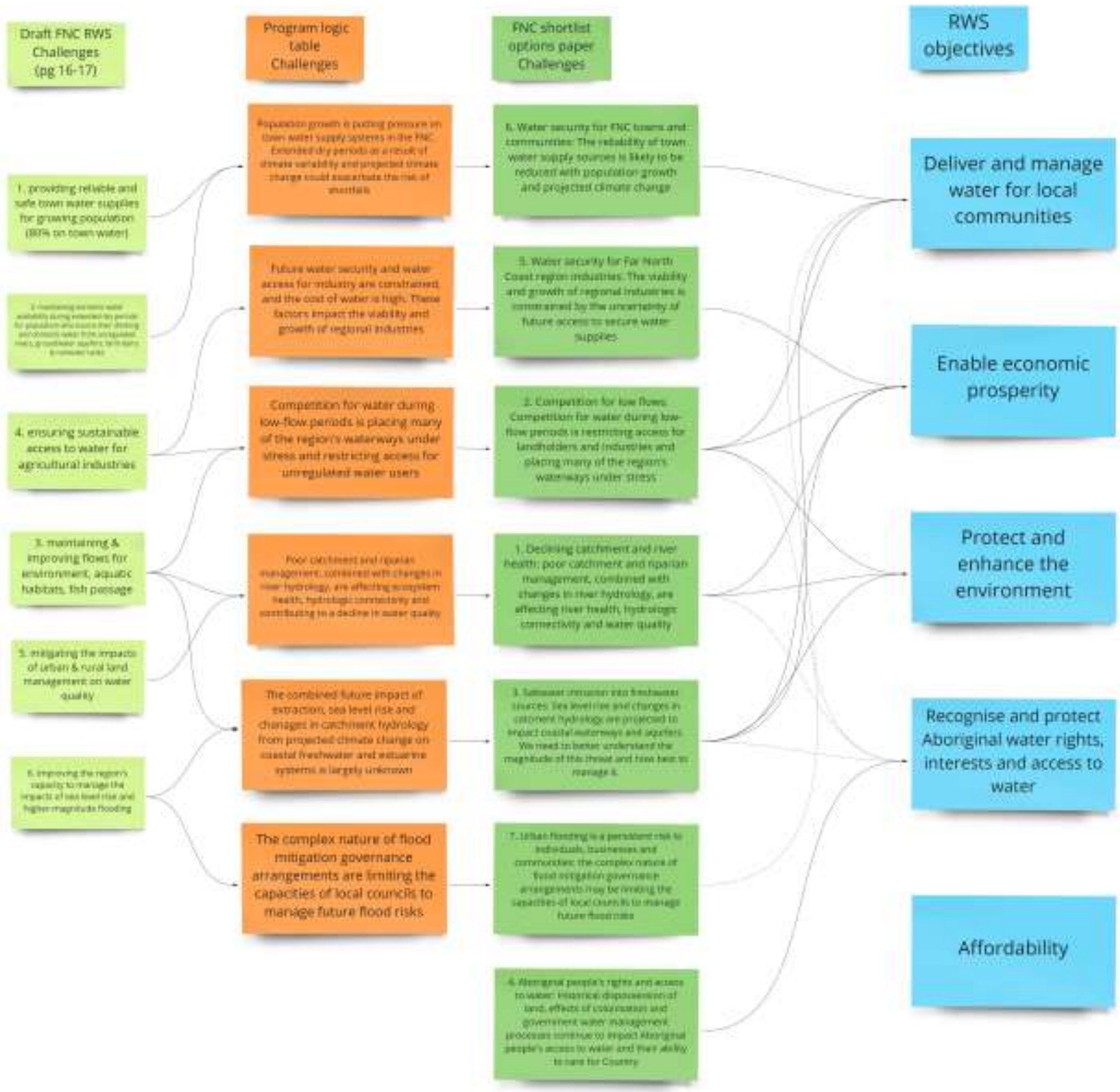

Figure 11. Regional Water Strategy objectives and challenges mapped to ascertain internal consistency

Key insight: RWS objectives provide an organising framework for assessing the sufficiency of options. The contextualisation of these in the FNC context (via challenges) places emphasis on economic and then environmental aspects. The flood challenge is only implicitly represented in the objectives framing.

C.4 Dependencies between objectives and scope of CSIRO review

Identifying the dependencies between RWS objectives allowed the identification of foundational objectives – those which are relied upon to achieve others. This provides an opportunity to back-check whether the relative attention paid to each of the objectives by the short-list of options areas is proportionate and balanced.

The mapping (see Figure 12) revealed interdependencies between ‘enhance the environment’ and ‘Aboriginal rights and interests’ which were foundational to both the ‘water for local communities’ and the ‘enable economic prosperity’ objectives. The economic objective was also considered to be reliant on achieving the ‘water for local communities’ objective. The ‘affordability’ objective did not link into the dependencies map – this is achieved by passing proposed actions through this lens.

Considering the relationship of the three focus areas of the CSIRO review (water security, flooding (Lismore) and water quality (Richmond)) to the objectives, none of the review foci linked directly to ‘Aboriginal rights and interests’, ‘enabling economic prosperity’, or to ‘affordability’. All three mapped to ‘water for communities’, and water quality also mapped to ‘enhance the environment’. This indicates the constraints of the CSIRO review, including the absence of consideration of Aboriginal rights and interests, a very limited consideration of environmental objectives (confined only to water quality in just one catchment), consideration of economic enablers only via dependencies on community water availability, and the constrained geography of flood considerations. The CSIRO review therefore places more emphasis on specific areas in which it can address the strategy’s ability to meet its objectives. It also contributes guidance for considering pathways to implementation.

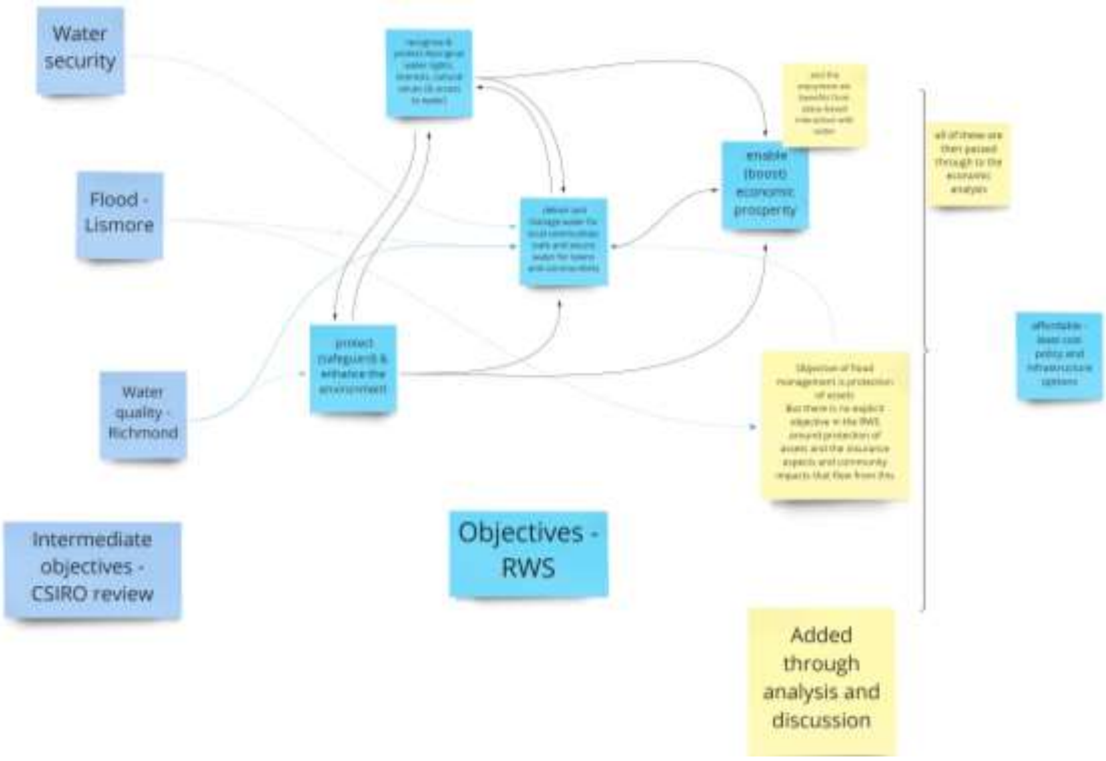

Figure 12. Snapshot of analysis of objective dependencies for those listed in the Regional Water Strategy (bright blue), CSIRO areas of focus (dull blue) and those that were added through discussion and workshopping (yellow).

Key insight: Environment and Aboriginal rights and interests objectives are foundational to achieving community water and economic objectives. The economic objective is also dependent on the community water objective.

C.5 Sufficiency of short-list options areas for addressing RWS objectives

Using objectives as the backbone framing, we mapped short-list option areas to specific objectives. This revealed a strong suite of option areas addressing the environment (13) and community water (12) objectives; a modest but specific and targeted suite addressing Aboriginal rights and interests (7) and a small suite focussed on the economic prosperity objective. This distribution shows that options for actions are likely to emphasise water security and environmental outcomes and also include specific actions for the inclusion of Aboriginal rights and interests. The focus of option areas is likely to service objectives well with respect to the dependencies between objectives, as the underpinning objectives are likely to be relatively well supported by the short-list action areas.

A similar exercise using the three focus areas of the CSIRO review showed (see Figure 13) a strong emphasis of the options areas on water security, a modest focus on water quality, and a very weak focus (just one action area) on flooding. This may be a flow through from the challenges and objectives framework, which articulates flooding as a challenge that is only weakly linked to an objective (section 4 this Appendix).

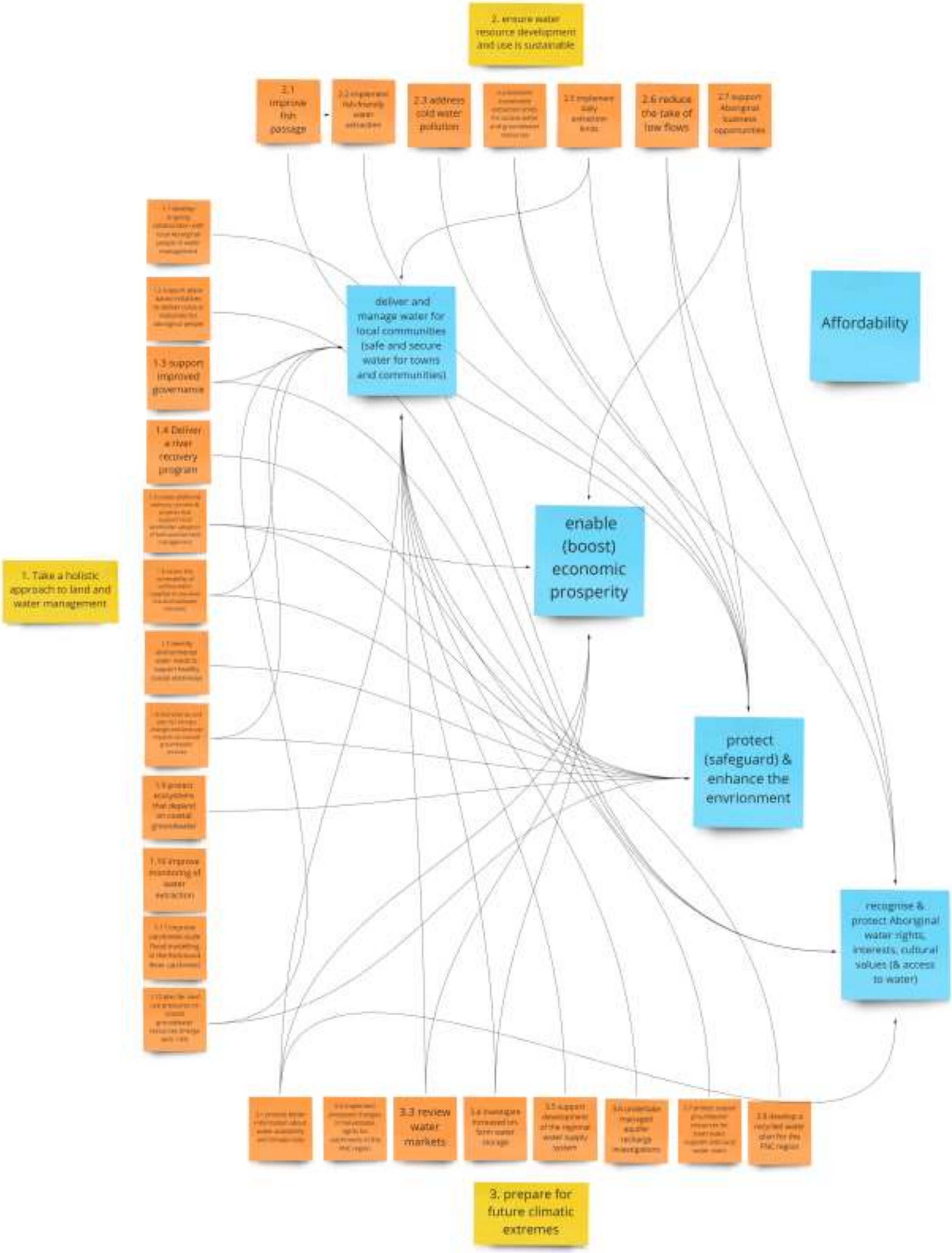

Figure 13. Mapping of short-list option areas (orange tabs) to Regional Water Strategy objectives (blue tabs) indicating relative attention paid to each objective by the short-list action areas.

Key insight: The objectives are generally well serviced by the short-list option areas and the foundational objectives are supported by numerous options, however, the least-cost objective is not addressed and specific options to address flooding are weak.

C.6 Potential tensions

We scanned for the possibility of perverse outcomes or unintended consequences by identifying the potential for each short-list option area to adversely affect each objective. This highlighted that options designed to address water security for towns and communities have the potential to adversely impact the environment. There is also a possibility for these to be in tension with the Aboriginal rights and interests objective, and this would need to be tested with Aboriginal groups. Conversely, options that aim to address environmental sustainability and protect water-dependent ecosystems, may reduce water availability and supply for towns and communities. This assumes an environment of water scarcity, where trade-offs would need to be made. While in many years the DPE team advises this is unlikely, these tensions may arise in dry years.

This scan provides awareness of areas of potential tensions. It reveals areas where particular attention may be required in order to avoid perverse outcomes in the final design of the options package, and to manage stakeholder engagement cognisant of potentially competing interests. It is also an opportunity to frame the prioritisation of short-list action areas in the context of objective dependencies, highlighting the dependency of long-term sustainable community and economic outcomes on meeting environment objectives and exploring options that might achieve synergies.

Key insight: There is potential for options designed to address community water security to be in tension with options designed to enhance environmental outcomes in situations where water is scarce. There is opportunity to bring more focus to the dependency of long-term sustainable community and economic outcomes on meeting environmental objectives, and to seek options that might achieve synergies.

C.7 The broader place-based system and complementarity of RWS objectives to other visions

In order to place the water strategy in a wider place-based systems context, and identify areas for possible synergies, potential complementarity between the water strategy objectives and the visions of other regional and state strategies was briefly reviewed. Three regional and economic development focussed plans were included along with two green infrastructure related strategies, and four environmental conservation and biodiversity focused strategies (see Appendix A). These strategies were also scanned for their treatment of water.

This showed (see Figure 14) complementarity between the economic and community water objectives of the RWS and regional development strategies. The RWS environment objective mapped to the visions of both environmental strategies and regional development strategies, which often focussed on the biodiverse natural environment of the FNC as an asset for regional development. Aboriginal rights and interests were also important to regional development strategies, as well as a number of environmental strategies.

This work illuminates where complementary engagement may be useful. Various agencies and organisations have carriage of each of the strategies considered, and where complementarity between those visions and the objectives of the RWS exist, there may be potential to partner to achieve RWS goals. In this case, there is an opportunity to design infrastructure that provides multiple benefits. Agencies may be investing for different reasons in the same infrastructure and multiple benefits may be achieved at lower cost. For example, combining a green infrastructure solution with re-zoning to address flood risk, providing multiple benefits to biodiversity, water quality, local recreation, amenity, tourism potential, as well as mitigating property damage and reducing emergency and disaster response impacts.

Our partial systems-boundary analysis identified key actors in the water sub-system as including:

- local government: Byron, Ballina, Kyogle, Richmond Valley and Tweed Shire LGAs and the Lismore City Council
- state government: DPE planning, water planning, water science, water utilities, agriculture, freshwater fisheries and biodiversity conservation divisions; Water NSW; Office of Local Government; Local Land Services North Coast
- private entities: Rous County Council Regional Water Utility; private landholders and farmers; water management businesses

Extended actors in the broader place-based system may include, for example, Resilience NSW, NSW State Emergency Service, Infrastructure NSW, DPE Environment, Energy and Science Division, and other government agencies with carriage of strategies and plans whose visions and objectives interact with RWS objectives and the water subsystem. A full place-based systems analysis was out of scope for this project. An extension of this work could permit a fuller investigation and definition of the broader place-based system, including identification of relevant actors, policy and other levers, and options for cooperation to realise multiple benefits at least-cost.

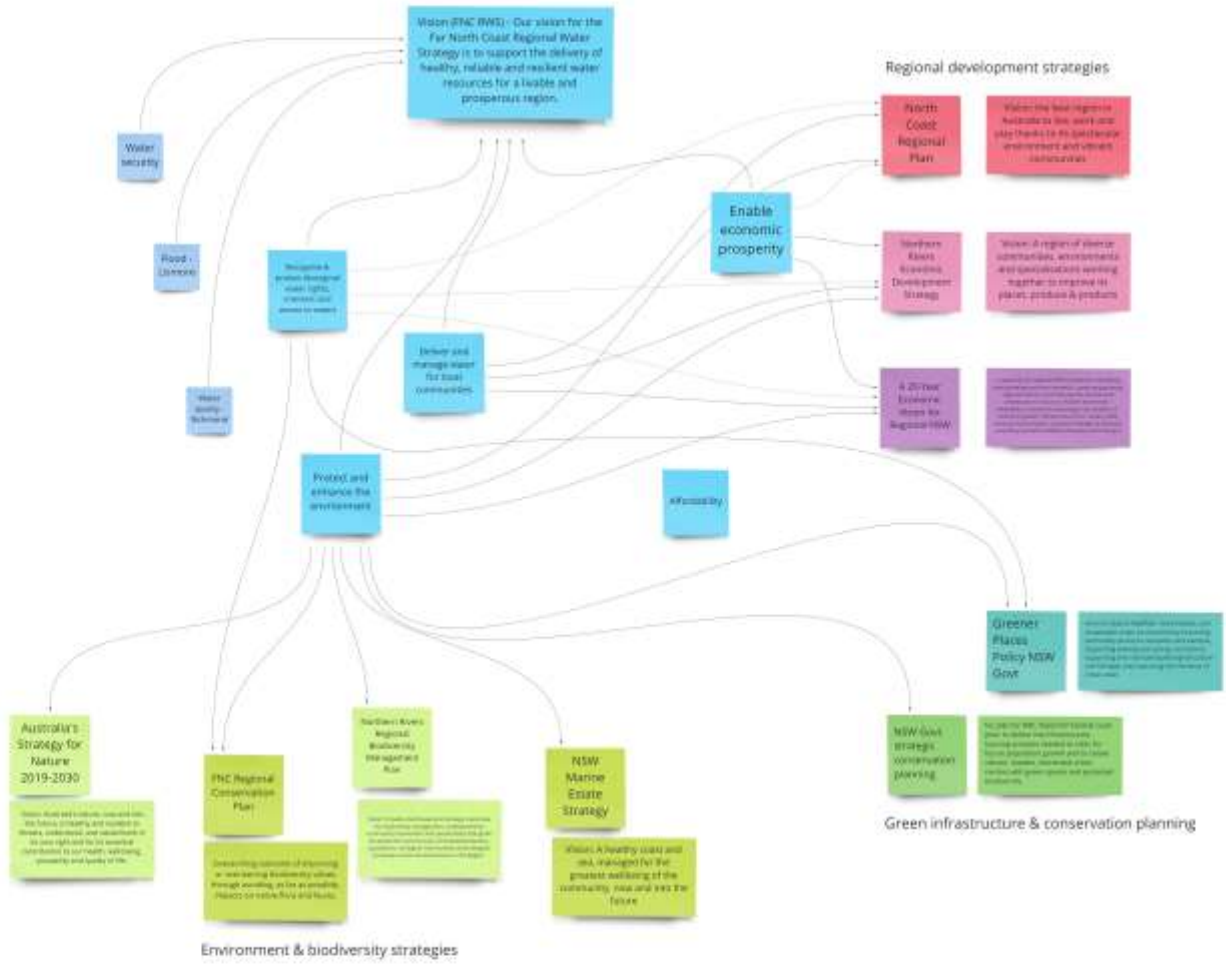

Figure 14. Complementarity of Regional Water Strategy objectives to the visions of regional development and environmental strategies and plans relevant to the Far North Coast NSW region.

Key insight: There are many potential entry points for considering complementary of options under the RWS with objectives and outcomes sought in related place-based regional development and environmental strategies and plans. A broader systems approach is likely to help identify suites of options that provide a better overall cost benefit ratio when multiple benefits are considered.

C.8 Brief overview of the options selection

The process of developing the long-list of options, and distillation of long-listed to short-listed options was not entirely clear from the documentation provided how. In workshopping this part of the process with DPE team, it was explained that it was a combination of

a) staying within organisational remit for water management,

b) bundling the sets of options that are tightly linked, and

c) selecting based on tractability for modelling and analysis within the required timelines.

It is common practice in strategy and planning to distil long-list options to short-lists based on these criteria and others. It potentially misses the opportunity to explore the options in the context of the complementarity to broader strategies as shown in section C.7 above, or to explore value creation and map broader sets of benefits and beneficiaries that might be possible through assessing a wider set of options. Additionally, when dealing with high levels of uncertainty about population, economic settings, and inadequate data for some of the analyses (as is the case in this FNC strategy) there is opportunity to conduct an 'options and pathways' type of analysis[77]. This allows for sequencing bundles of options, to ensure the most necessary near-term or foundational options to reach objectives are 'low-regrets'. These are actions that may require less investment in the near-term but maintain the options for further investment in the interventions as the future trajectories on the most uncertain aspects (e.g., their demand side) become clearer.

It is also possible that there would be tensions and trade-offs (or at least lost opportunities for synergies) in an approach focussing only on the narrow objectives for water and the least-cost options to meet them that lie wholly within the remit of the water sector (and/or DPE) to action. This compares to taking a broader approach to bundled and sequenced option sets across all sectors that might be used to meet an expanded set of regional and state objectives.

Key insight: Keeping options broad for as long as possible is necessary to reveal potential interconnections that could deliver multiple benefits and reduce cost benefit ratios.

[77] For examples, see Footnote 38.

Appendix D Detailed review of bio-physical content of water strategy documents

This appendix provides additional detailed comments on the review of the Far North Coast Regional Water Strategy documents and supporting material with a focus on bio-physical content. It complements the main report.

D.1 Review of datasets underpinning the Far North Coast Water Strategy

This section reviews the foundational bio-physical datasets used by DPE to analyse and short-list the options in the strategy. Three datasets are extensively used throughout the RWS and Consultation Paper:

1. Historical climate data underpins water resources assessment during the past 130 years.
2. Future climate data are used to extend the assessment to the next century.
3. Hydrological model outputs form the core of the option selection process undertaken by DPE.

A fourth dataset (flood modelling) is discussed in this section but is not currently used by DPE. Flood modelling has not been used to assess the options, however, the review team considered it important to provide a quick summary of data availability in this field.

D.2 Historical climate data

Historical climate data used by DPE throughout the RWS comes in two forms:

- A set of point measurements of climate variables such as rainfall, evaporation and temperature. The measurement stations are often monitored by the Bureau of Meteorology, which also store and distribute the associated data through online services[78].
- Gridded surface of the same climate variables computed either by the Bureau of Meteorology (AWAP product, see Jones et al., 2009) or the Queensland government (SILO product, see Jeffrey et al., 2001). DPE generally favours Jeffrey et al. for analyses.

Gridded datasets are spatially interpolated to fill gaps within a point data timeseries and provide estimates for grid cells where no point data is available. The differences between datasets can lead to a significant mismatch between point and gridded values that can affect models using these variables as inputs.

These discrepancies are further compounded by the fact that rainfall stations data availability is not homogenous through time and space across the FNC region, as revealed in Figure 15. This

[78] http://www.bom.gov.au/climate/data/

Figure suggests that station coverage was limited away from coastal areas prior to 1920, especially for the Richmond catchment. It also indicates that the southern part of the Richmond catchment remains poorly covered, even today, and that there are a significant number of stations available in the records of the Bureau of Meteorology that have not been used to generate SILO grids.

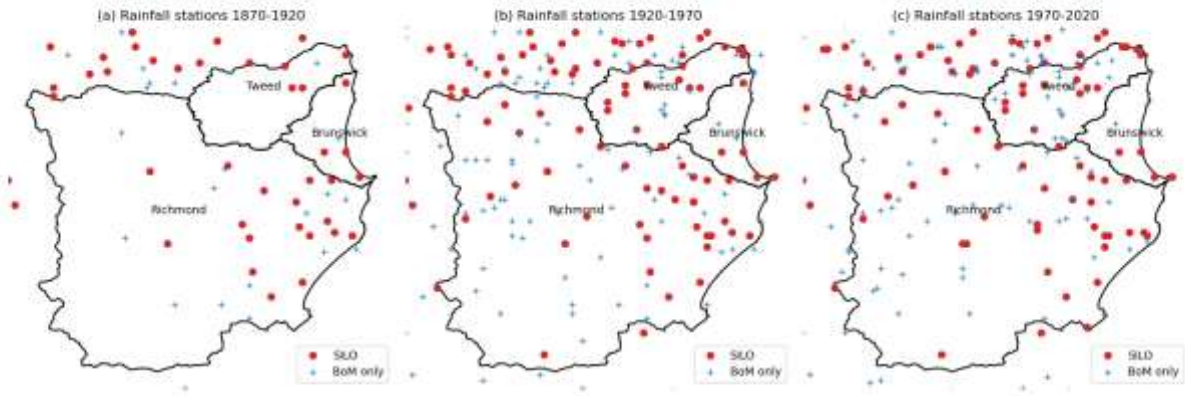

Figure 15. Availability of rainfall stations in the Far North Coast region (source Australian Bureau of Meteorology data).

More information is needed to (1) review the availability and quality of climate data across the region, and (2) ensure that similar climate data products are used consistently across all modelling work undertaken under the umbrella of the RWS.

D.3 Future climate data

The development of the RWS is informed by a four-step approach to climate data sets:

1. Use observed historical climate of 130 years.
2. Extend the historical climate with paleoclimate data (tree rings, river sediments, ice cores, cave stalactites and stalagmites and soil patterns) to 500 years.
3. Use stochastic modelling to extend the data to 1000 sets of 40 years scenarios (rolling windows of 40 years with 9 years overlap from continuous series of 10,000 years).
4. Use bias-corrected future projections from NARCliM (Evans et al., 2014) to generate monthly scaling factors to scale the 10,000 years of stochastic data and generate future climate sequences.

The approach used by DPE is different to that used in most other similar studies (CSIRO Water for Healthy Country Flagship, 2008; Petheram et al., 2013, 2018), especially the extension of the duration of record using stochastic modelling.

The report from an 'Independent review of the climate risk method for the NSW Regional Water Strategies Program' (Independent Expert Panel, 2020) has been provided as one of the supporting documents. In this document, the Independent Expert Panel (referred to as the "panel" hereafter) states that the DPE climate modelling methodology is summarised in a draft Methods Paper provided to them (which is underpinned by three papers that develop the extended climate sequences for the regions). The panel only reviewed material available to it at the time of review and did not review material still under development.

The panel states that the overall methodology used by DPE to use observational and paleoclimate data informed by an understanding of climate drivers to select, calibrate and test stochastic models and the factoring of NARCliM projections is consistent with best-practice approaches to climate risk management. The panel suggested that ongoing improvement of the methodology adopted by DPE be given high priority. It should include an assessment of non-stationarity in the historical record to determine whether changes in climate in recent decades affect estimates of present-day climate risk compared with climate risk based on the whole observed record.

Other than the brief description in the Methods paper, the panel did not have details of the application of NARCliM models to the stochastic data sets. This was required by the panel to make a detailed assessment of the merits and potential weakness of its implementation. In the absence of full technical details, the panel states that "in the analysis, DPE plans to use the GCM/RCM combination that produces the lowest near future rainfall, scaling the stochastic data calibrated to historical and paleo data (presumably using the ratio of the daily means as the scaling factor)".

Despite the recommendation by the panel to use daily scaling factors, the information provided in the RWS suggests that DPE has used constant monthly scaling factors based on the bias corrected NARCliM future climate projections in this analysis. This is confirmed in the report on analysis of option for the Richmond valley (See Hydrologic Analysis of Options for Regional Water Strategies – Richmond Valley, section 3.4, page 12).

D.3.1 Monthly scaling factors

The choice of monthly factors raises two issues for representing future extreme flood events:

- The monthly scaling factors remain constant in time whereas climate trends modelled by Global Climate Models may change progressively over time as indicated in recently released IPCC report[79], which clearly states that the future climate will intensify exponentially (i.e. nonlinear change in future climate with increasing CO_2 with more extremes dry and wet spells) as we move ahead in time.
- Flood events in the FNC region are much shorter than a month (less than 10 days). This is indicated in Figure 2 which shows the number of days above minor flood level in Lismore between 2005 and 2021. Consequently, the use of monthly scaling factors for predicting future extreme flood events is smearing out the future extreme events and not capturing their full extent.

The limitations of monthly scaling factors is further demonstrated in Figure 16, which compares mean monthly scaling factors (Figure 16.a) with scaling factors of 10 years return period daily rainfall (Figure 16.b) between two contrasted periods in the Richmond river catchment at Wiangarree. This example is a simple attempt to reproduce a comparison between the climate

[79] AR6 Climate Change 2021: The Physical Science Basis, https://www.ipcc.ch/report/sixth-assessment-report-working-group-i/.

from the instrumental period (considered as wet) and future scenario (considered as dry). Monthly factors show limited variations across the year with values ranging from 0.61 in April to 0.93 in February. Conversely, the daily scaling factors for extreme rainfall are much more variable with values between 0.6 in May to 1.08 in August. It is remarkable that some daily scaling factors are above 1 (i.e. extreme rainfall is higher during a dry period compared with a wet period), whereas monthly scaling factors are systematically below 1 (i.e. monthly values are lower during a dry period).

It appears problematic to use fixed monthly scaling factors in the Far North Coast region where flood dynamics are much shorter than a month and potentially subject to evolution during the coming century.

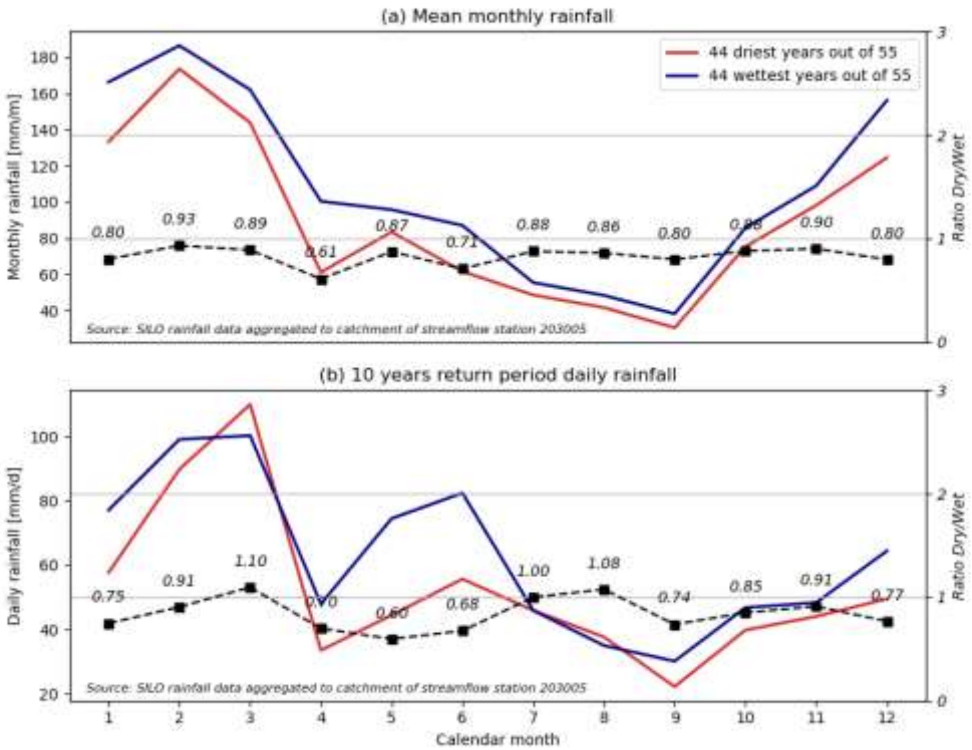

Figure 16 Comparison of scaling factors (ratio Dry/Wet) obtained from mean monthly (figure a) and 10 years return period daily rainfall (figure b) during two contrasted periods in Richmond River at Wiangaree catchment (203005). The scaling factors are shown as square markers measured on the axis shown in the right-hand side of the figure.

D.4 Hydrological modelling reports

The RWS provides a high-level overview of hydrological modelling (landscape and river system) undertaken to generate historical and future water availability estimates for the region. The document indicates that water availability estimates underpinning the water strategy, including the assessment of long and short-listed options, were obtained by running the hydrological models forced by different climate scenarios. The review team was provided with four technical reports presenting the hydrological modelling method:

- Richmond valley – conceptualisation report (referred to in this review as “Richmond conceptualisation report” hereafter)
- Richmond valley – analysis of options report (referred to in this review as “Richmond analysis report” hereafter)
- Tweed valley – conceptualisation report (referred to in this review as “Tweed conceptualisation report” hereafter)
- Tweed valley – analysis of options report (referred to in this review as “Tweed analysis report” hereafter)

These reports contain a considerable amount of hydrological analysis. A wide range of options have been considered by DPE and integrated into both Richmond and Tweed hydrological models, including a connection between the Richmond and Tweed systems related to the upgrade of Clarrie Hall dam. The review team was impressed with the number of variants tested by DPE, which suggests a strong expertise and familiarity with this kind of study.

However, there are important limitations in the work presented in the four reports listed above. The review team note that the reports were provided in draft form only, with important missing elements as detailed below. Without these elements, it was not possible to fully review the modelling method. The elements missing in the hydrological modelling reports are:

- *Overview of climate data availability and quality*: The hydrological modelling reports indicate that most analyses are conducted using point rainfall data (e.g. Tweed conceptualisation report, section 4.1). However, the first version of the Tweed model was developed using SILO gridded dataset and then subsequently converted to point data (Tweed conceptualisation report, section 3.1). It is not clear why point rainfall data were preferred over the gridded data used in the previous version of the model. In addition, the method used to compute catchment rainfall from the point dataset is not described in any report. Finally, Figure 15 (above) suggests that the availability of rainfall data vary significantly in time and space, which could lead to different levels of accuracy of the hydrological models. This issue is not discussed.
- *Streamflow data availability and quality*: The Tweed conceptualisation report provides valuable information about streamflow data availability in the Tweed valley through Table 6. However, there is no comment on the quality of the data including the number of gaugings and the degree of extrapolation beyond the maximum gauged flow as shown by CSIRO (2009, see page 207). A similar lack of information is noted for the Richmond reports, with Table 1 of the Richmond analysis report providing information about data availability periods, but nothing about data quality.
- *Calibration approach for rainfall–runoff models in headwater catchments*: Both hydrological models for the Richmond and Tweed valleys rely on the Sacramento rainfall–runoff model (Burnash et al., 1973) to simulate streamflow generated in headwater catchments. The calibration of this model is a delicate operation because it is heavily parameterised compared to simpler alternatives such as the GR4J model (Perrin et al., 2003). Consequently, the choice of calibration algorithm and objective function used to quantify goodness of fit are critical in

obtaining robust estimates of runoff. No information was provided in any of the hydrological modelling reports related to rainfall–runoff model calibration and value of parameters obtained at the end of that process.

- *Validation of rainfall–runoff models performance in headwater catchment*: It is well established in the scientific literature that rainfall–runoff models lack accuracy in simulating periods that are significantly wetter or drier than their calibration regime (Andréassian et al., 2009; Coron et al., 2012; Vaze et al., 2010). The amount of error introduced by rainfall–runoff models can be as large as 10 to 30% bias, which in the case of the FNC region would amount several times the total water demand in the region. This issue is particularly relevant to the hydrological analysis undertaken by DPE where 1,000 replicates of 40 years periods are run through the models. Some of these stochastic runs are characterised by extreme dry or wet conditions that were never seen by the models during their calibration and are likely to stretch rainfall–runoff model performance beyond the acceptable. Consequently, the review team recommend a thorough review of rainfall–runoff model performance using a rigorous leave-out validation scheme where some part of the data is used for calibration and another part is left for validation (KlemeŠ, 1986). The review team noted a statement in the Tweed conceptualisation report indicating that 'it was chosen not to perform a validation for the headwater flows' (section 4.10). This is a drift from well accepted practice in the hydrological field and the review team suggests that the performance assessment should be reviewed as a matter of urgency. It is extremely risky to use rainfall–runoff model outside of their calibration range without proper performance evaluation on both low and high flows.
- *Calibration approach for hydrological models in residual catchments:* Compared to headwater catchments, residual reaches present additional complexity related to the impact of water extractions and transmission losses. The Richmond and Tweed conceptualisation reports briefly describe the structure retained for residual reach models, but do not clarify how transmission losses are setup, nor how they are calibrated and how much they amount compared to inflows and outflows. This point is important because transmission losses can interfere with other model components and lead to model overfitting, which then translates into poor generalisation capacity. The review team recommends using transmission losses modelled as parametric functions of reach inflow, such as suggested in Lerat et al. (2013). In addition, the review team noted that a significant number of river reaches are within the tidal zone of the Richmond and Tweed rivers. It is not simple to calibrate hydrological models in such areas as traditional flow measurement becomes unreliable in medium to low flows. The review team recommends describing precisely how calibration for hydrological models in residual catchments was undertaken.
- *Validation of hydrological model performance in residual catchments*: Similarly to rainfall–runoff models, residual reach models performance must be tested using a rigorous leave-out validation scheme to evaluate their capacity in extrapolating beyond calibration conditions.

In addition to these specific issues, the review team has identified three broader areas where the current hydrological modelling method implemented by DPE can be improved.

1. There is limited or no assessment of the environmental impact of options on flow regimes. The Consultation Paper suggests that this assessment is currently on-going with multiple placeholders for tables referred to as “Summary environmental assessment placeholder” (for example at the bottom of page 8 in Appendix 2 of the paper). However, these tables were not provided to CSIRO for review. The review team recommends completing an environmental assessment of proposed options as a matter of priority, especially when some of these options aim at improving environmental health (for example option 21 “Establish and/or increase environmental water releases from major storages in the Far North Coast” assessed in the Richmond analysis report in section 4.10).
2. The options tested in the Richmond and Tweed analysis reports are compared based on mean annual statistics only (essentially mean annual demand shortfall and mean daily flows for the Tweed only). One exception is the analysis of differences in flow duration curve downstream of Clarrie Hall dam in the Tweed analysis report. Apart from this brief exploration of low flow behaviour, options are systematically assessed based on yearly averages. This masks their impact on low flows because of the predominance of high and medium flows in the computation of annual averages. Mean annual flow and minimum flow are not necessarily correlated as shown in Figure 3. Another example is provided in the Tweed analysis report in Figure 5 and 6 where variations in daily flow are apparent but do not show in mean annual totals. The review team recommends introducing additional metrics focusing on low flows.
3. The review team notes that most catchments in the Far North Coast region react extremely quickly during floods compared to other part of NSW. Figure 17 provides an example of sub-daily dynamics in an upstream catchment of the Tweed basin during the December 2020 flood. The figure shows that the flood rises and falls within approximately 12 hours. This behaviour suggests that hydrological models operating at daily time step may not be appropriate to characterise the hydrological flow regime during flood events in the Far North Coast region. This is not likely to be an issue for the analysis of water security options as currently performed for the RWS but could become problematic if water security and flooding issues were analysed jointly as is recommended in this review. The review team recommends considering sub-daily hydrological models as part of future modelling work undertaken by DPE in the Far North Coast region.

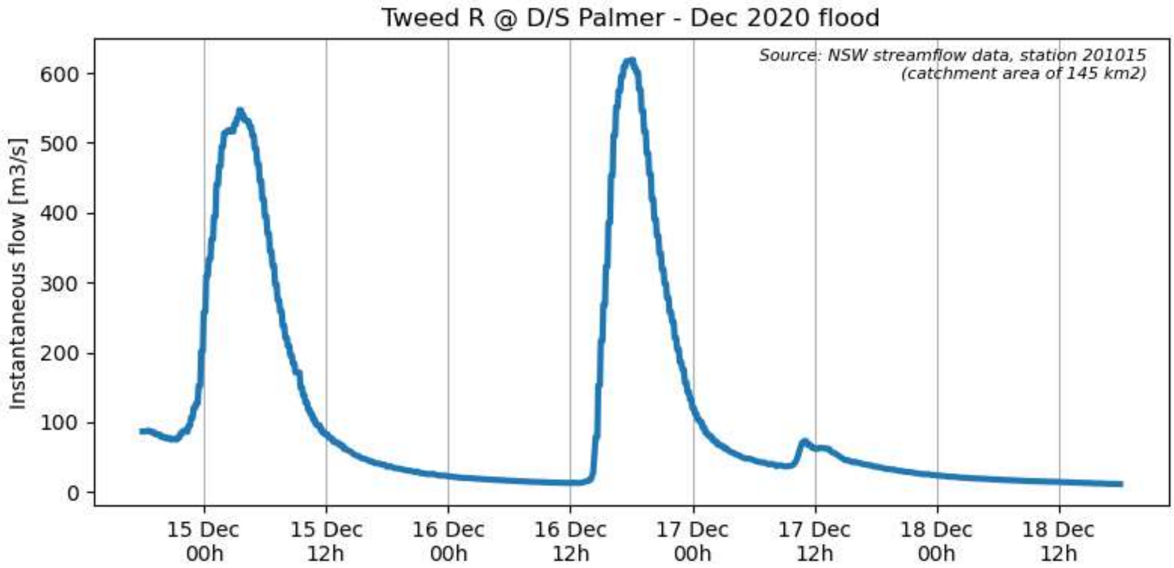

Figure 17: Example of sub-daily streamflow hydrograph in the Tweed catchment

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