


Town Water Supply Security Using NSW Regional Water Strategy Climate Data

Yass Case Study

Final

27/2/2025

Acknowledgement

This report was prepared by HARC for the NSW Department of Climate Change, Energy, the Environment and Water (the Department). HARC acknowledges the contribution of the project steering committee to this project, which included representatives from the Department and Yass Valley Council. HARC also acknowledges the provision of data and the co-operative sharing of knowledge by the Yass Valley Council over the course of the project.

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Executive Summary

The role of this case study

The NSW Department of Climate Change, Energy, the Environment and Water (the Department) is committed that all local water utilities should have in place effective, evidence-based strategic planning[1]. This will ensure utilities deliver safe, secure, accessible, and affordable water supply and sewerage services to customers. It will also ensure they can manage keys risks now and into the future, and in the event of significant shocks. Local water utilities remain responsible for conducting strategic planning.

Through the Department's assurance role under Section 3 of the *Regulatory and Assurance Framework for Local Water Utilities* (the "RAF"), the Department establishes what outcomes it expects effective, evidence-based strategic planning to achieve (see Section 3.2 of the RAF) and assesses if a utility's strategic planning achieves these outcomes to a reasonable standard (see sections 3.3 and 3.4 of the RAF).

Under Section 3 of the RAF, the Department provides supplementary guidance on achieving strategic planning outcomes to a reasonable standard. The Department's *Guidance on Strategic Planning Outcome - Understanding Water Security* (the "Water Security Guidance") expects that a local water utility should address current and future risks around continuity and reliability of access to water supply sources.

The Department's Regional Water Strategies (RWSs) bring together up-to-date information and evidence with the aim to balance different water needs and deliver the right amount of water for the right purpose at the right times within regions of the State. It has developed stochastic datasets, combined with paleo-climate information, that were used in the RWS water resource modelling. These datasets were developed to better understand climate variability and the potential for droughts (and floods) worse than those seen over the 130 year historical climate record. The Department's Water Security Guidance recommended that the town water security analysis should be done using robust climate data and models and indicated that RWS datasets have the potential to provide input data for a local water utility's water security analysis.

The Department employed HARC in 2022 to explore how these datasets could be applied to modelling town water security. This informed the development of a step-by-step procedure for applying the stochastic datasets for this purpose. This procedure was incorporated as optional how-to-guidance into Appendix A of the Water Security Guidance. To confirm the suitability of using RWS data and models in a real-world application, the step-by-step procedure of optional how-to-guidance has been applied to the Yass town water supply system. This is a supplementary case study as part of the Appendix B of the Water Security Guidance. The insights and learnings from this case study will be used to improve the optional how-to guidance (Appendix A) of the Water Security Guidance.

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[1] NSW Department of Planning and Environment (DPE Water) *Regulatory and Assurance Framework for Local Water Utilities,* July 2022.

The Yass supply system, which provides drinking water to the towns of Yass, Murrumbateman, Bowning and Binalong, was specifically chosen for this case study by the Department because the supply system has a recent history of water restrictions, coupled with ongoing growth in demand for water. Options for supply source development are being actively investigated and discussed. This case study supplements existing information available to Yass Valley Council, as part of a multiple lines of evidence approach to decision making. The scope of work of this study does not consider water security improvement scenarios associated with demand management or additional supply sources.

Yass water resource model

A Source water resource model of the Yass supply system was created to assess supply system yield. It adopted the relevant parts of the Department's Upper Murrumbidgee Source model, which was previously used for the Murrumbidgee Regional Water Strategy[2,3]. The Yass Source model covers the headwaters and catchments of the Yass River upstream of the Yass Dam, down to the streamflow gauge located approximately 2km downstream of the dam. It also includes rural water use from the Yass River and its tributaries upstream of Yass Dam. HARC verified that the Yass Source model was able to reproduce the Murrumbidgee Source model outputs. After that verification, some adjustments were made to the town water demand model. This was done for consistency in model form with previous work (HARC, 2022). The demand model was used to derive a fixed dry-year demand pattern, as well as a demand pattern that varies from year to year based on prevailing climate conditions.

The outcomes of this model verification process were that:

1. There is considerable information uncertainty with regards to the Yass supply system. This includes uncertainty about upstream irrigation demands, and discrepancies between reservoir water levels that were continuously monitored and those from Council staff field measurements during the last drought in 2019. There is no long-term monitoring of reservoir inflows near the dam (the nearest long-term streamflow monitoring gauge is over 40 km upstream at Gundaroo), and the long-term monitoring of outflows 2 km downstream of the dam includes ungauged local catchment inflows between the dam wall and the streamflow gauge.
2. This uncertainty manifest as uncertainty in the estimate of inflows to Yass Dam during the project. Whilst this led to a final inflow estimate that generated a good match to downstream gauged flows, and a reasonable fit to historical drawdown events in Yass Dam, there is the potential for further improvement in these inflows as more and better quality information about the supply system is collected over the coming years.
3. This highlights the benefit of ensuring that the supply system model used to estimate town water supply yield is well calibrated and informed by good quality, long-term monitoring data, prior to using stochastic climate inputs. Yass Valley Council has started this process by installing a radar sensor for improved measurement of dam water levels in April 2022.

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[2] NSW Department of Planning and Environment (DPE Water) *Draft NSW Murray and Murrumbidgee Regional Water Strategies. Climate and Hydrological Modelling*. December 2022.
[3] NSW Department of Climate Change, Energy, the Environment and Water (the Department) *Draft Regional Water Strategy. Murrumbidgee: Shortlisted Actions – Consultation Paper*. May 2024.

Water security analysis approaches adopted in this case study

Supply system yield for town water security is the volume of water that can be delivered from a supply system without breaching the level of service objectives for that supply system. The "x/y/z" performance-based approach for assessing supply system yield is outlined in the Department's Water Security Guidance. It incorporates three different level of service objectives for the duration (x), frequency (y), and severity (z) of water restrictions. The Department's Water Security Guidance states that it is critical to understand and determine the level of service and/or risk approach for a utility's water supply systems in consultation with customers and the community. In the absence of customer and community consultation for this case study, the level of service adopted in this case study when applying the x/y/z approach is for restrictions to occur not more than 5% of the time (x), in not more than 10% of years (y) and with an assumed 10% reduction in demand (z) when restrictions are implemented. This level of service objective has been commonly applied across NSW to date.

The Department's guidance also allows for the adoption of any other credible and robust approach, provided there is clear justification for its application. In addition to applying the x/y/z approach, HARC has also adopted an "alternative" performance-based approach. This approach is informed by methods adopted in other jurisdictions of Australia. It makes different assumptions to the x/y/z approach to reflect local conditions for inter-annual variability in demand, water savings under restrictions, restriction triggers, and storage buffers set aside for unforeseen events. Both the x/y/z approach and the alternative approach align with the Department's current guidance within the RAF. To enable direct comparisons between the results of the two methods, in this case study, the same duration (5%) and frequency (10%) criteria have been adopted for the alternative yield analysis approach.

The approaches taken to assess supply system yield in this case study differ from the supply shortfall risk analysis that was undertaken for towns throughout the Murrumbidgee River basin, which was previously presented in the Department's *Draft Regional Water Strategy (RWS) Murrumbidgee Shortlisted Actions Consultation Paper* from May 2024. It was noted in the RWS consultation paper that a supply shortfall risk analysis is "not appropriate for detailed purposes like secure yield analyses or other strategic planning" by a local water utility. Although the two analyses are underpinned by the same water resource model and stochastic climate datasets, the outcomes differ due to differences in assessment method and purpose. The supply shortfall risk analysis was intended as a high-level, comparative analysis of supply risks to different towns across the region, whilst the yield analysis in this case study is a more detailed local assessment that takes into account supply system operating rules and level of service objectives for water restrictions. For a supply system like Yass, where there are currently no significant readily available contingency supply measures and a number of input information uncertainties, the supply system must currently be conservatively managed. This occurs, for example, through the use of water restrictions, which were not part of the RWS consultation paper's high-level comparative analysis.

Methods to use the RWS stochastic datasets

The stochastic data was prepared as per the step-by-step procedure in the Department's Water Security Guidance. This involved obtaining the stochastic data from the SEED Open Data Portal[4], dividing the 10,000 years of stochastic data into 130-year sequences, and checking the cumulative deviation from mean rainfall conditions at the boundaries of each 130-year sequence. After examining the cumulative deviation from mean rainfall conditions for each stochastic replicate, the streamflow replicates were shifted by ten years (i.e. 130 year sequences starting from year 10 rather than year zero) to avoid splitting the three most severe drought events over the 10,000 year stochastic sequence.

Findings from applying the stochastic data for this case study were as follows:

1. This study demonstrated how the Department's Regional Water Strategy stochastic data can be used to better understand uncertainty in yield estimates and inform water security risks for a real-world town water supply system.
2. The previously developed step-by-step procedure (see Appendix A of the Department's Water Security Guidance) was able to be successfully applied to this case study.
3. A cumulative rainfall deviation check was helpful for dividing the stochastic replicates into 130 year sequences. Calculating cumulative deviation from mean rainfall conditions (where the mean is calculated using the whole 10,000 year sequence) for each replicate individually (i.e. where the cumulative deviation is reset to zero at the start of each replicate) was able to readily identify whether a drought was occurring at the boundaries of each replicate, to inform whether to shift those boundaries or not.
4. The median yield from the stochastic climate data was found to sometimes differ from the yield estimated using the instrumental climate data. It was initially thought that these would be approximately equal, but this did not hold true for the Yass case study.
5. The stochastic data was readily adjusted to estimate yield under projected climate change using one NARCliM climate projection.
6. The stochastic data was readily applied when adopting alternative inflow assumptions, alternative non-urban demand assumptions, alternative yield assessment techniques, different restriction trigger rules, and different level of service objectives.
7. The assumed demand patterns associated with each yield assessment approach can influence the yield assessment outcomes. The x/y/z approach assumes a fixed dry-year demand pattern applied each year, whereas the alternative yield approach assumes the demand pattern can vary from year to year based on prevailing climate conditions; and
8. The suite of optimised restriction triggers that maximise yield for each climate replicate can help inform the design of a single set of restriction triggers for operational purposes and for yield analysis across all replicates that is consistent with water utility operations.

[4] NSW Department of Climate Change, Energy, the Environment and Water (the Department) *Water Modellling – Paleo Stochastic Climate Data – Murrumbidgee*. Published 28/10/2022.

Yield estimate for the Yass supply system

Yield available from the Yass supply system. The outcomes of this case study highlight that a range of yields from the Yass supply system are possible due to climate variability, climate change, assumed operating rules, assumed level of service objectives, and the yield assessment method. Yield estimates generated from this study ranged from a low of ~400 ML/annum to a high of ~3,500 ML/annum, with these reducing further under a drier climate change scenario. A summary of these results is presented in Figure 1. In decreasing order of magnitude, the drivers of this uncertainty were:

- Restriction trigger assumptions, with Yass Valley Council's current operational triggers (Level 1 = 81% of storage capacity) generating significantly lower yields than when using lower restriction triggers (Level 1 = 72% or 63% of storage capacity) and triggers that were optimised for each climate replicate to maximise yield.
- Natural climate variability, as represented by the stochastic data. This uncertainty is irreducible, and reflects our imperfect knowledge of what climate conditions will unfold at any given time over the coming decades;
- Projected climate change uncertainty. Whilst only one climate change projection (from NARCliM 1.0) was modelled, it demonstrated the potential for climate change to change supply system yields;
- Information uncertainty specifically associated with the Yass supply system. This can be reduced through improved monitoring; and
- Upstream irrigation demand uncertainty. This is associated with uncertainty about irrigation supply behaviour during and immediately after extended dry periods, and to a lesser extent, uncertainty in the future uptake of currently under-utilised irrigation licences.

Level of service objectives also influence yield, but are a matter of customer and Council choice, rather than an input uncertainty. The yield assessment method also influences outcomes, with the yields assessed using the x/y/z approach being lower than the equivalent yields using the alternative approach.

The lower yield distribution resulting from adopting the same restriction triggers across all climate replicates is considered by HARC to reflect the yield which a local water utility could expect in practice. Operationally, local water utilities adopt one set of fixed restriction triggers, not different triggers for different potential future climates. This is because they do not know what climate conditions will actually prevail over the coming years. Assuming adaptive restriction triggers based on anticipated climate conditions would be inherently risky, given the low skill of climate models beyond a few weeks or months. As indicated in Figure 1, the current yield estimate for Yass is 400-1,300 ML/annum assuming Council's current restriction triggers (Level 1 restrictions at 81% of storage capacity). This yield was limited by the 10% annual likelihood of restrictions. The range of current yield estimates reflects the range of possible climate variability using 76 stochastic streamflow sequences of 130 years in length, for comparison against the yield of 800 ML/annum using the single streamflow sequence from the 130 year instrumental climate record.

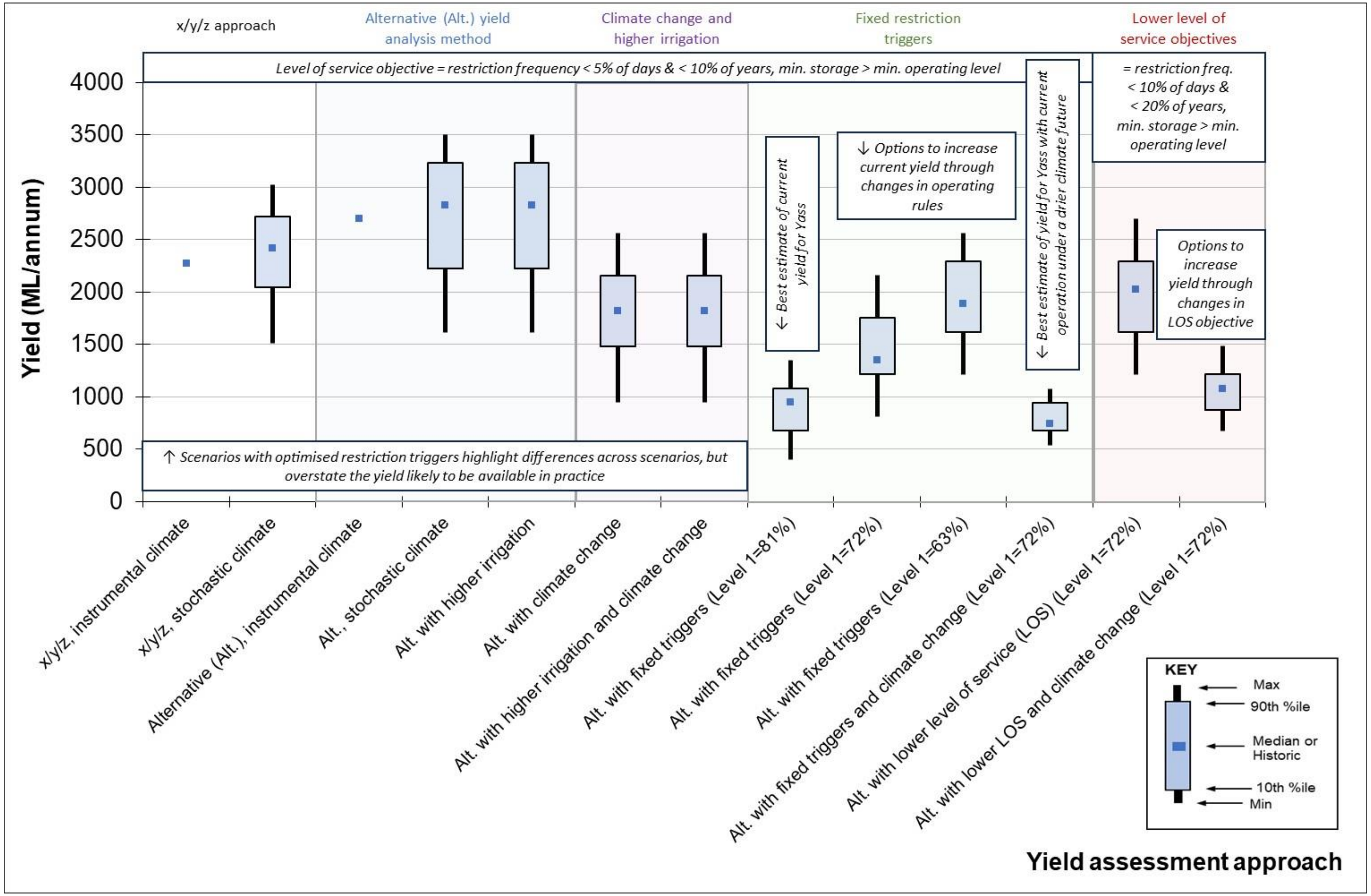

Figure 1 Overview of yield estimates using different input assumptions and assessment techniques

X

Lowering storage level triggers for introducing restrictions increased yield, without resulting in minimum operating levels being reached at yield in all but the driest stochastic replicates. When the triggers were lowered (Level 1 = 72% or 63% of storage capacity), yield increased significantly, and approximately doubled to tripled for the drier replicates.

For a supply system like Yass, where there are a number of input information uncertainties, as well as no readily available, large-scale contingency supply measures, setting the restriction triggers at a high level provides insurance against both climate and non-climate risks to water availability. Lowering the restriction triggers potentially increases that risk. Setting restriction triggers should ideally be informed not only by yield analysis considerations, but also by the likely time available for customers to respond to different restriction levels, and the lead time required to implement contingency supply measures and/or the next supply system augmentation. The implementation of water restrictions can also be influenced by a desire for consistency with water restrictions in the surrounding region (Canberra), as occurred at Yass in the 2019 drought.

When restriction triggers were optimised for each replicate to maximise yield (and ignoring any the other considerations above), both the x/y/z and the alternative yield analysis approaches resulted in a Level 1 restriction trigger in the order of ~65-75% for the driest climate replicates. This was lower than Yass Valley Council's current 81% restriction trigger for Level 1 (see Figure 2). The lower yield when restriction triggers were set at 81% was driven by the need to meet the annual likelihood of restrictions below 10%, not by the minimum volume in storage. This indicated that the restriction triggers could be lowered in the model to increase yield without storage volumes reaching the minimum operating level when demand is at yield. This was confirmed when running the model with the (lower) Level 1 restriction trigger at 72% of storage capacity.

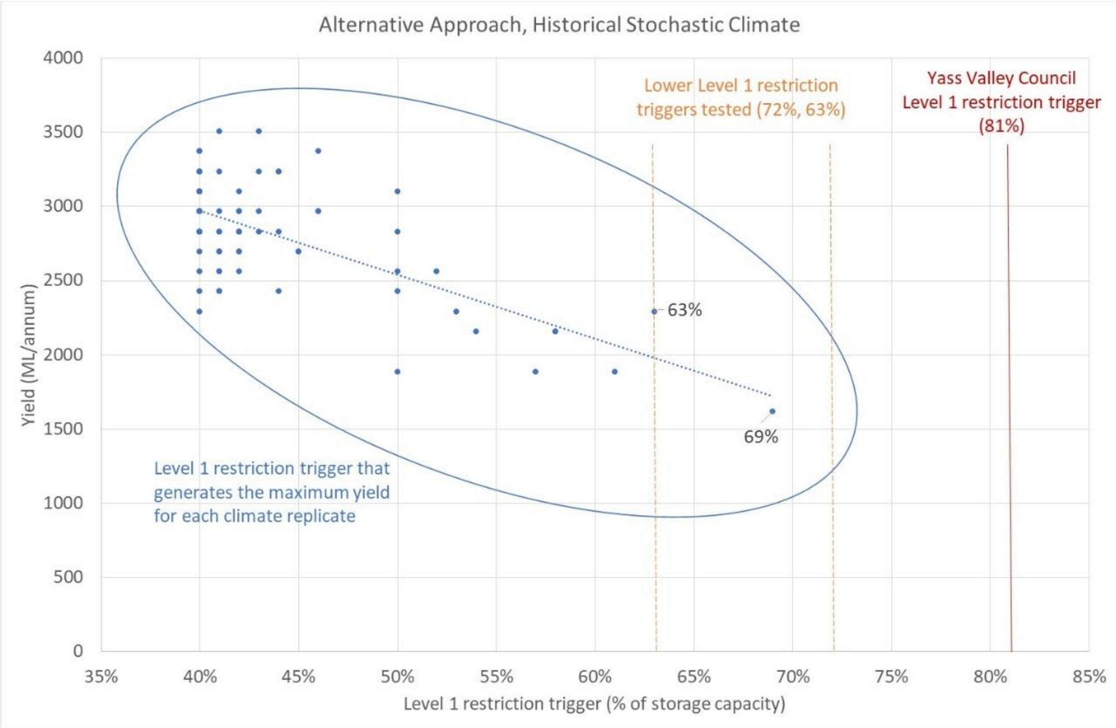

Figure 2 Relationship between yield and restriction trigger level across different climate replicates for the alternative yield assessment approach

Alternatively, a lower level of service objective for the annual likelihood of restrictions (20% annual likelihood instead of a 10% annual likelihood) will also increase the yield. This is because the annual likelihood of restrictions is almost always the limiting factor within the level of service objectives when determining yield for the Yass supply system.

In the absence of a single definitive yield estimate, and a much lower yield estimate when applying Council's current restriction triggers, all of the above point toward the value of robust and adaptable supply enhancement and demand reduction strategies for the Yass supply system over the coming years and decades. In the short-term, subject to further consideration of lead times for contingency supply measures and the insurance value provided by the current water restrictions (e.g. for risks unrelated to climate, such as unforeseen pipe bursts), supply system yield could be increased by lowering restriction triggers. This is estimated to be associated with low risk of reaching minimum operating levels due to climate variability, when demands are at that yield.

It is not possible to assign a precise likelihood to the various yield estimates across different scenarios. This means that any risk-based decision making using these yields would be informed by qualitative rather than quantitative likelihoods for any given yield estimate. Some examples of qualitative, risk-based interpretations of the yield analysis results that reflect different risk appetites are provided in the body of the report (i.e. example risk avoidance, risk averse, and risk-balanced approaches). An example supply-demand projection derived from this information for an example scenario (Level 1 restriction triggers set at 72%, alternative yield assessment approach) is shown in Figure 3. This is based on a simple linear climate change projection from 2020 to 2070 for only one such projection and assumes the growth in demand previously adopted by Yass Valley Council[5]. Under this scenario, there is a 98% likelihood that level of service objectives could be met in the year 2020, reducing to zero likelihood between 2045-2050, depending on growth assumptions, assuming a relatively dry climate change projection. A broader range of climate change projections, such as all of the projections available from NARCliM 2.0 (or at least the range of those projections), would enhance the understanding of the likely timing of required actions at different levels of climate change risk.

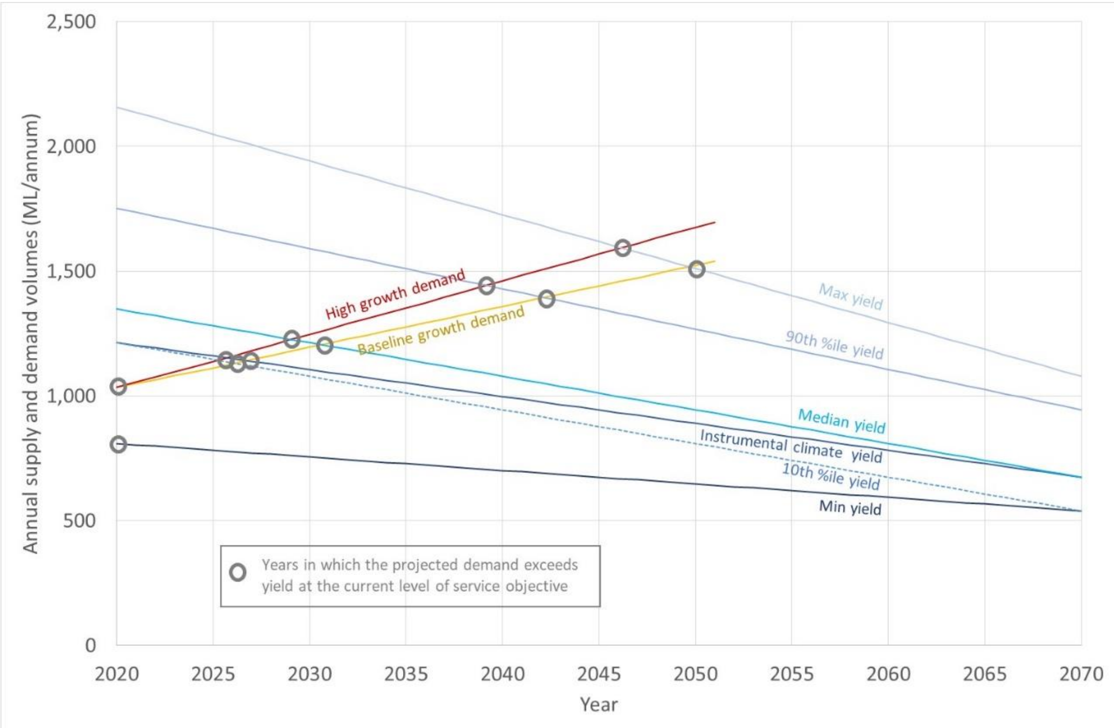

Figure 3 Example supply-demand projection for the Yass supply system, with Level 1 restriction triggers set at 72% of storage capacity, alternative yield analysis approach

Suggested improvements for modelling the Yass supply system

As a result of undertaking this case study of the Yass supply system, the following improvements are suggested for future water resource modelling of the Yass supply system:

1. Resolving the discrepancies in the Yass Dam water level from continuous monitoring versus the Council staff field measurements would allow a reliable estimate of continuously monitored volume in the dam to be obtained. Correspondence from Yass Valley Council (K. Kugaprasatham, pers. comm. to P. Toop, 29/11/2023) indicates that a better radar sensor was installed in April 2022, which is expected to address this recommendation.

2. Subject to (i) completion of suggestion 1 and (ii) advice from a hydrographer about site suitability, monitoring inflows and/or outflows at the dam over a concurrent period during

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[5] Public Works Advisory *Integrated Water Cycle Management Strategy. Draft Issues Paper*. June 2021. Prepared for Yass Valley Council.

drought, with at least one of these monitored indefinitely, would provide valuable information for future yield assessment. Monitoring inflows may provide useful information not only during droughts, but potentially also at other times for other purposes (e.g. flood warning). Monitoring outflows at the dam would allow reservoir inflows to be back-calculated, and would help to isolate the influence of local runoff events between Yass Dam and the nearest streamflow gauge, 2 km downstream. However, monitoring outflows at the dam would be a lower priority if inflows can be monitored, because the local runoff between the dam and the existing downstream gauge is small relative to upstream inflow uncertainty. Moreover, Yass Valley Council has indicated that monitoring outflows at the dam wall is likely to be difficult due to the nature of the weir structure.

Reflections on town water security modelling methods

As a result of undertaking this case study of the Yass supply system, the following reflections are made on the methods used when assessing water security for town water supplies:

1. When applying the stochastic data, the effect on yield of adopting different restriction triggers can be tested using that stochastic data, but only to select a suitable restriction trigger(s) for operational and planning purposes. After this initial exploratory analysis, HARC recommends using the same restriction trigger(s) for the yield analysis (or have consistent design assumptions) across all replicates for a given level of demand. This better reflects operational practice in the context of future climate uncertainty. This also helps to preserve links between the storage level at which restrictions are set and the likely duration of supply available for a local water utility to implement contingency supply measures once that restriction trigger has been reached.

2. Explicitly acknowledging the presence or absence of buffer storages can result in greater transparency in yield analysis. Buffers represent water set aside in storage for unforeseen events, including droughts worse than modelled, unforeseen increases in town water use, and to allow sufficient time to implement contingency supply measures (including consideration of any uncertainty in the time required). The two yield analysis approaches applied in this study address this issue differently. The x/y/z approach assumes an implicit storage buffer volume (i.e. it is an outcome of the approach, not an input to it), whilst the yield analysis under the alternative approach allows any storage buffer volume to be explicitly designed for as an input to the yield analysis.

3. The use of a climatically variable demand model when using stochastic replicates, particularly for supply systems with demands that are more sensitive to climate variability, will ensure that the possibility of different seasonal and inter-annual patterns of demand are taken into account in the different climate replicates. In very dry years within the stochastic data, it is possible to generate a pattern of demand from the demand model that results in demands that are higher than those generated when using the average dry-year demand pattern from the x/y/z approach. This higher demand results in the storage being drawn down faster in those very dry years, which reduces the supply system yield.

4. The term “secure yield” should no longer be used. Historical experience, paleoclimate information, climate change projections, and lessons from other parts of Australia have demonstrated that all surface water supply system yield estimates other than zero have a risk of

not being achieved under future conditions. This was confirmed by the yield analysis with the stochastic data, which confirmed the possibility of supply system yields much lower than the "secure yield" derived using the instrumental climate data.

5. Further guidance on climate change adjustment factors for the stochastic (or instrumental) climate datasets would allow local water utilities to assess yield over a range of plausible climate change scenarios, rather than just a single climate change scenario. For this case study, NARCliM 1.0 climate change adjustment factors were specifically obtained from the Department, and only one of many plausible future climate scenarios was modelled. A broader range of climate change projections, such as all of the projections available from NARCliM 2.0 (or at least the range of those projections), would enhance the understanding of the likely timing of required actions at different levels of climate change risk.

6. Prior to adopting the Regional Water Strategy (RWS) models and datasets, consideration should be given to their suitability for local water security planning for a given town water supply system. This includes consideration of the goodness of fit of those models to local low flow behaviour, as well as consideration of climate variability that has occurred since those models and datasets were developed in 2018. Characterising recent droughts (since 2018) and performing model verification tests using local water resource data, can be used to confirm the suitability of the RWS models and datasets for local town water security planning.

1. Introduction

1.1 The role of this case study

The NSW Department of Climate Change, Energy, the Environment and Water (the Department) is committed that all local water utilities should have in place effective, evidence-based strategic planning (DPE Water, 2022c). This will ensure utilities deliver safe, secure, accessible, and affordable water supply and sewerage services to customers. It will also ensure they can manage keys risks now and into the future, and in the event of significant shocks. Local water utilities remain responsible for conducting strategic planning.

Through the Department's assurance role under Section 3 of the *Regulatory and Assurance Framework for Local Water Utilities* (the "RAF", DPE Water, 2022c), the Department establishes what outcomes it expects effective, evidence-based strategic planning to achieve (see Section 3.2 of the RAF) and assesses if a utility's strategic planning achieves these outcomes to a reasonable standard (see sections 3.3 and 3.4 of the RAF).

Under Section 3 of the RAF, the Department provides supplementary guidance on achieving strategic planning outcomes to a reasonable standard. The Department's *Guidance on Strategic Planning Outcome - Understanding Water Security* (the "Water Security Guidance", DPE Water, 2022a) expects that a local water utility should address current and future risks around continuity and reliability of access to water supply sources.

The Department's Regional Water Strategies (RWSs) bring together up-to-date information and evidence with the aim to balance different water needs and deliver the right amount of water for the right purpose at the right times within regions of the State. It has developed stochastic datasets, combined with paleo-climate information, that were used in the RWS water resource modelling. These datasets were developed to better understand climate variability and the potential for droughts (and floods) worse than those seen over the 130 year historical climate record. The Department's Water Security Guidance recommended that the town water security analysis should be done using robust climate data and models and indicated that RWS datasets have the potential to provide input data for a local water utility's water security analysis.

The Department employed HARC in 2022 to explore how these datasets could be applied to modelling town water security, with the findings from that work reproduced in Appendix A.7 of this report. This informed the development of a step-by-step procedure for applying the stochastic datasets for this purpose. This procedure was incorporated as optional how-to-guidance into Appendix A of the Water Security Guidance. To confirm the suitability of using RWS data and models in a real-world application, the step-by-step procedure of optional how-to-guidance has been applied to the Yass town water supply system. This is a supplementary case study as part of the Appendix B of the Water Security Guidance. The insights and learnings from this case study will be used to improve the optional how-to guidance (Appendix A) of the Water Security Guidance.

1.2 Water security analysis approaches

Supply system yield for town water security is the volume of water that can be delivered from a supply system without breaching the level of service objectives for that supply system. The x/y/z performance-based approach for assessing supply system yield is outlined in the Department's Water Security Guidance indicating three different level of service objectives. The 5/10/10 design rule, which has commonly been applied in yield analysis in NSW to date, is an example of the x/y/z approach. The level of service objectives of this design rule are that:

- the total time spent with water use restrictions (x) should be no more than 5% of the time;
- the percentage of years with restrictions (y) should not be more than 10% of years; and
- when restrictions are applied the water supply system should be able to provide 90% of the unrestricted water demand (i.e. an assumed 10% reduction (z) in demand) through a repeat of the worst recorded drought, without reaching the minimum operating level.
- Under an x/y/z approach, these design criteria can be adjusted to other values, with 5/10/10 being historically the most common design criteria recommended by the Department and adopted by local water utilities across New South Wales. Yield under the x/y/z approach is the maximum average annual demand that meets all of these three criteria.

The Department's Water Security Guidance states that it is critical to understand and determine the level of service and/or risk approach for a utility's water supply systems in consultation with customers and the community. This is formulated within the context of an x/y/z yield analysis approach, but the Department's guidance also allows for the adoption of any other credible and robust approach, provided there is clear justification for its application.

In addition to applying an x/y/z approach, HARC has also adopted an "alternative" performance-based approach, informed by methods adopted in other jurisdictions of Australia. It makes different assumptions to the x/y/z approach to reflect local conditions for inter-annual variability in demand, water savings under restrictions, restriction triggers, and storage buffers set aside for unforeseen events.

As such, both the x/y/z approach and the alternative approach align with the Department's current guidance within the RAF. To enable direct comparisons between the results of the two methods, in this case study, the same duration (5%) and frequency (10%) criteria have been adopted for both approaches.

The approaches taken to assess supply system yield in this case study differ from the supply shortfall risk analysis that was undertaken for towns throughout the Murrumbidgee River basin, which was previously presented in the Department's *Draft Regional Water Strategy (RWS) Murrumbidgee Shortlisted Actions Consultation Paper* from May 2024 (The Department, 2024). It was noted in the RWS consultation paper that a supply shortfall risk analysis is "not appropriate for detailed purposes like secure yield analyses or other strategic planning" by a local water utility. Although the two analyses are underpinned by the same water resource model and stochastic climate datasets, the outcomes differ due to differences in assessment method and purpose. The supply shortfall risk analysis was intended as a high-level, comparative analysis of supply risks to different towns across the region, whilst the yield analysis in this case study is a more detailed local assessment that takes into account supply system operating rules and level of service objectives for water restrictions.

For a supply system like Yass, where there are currently no significant readily available contingency supply measures and a number of input information uncertainties, the supply system must currently be conservatively managed. This occurs, for example, through the use of water restrictions, which were not part of the RWS consultation paper's high-level comparative analysis.

1.3 About the Yass supply system

The Yass supply system was specifically chosen for this case study by the Department because the supply system has a recent history of water restrictions, coupled with ongoing growth in demand for water, with options for supply source development being actively investigated and discussed. This case study supplements existing information available to Yass Valley Council, as part of a multiple lines of evidence approach to decision making. The scope of work of this study does not consider water security improvement scenarios associated with demand management or additional supply sources.

The Yass supply system provides water to the towns of Yass, Murrumbateman (connected in May 2021), Binalong and Bowning (connected in 1989). The Yass Dam was raised in 2013. It is anticipated that the yield provided by the current supply system will no longer be able to maintain target levels of service to customers in the near future (GHD, 2022), with further growth in population and demand for water anticipated over the coming decades (YVC, 2019). Previous yield analyses have been undertaken for the supply system (as reported in GHD, 2022 and Public Works Advisory, 2021b), but not with the RWS stochastic datasets.

For the Yass case study, HARC utilised the Department's Upper Murrumbidgee Source water resource model and its associated rainfall-runoff models. These have been used in the development of the RWS for the Murrumbidgee River (DPE Water, 2022b; the Department, 2024).

2. Yass Supply System Configuration

2.1 Introduction

This section of the report presents the modelling assumptions for the Yass Supply System configuration and the catchments upstream of Yass Dam.

2.2 Model layout

A daily time step Source model of the Yass supply system, including the catchment upstream of Yass Dam, was created for this project. The Yass Source model was based on the relevant parts of the Upper Murrumbidgee Source model, as provided by the Department (Upper_Murrumbidgee_Stitch_5_12_0_V18c_ins.rsproj), but with an adjustment by the Department during the project to include an in-stream loss upstream of Yass Dam and to change the cease to divert reference gauge for private diverters upstream of the dam (final model version from the Department for this project: Upper_Murrumbidgee_Stitch_5_12_0_V20_toHARC.rsproj). The Upper Murrumbidgee Source model has recently been used for the Murrumbidgee Regional Water Strategy (RWS), with further information about the modelling approach adopted for the RWS using this model in DPE Water (2022b). All modelling for this project has been undertaken in Source version 5.16.

The schematic layout of the Yass Source model, as extracted from the Upper Murrumbidgee Source model and including the in-stream loss upstream of Yass Dam, is shown in Figure 4.

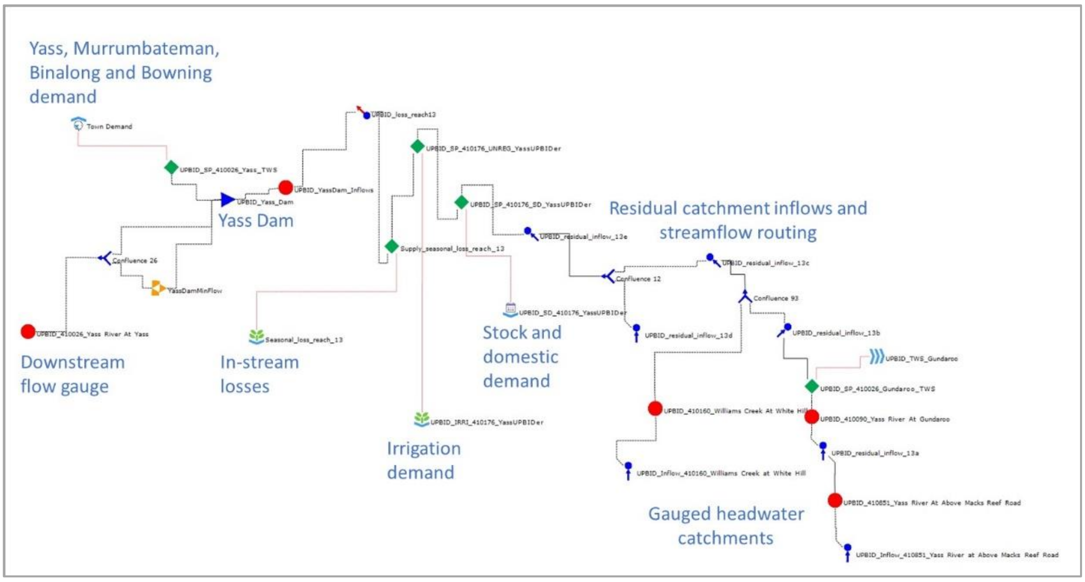


Figure 4 Schematic of the Yass Source model

The model extent includes seven catchments upstream of Yass Dam, consisting of two gauged headwater catchments and five inter-station (residual) catchments, as listed in Table 1 and mapped in Figure 5. Streamflow inputs for these sub-catchments were derived using the Department's Sacramento rainfall-runoff models. The two gauged headwater catchments are Yass River above Macks Reef Road (gauge number 410851) and Williams Creek at White Hill (gauge number 410160). Streamflow gauges are also represented in the Yass River at

Gundaroo (gauge number 410160) and the Yass River at Yass (410026), which is located approximately 2 km downstream of Yass Dam. The model includes flow routing along river reaches. There is a Source loss node, but it is set to zero loss, with no losses also in upstream flow routing reaches. Instead, losses have been represented by the Department using an irrigation demand node that intermittently draws water from the river. In Figure 5, residual catchment 13f, which covers the Yass River catchment from Yass to Burrinjuck Dam, is downstream of the Yass Source model extent.

Table 1 Yass Source model sub-catchments

Sub-catchment	Sub-catchment name
R13a	Yass River from Macks Reef Rd (gauge number 410851) to Gundaroo (gauge no. 410090)
R13b	Yass River from Gundaroo to Williams Creek
R13c	Yass River from Williams Creek to Murrumbateman Creek
R13d	Murrumbateman Creek upstream of Yass River
R13e	Yass River from Murrumbateman Creek to downstream of Yass Dam (gauge no. 410026)
HW 410851	Yass River above Macks Reef Road
HW 410160	Williams Creek at White Hill

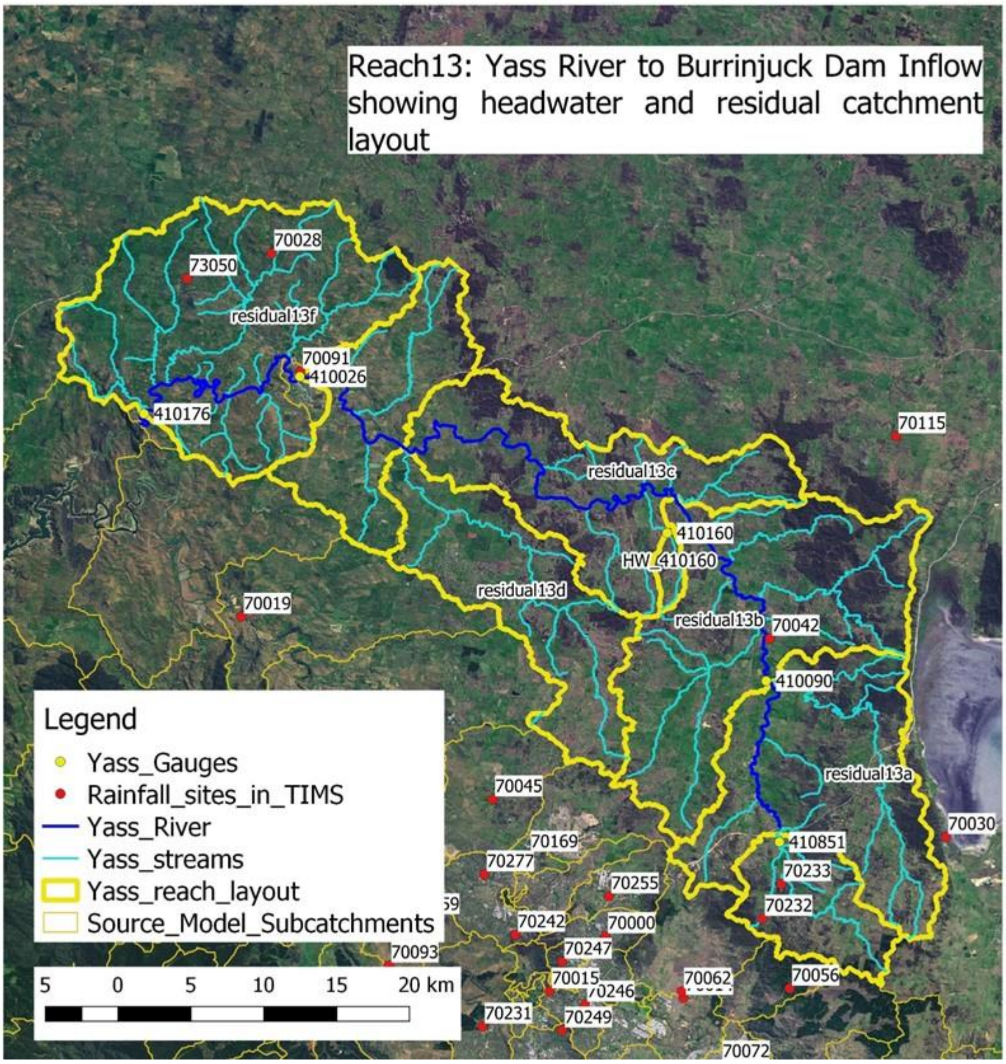


Figure 5 Map of headwater and residual catchments (Source: NSW DCCEEW Water Group)

Rural demands are represented by an irrigation demand node, and a domestic and stock demand node, upstream of Yass Dam.

The urban supply system is represented by Yass Dam, with a single urban demand node representing total supply to Yass, Murrumbateman, Binalong and Bowning. The town of Gundaroo is also represented in the model, but with demands set to zero because Gundaroo does not currently receive supply from the Yass River.

Further details on each of these modelled elements are provided in the following sections. This includes some adjustments to the representation of the Yass Supply System, based on information received from Yass Valley Council for this case study, as discussed below.

2.2.1 Key dates

The dates on which significant supply system changes occurred were:

- Yass Dam upgrade: 2013

- Murrumbateman connection to Yass supply system: May 2021
- New restriction triggers adopted: 25 March 2020

2.3 Yass Dam

2.3.1 Yass Dam rating table

Yass Dam is modelled as having a full supply volume of 2,465.9 ML at a reduced level of 500.4 m. This information from the Upper Murrumbidgee Source model is consistent with that received from the Yass Valley Council (YVC) for this case study (2,465 ML full supply volume) (K. Kugaprasatham, YVC, pers. comm. 22/3/2023). According to a diagram of the Yass Dam intake valve levels provided by YVC (see Appendix A.1), the lowest inlet valve is at a level of 491.026 m, with 4.2m below this inlet valve to the scour valve. The dam as modelled using the reservoir rating table in Table 2 represents the live storage volume above the minimum operating level for supply to Yass township, with dead storage not being modelled. The crest of the dam is at 500.400 m, with no separate spillway.

Table 2 Yass Dam Level-Volume-Area Relationship

Level (m)	Volume (ML)	Surface Area (km²)
0.0	0.0	0.000
490.0	0.0	0.000
491.0	0.1	0.000
492.0	1.3	0.003
493.0	20.4	0.045
494.0	104.1	0.116
495.0	253.0	0.184
496.0	470.4	0.249
497.0	748.6	0.310
498.0	1,110.6	0.412
499.0	1,585.4	0.534
499.4	1,810.4	0.584
499.9	2,120.4	0.656
500.0	2,186.7	0.670
500.4	2,465.9	0.725

The storage capacity of Yass Dam was lower in the pre-dam upgrade period, with a capacity of 872 ML (compared to 2,465 ML currently). The Yass Dam level-volume-area relationship at that time is provided in Appendix A.2.

2.3.2 Yass Dam outlet capacity

The outlet capacity on the supply to Yass was set at 10 ML/day for water levels above 492.5 m (corresponding to a volume in storage of ~10 ML). This was increased to 13 ML/day based on advice from Yass Valley Council (K. Kugaprasatham, YVC, pers. comm. 5/7/2023). This outlet capacity to the town water supply was a limiting constraint when demands exceeded 13 ML/day, and was relaxed for yield modelling at higher than current levels of demand, as discussed further in Section 2.4.

The dam can be temporarily surcharged above the full supply level during high inflow events. The Source model only coarsely models the discharge over the dam crest. The storage discharge relationship assumes no spills until the water level reaches 500.4 m, as shown in Table 3, consistent with the latest version of the Upper Murrumbidgee Source model.

Table 3 Yass Dam modelled spills over the dam crest

Level (m)	Discharge (ML/day)
0.0	0
500.399	0
500.4	10,000
501.0	100,000
502.0	1,000,000

The storage and spill behaviour were confirmed in Figure 6, where it can be seen that in the Yass Source model, spills only start to occur once the full supply volume of 2,465 ML (corresponding to the crest level of 500.4 m) has been reached.

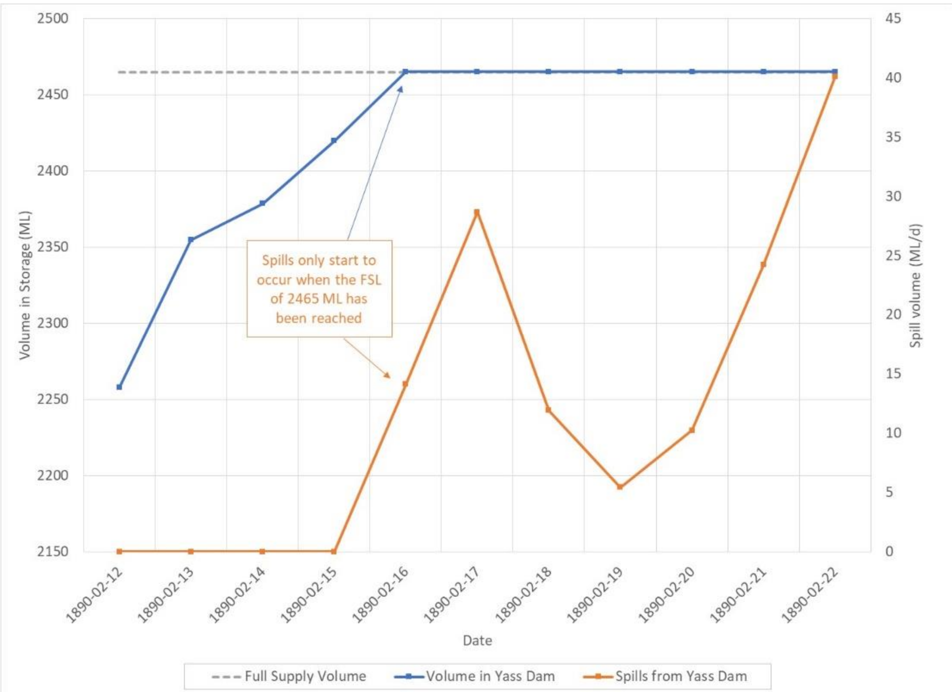


Figure 6 Spill behaviour in Yass Dam for an example period when Yass Dam reaches its full supply volume

2.3.3 Net evaporation from Yass Dam

Net evaporation from Yass Dam was modelled using the rainfall and Morton's shallow lake potential evapotranspiration at Yass (Linton Hostel) (site number 070091). All climate data was sourced from the SILO database, as extracted by the Department at the time of developing the Upper Murrumbidgee Source model. More recently extracted data from SILO was appended to the Department's historic climate dataset, for the sole purpose of validating the Yass Source model against very recent historical behaviour.

2.3.4 Minimum passing flows

According to the approval issued under the Water Management Act 2000 for Yass Dam, there is a requirement to provide 0.5 ML/day at the Railway Weir (former gauging station 410046), 4 km downstream of the dam, when inflows are greater than zero. This approval is documented on the NSW Water Register (located online at https://waterregister.waternsw.com.au) for approval number 10 CA 413762. Yass Valley Council makes releases over and above this minimum requirement to reduce complaints from rural water users between Yass Dam and Railway Weir. Yass Valley Council (K. Kugaprasatham, YVC, pers. comm. 5/4/2023) advised that in practice they release 1-2 ML/day downstream in total for these two purposes (when inflows are greater than zero but the dam is not spilling).

Examination of a limited amount of dam release data indicated that Yass Valley Council made releases of 1 ML/day from 1 November 2019 to 10 January 2020, with historical flows observed at the streamflow gauge 2 km downstream of the dam (Yass River at Yass, site 410026) in the order of 0-2 ML/day when Yass Dam was drawn down in 2019/20 (see Figure 21 in Section 2.10.2 for an illustration of this). On this basis, for the yield analysis, a minimum passing flow requirement of 1 ML/day was specified in the model, when inflows to the dam are greater than zero. When there is no inflow to the dam, there is no minimum passing flow requirement.

The Upper Murrumbidgee Source model assumes slightly different minimum passing flow rules, but these generate the same release pattern from Yass Dam under most inflow conditions, and a similar release pattern during very low inflow conditions. The Upper Murrumbidgee Source model assumes a minimum passing flow requirement of 1 ML/day, when inflows to the dam are greater than 1 ML/day (i.e. the same as the Yass Source model), but assumes no passing flow requirement during very dry periods when inflows to the dam are less than 1 ML/day. However, the Upper Murrumbidgee Source model still makes releases of 1 ML/day when inflows are above zero but less than 1 ML/day. This is due to assumed water deliveries in the model to downstream private diverters between Yass Dam and Burrinjuck Dam, which are not represented in the Yass Source model. The net effect of these two factors is a similar release pattern in the two models when inflows are above zero but below 1 ML/day.

These various passing flow rules are summarised in Table 4.

Table 4 Yass Dam passing flow rules

	Passing flow requirement when inflow is zero (ML/d)	Passing flow requirement when inflows are greater than zero but less than 1 ML/d (ML/d)	Passing flow requirement when inflows are 1 ML/d or greater (ML/d)
Water Sharing Plan Rules (requirement at Railway Weir, 4 km downstream of Yass Dam)	0	0.5	0.5
Yass Source Model (June 2024) (requirement at Yass Dam)	0	1.0	1.0
Upper Murrumbidgee Source Model (June 2024) (requirement at Yass Dam)	0*	0.0*	1.0
Yass Valley Council practice (requirement at Yass Dam)	0	1-2	1-2
Historical observations, 1 Nov 2019 to 10 Jan 2020 (at Yass gauge, 2 km downstream of Yass Dam)	Passing flow typically just above 1.0 ML/d, but dropping to zero at the height of the drought, when (ungauged) inflows were presumably zero.		

*Releases of 1 ML/d are modelled as being made to meet downstream irrigation, and domestic and stock demands in Yass River between Yass and Lake Burrinjuck, if needed during low flow periods.

The adopted minimum flow requirements were represented in the Yass Source model as a valve with discharge rates shown in Table 5. In practice, the Yass Valley Council closes the valve for minimum flow releases when spills occur. Source does not allow a valve to have a lower discharge rate at higher water levels, so it was modelled with the valve remaining open, even when the dam is spilling. The model behaviour is shown using a sample period in Figure 7. This confirms that the model is behaving as expected, with minimum passing flows of 1 ML/day being made when the dam inflows are greater than zero, and no minimum passing flows when dam inflows are zero. Note that there is a one-day lag between the reference inflow used and the minimum passing flow provided. This is because Source does not allow modelled variables to be referenced on the current time step.

Table 5 Level-discharge relationship for minimum flow releases from Yass Dam

Reduced Level (m)	Maximum discharge (ML/day)
0	0
491.999	0
492.000	1
500.399	1
500.400	1
999.999*	1

*notional value added to the Source model to ensure that the 1 ML/d discharge is always provided when the reduced level is at or above 492 m.

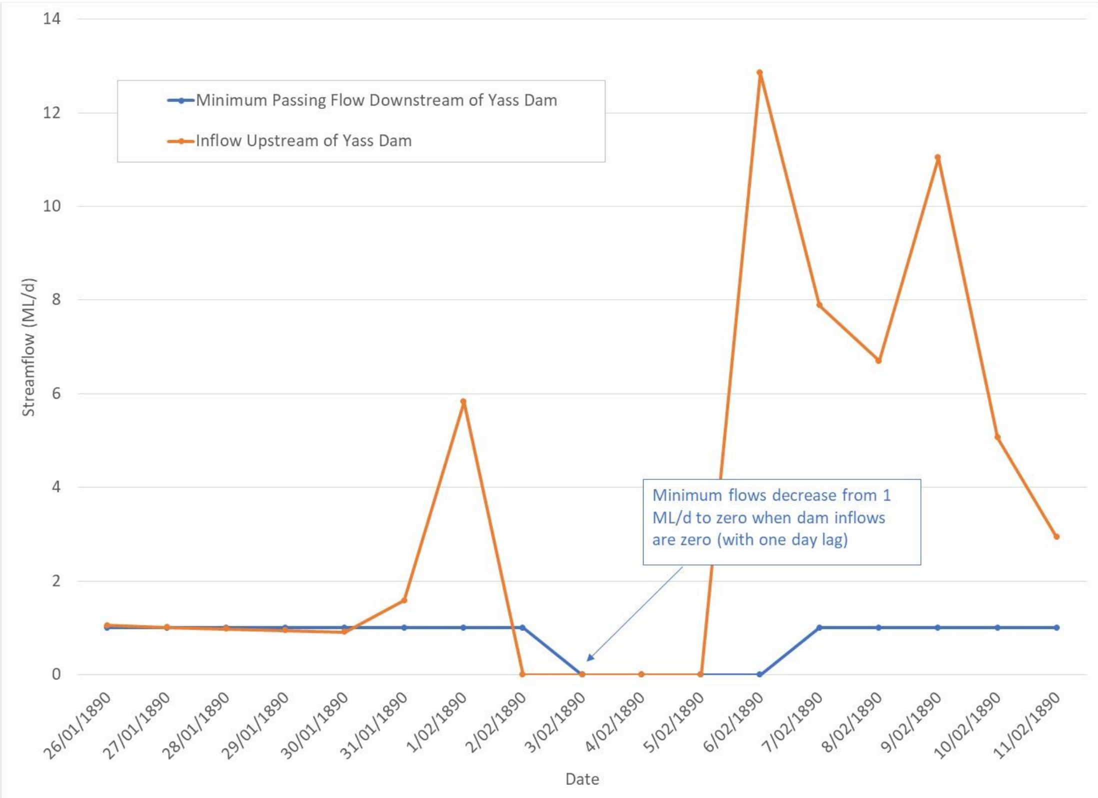


Figure 7 Incorporation of minimum passing flows downstream of Yass Dam, sample period when Yass Dam inflows dropped to zero

2.3.5 Historical water levels

Historical water level information was provided by Yass Valley Council, for the purpose of verifying the Yass Source model behaviour over a recent historical period. Consideration of this data is presented in Appendix A.2. Examining the data identified some discrepancies between the continuously monitored water levels and field measurements by staff, with Yass Valley Council indicating that the field measurements were the more reliable dataset to use at the current time.

The outcome of that analysis was that in the period since the dam wall was raised in July 2013, the only period in which the reservoir was significantly drawn down was from November 2019 to February 2020, with a maximum observed drawdown of 1.39 m below crest level (to 64% of the full supply volume) on 7 February 2020.

Yass Valley Council also provided spot monthly water level readings in the pre-dam upgrade period over the Millennium Drought, from January 1998 to May 2006, and quarterly readings from May 2006 to October 2007. There were several dam drawdown events over the Millennium Drought.

2.4 Town demand modelling

2.4.1 Upper Murrumbidgee Source model town demand model

The Upper Murrumbidgee Source model represents the town demand as a fixed demand component equal to a critical human water need, plus a seasonally variable component that is fixed each year (based on average monthly variance in the observed data from 2000/01-2018/19), plus a daily variable component based on net evaporation deficits (i.e. evaporation minus rainfall) over a rolling 7 day period. There was also an allowance for population growth within the Upper Murrumbidgee Source model that can be enabled or disabled as required for any given scenario. HARC fixed the population at 10,492 people to match the town supply outputs provided by the Department, when verifying that the Yass Source model was able to match the Upper Murrumbidgee Source model behaviour, but otherwise did not rely upon the embedded population growth figures within the Upper Murrumbidgee Source model (see Section 2.4.2 for the population data adopted by HARC from another NSW Government source). This demand model setup was retained for initial verification of the Yass Source model against the Upper Murrumbidgee Source model, but was not used for any subsequent modelling for the project.

2.4.2 Demand modelling for this project

A demand model for the Yass supply system was set up for this project by HARC. As informed by a review of practices in other jurisdictions, this demand model uses climate-driven regression equations to generate urban water demands that include not only seasonal variability in demand, but also inter-annual variability in demand. This demand model was used primarily for the alternative yield approach, described in Section 5 of this report, but also informed the dry year demand patterns in Section 2.4.3 used in the Department's x/y/z yield approach, also described in Section 5 of this report.

These regression equations typically take the form:

$$D_t = \beta_0 + \beta_1 f_1(X_{1,t}) \ldots + \beta_n f_n(X_{n,t}) + \varepsilon_t \qquad (1)$$

where,

D_t = the observed per capita water demand at time step t,

β_n = the regression coefficient for variable n (β_0 is the intercept),

$X_{n,t}$ = independent variable n at time step t,

$f_n(X_{n,t}) = X_{n,t}$, if linear, or if non-linear then a transforming equation is used

In this case, the transforming equation that has been used is (Beatty, 2009).

$$f_n(X_{n,t}) = tan^{-1}\left(\left(X_{n,t} - \frac{v_{U,n} + v_{L,n}}{2}\right)\left(\frac{\pi}{v_{U,n} - v_{L,n}}\right)\right) \qquad (2)$$

with $v_{U,n}$ & $v_{L,n}$ = the upper & lower shape constants for variable n, and

ε_t = the error term or residual at time step t.

Other transforming equations can be used where they improve the statistical significance of the variables used.

The RWS data sets include rainfall and potential evapotranspiration data. The demand model has been developed using these two datasets.

Another variable that can be utilised is some type of indicator of soil moisture which is used to model the antecedent soil moisture effects on demand. In this study a soil moisture index (SMI) has been used that has been shown to be statistically significant in explaining water demands in a number of cities in Australia, New Zealand and North America as shown in Figure 8 (Beatty, 2009).

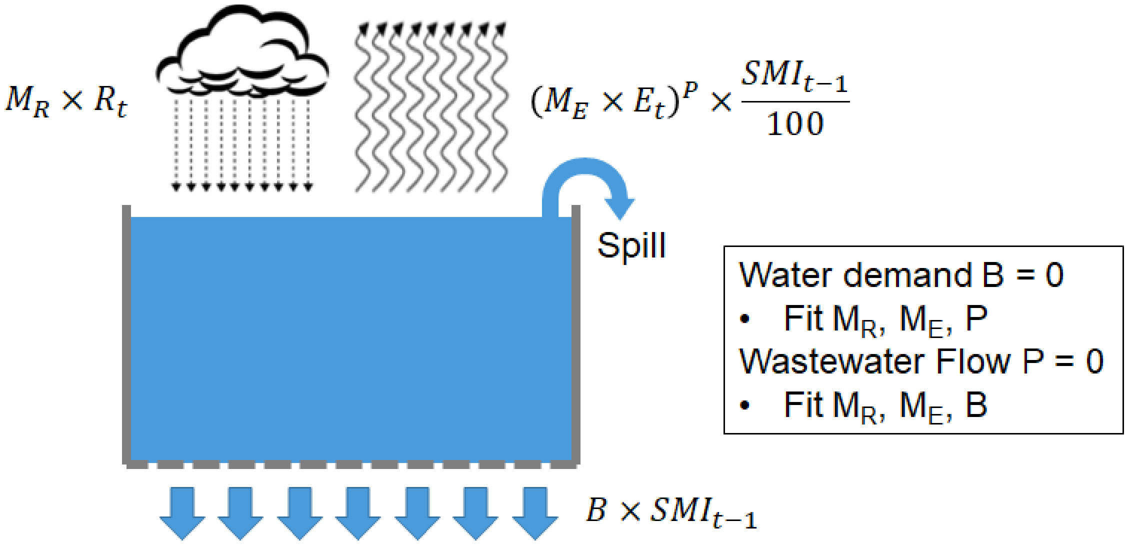


Figure 8 Schematic representation of the Soil Moisture Index

The soil moisture index, which ranges between 0 (dry) and 100 (saturated), is calculated using the following set of equations:

$$S_t = SMI_{t-1} + M_R R_t - (M_E E_t)^P \frac{SMI_{t-1}}{100} - B\, SMI_{t-1}$$
$$SMI_t = 0 \quad \text{if } S_t < 0$$
$$SMI_t = 100 \quad \text{if } S_t > 100$$
$$SMI_t = S_t \quad otherwise$$

Where SMI_t = Soil moisture index at time t

R_t = Rainfall at time t

E_t = Evaporation (Morton's wet area evaporation) at time t

M_R = Rainfall multiplier

M_E = Evaporation multiplier

P = Evaporation power

B= Base flow coefficient

The baseflow coefficient is only used when modelling wastewater flows, where the soil moisture index approximates a groundwater infiltration index. When modelling water demand, the baseflow coefficient is set to zero.

In this regression model, the observed climate data at station 70091 - Yass (Linton Hostel) was used. The results of the analysis of bulk water demands are provided in Table 6 to Table 8 below. A plot of the observed versus predicted demand is shown in Figure 9. This plot shows a good model fit over the calibration period. The calibration period covered the period from July 2017 to June 2022. The period of increased demand from July 2022 onwards was excluded from the calibration period. Yass Valley Council (K. Kugaprasatham pers. comm. 23/5/2023) indicated that water consumption in 2022/23 was temporarily higher than expected due to a leak in one of the service lines that has since been repaired, and a calibration issue with the inlet flow meter. Yass Valley Council confirmed that there had been no significant additional connections in 2022/23 driving the increase in demand in that year.

Table 6 Time series analysis of bulk water production - regression analysis results

Parameter	Value
R^2	0.56
Standard Error of Y estimate	87.45
F Statistic	765.83
Degrees of Freedom	1801

Table 7 Time series analysis of bulk water production - soil moisture index parameters

Parameter	Value
Rainfall multiplier	3.01
Evaporation multiplier	0.37
Evaporation power	2.68
Baseflow coefficient	0.000

Table 8 Time series analysis of bulk water production - independent variable parameters

Variable	Regression Coefficient	t-statistic	Upper Shape Constant	Lower Shape Constant
Intercept	829.19	18.11	N/A	N/A
Soil Moisture Index	-383.85	-31.03	199.44	-128.70
Rainfall	-8.14	-2.93	0.1824	-0.1454
Evaporation	241.21	6.71	12.4977	8.0545

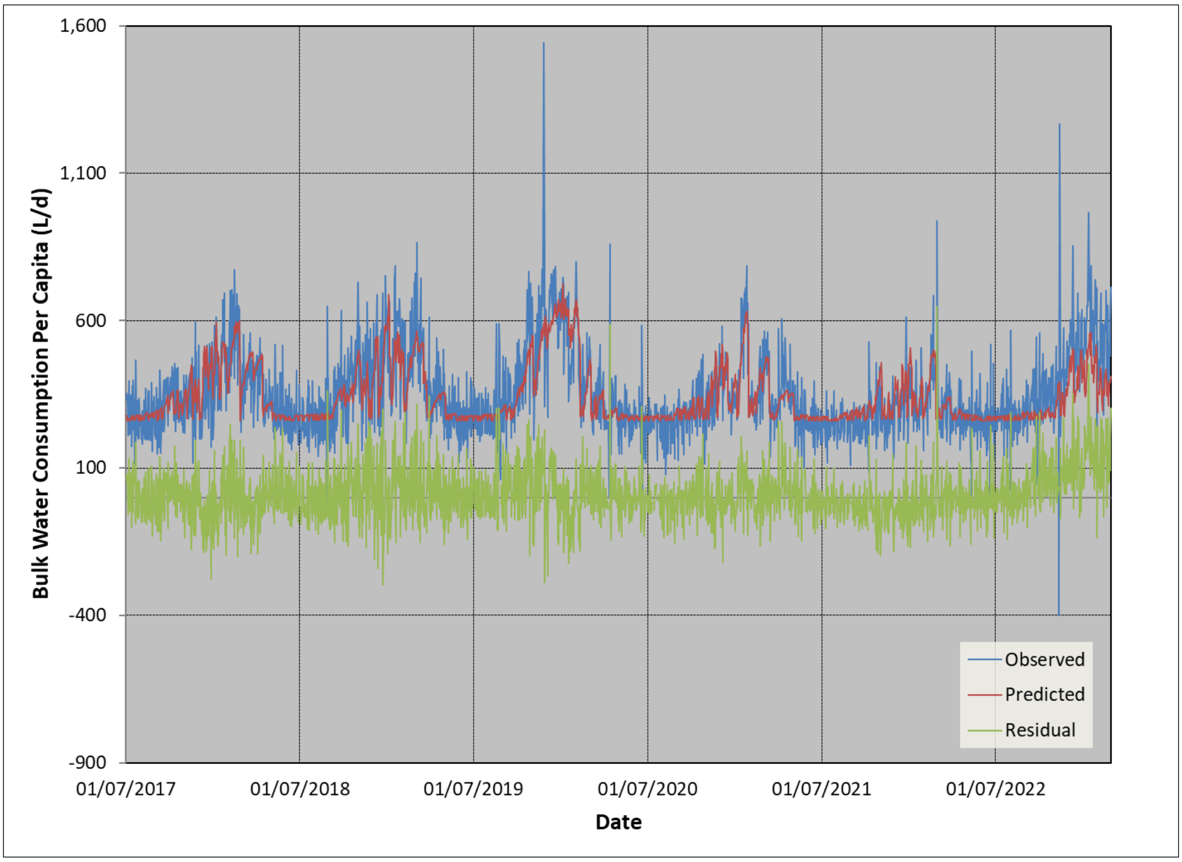


Figure 9 Time series analysis of bulk water demand per capita – Yass Supply System

2.4.3 Demand modelling for the x/y/z approach

The x/y/z modelling approach uses a fixed seasonal pattern each year. This seasonal pattern represents the pattern that occurs during dry years. The regression model outlined above in Section 2.4.2 was utilised to generate daily demand estimates using climate data from July 1970 to June 2020 (hindcasting period). The five years with annual demands above the 90th percentile in this hindcasting period were considered representative of "dry years". Multiple years are used to estimate the seasonal demand pattern, because any one year may exhibit an anomalous demand pattern that may not be typical of most dry years.

The demands predicted by the regression model for these dry years are shown in Figure 10. The demand patterns generally follow a similar seasonal pattern, but with differences on any individual day.

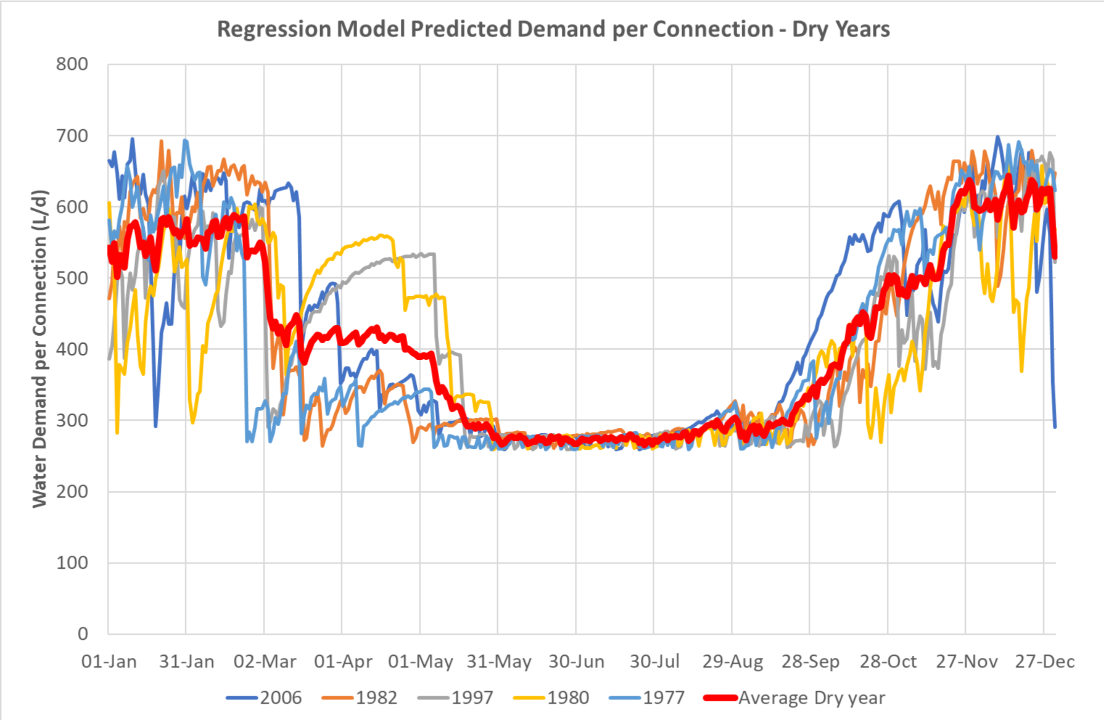


Figure 10 Regression model predicted demands in designated dry years

The average demand factors for these dry years are shown in Figure 11, in comparison to those for all years in the analysis period (since 1970). The 30-day smoothed average for the dry year demand is also shown, which removes some of the variance that results from the relatively small number of years in the dry year sample. These results show that even with several dry years in the sample, there is still deviation from long-term average seasonal demand patterns.

The divergence of demands occurs primarily in the summer period. In all dry years, these seasons are drier in comparison to the average of all years, as shown in Figure 12 which reports monthly average rainfall. During these periods, the dry year demand can be up to 5% higher than the average demand across all years.

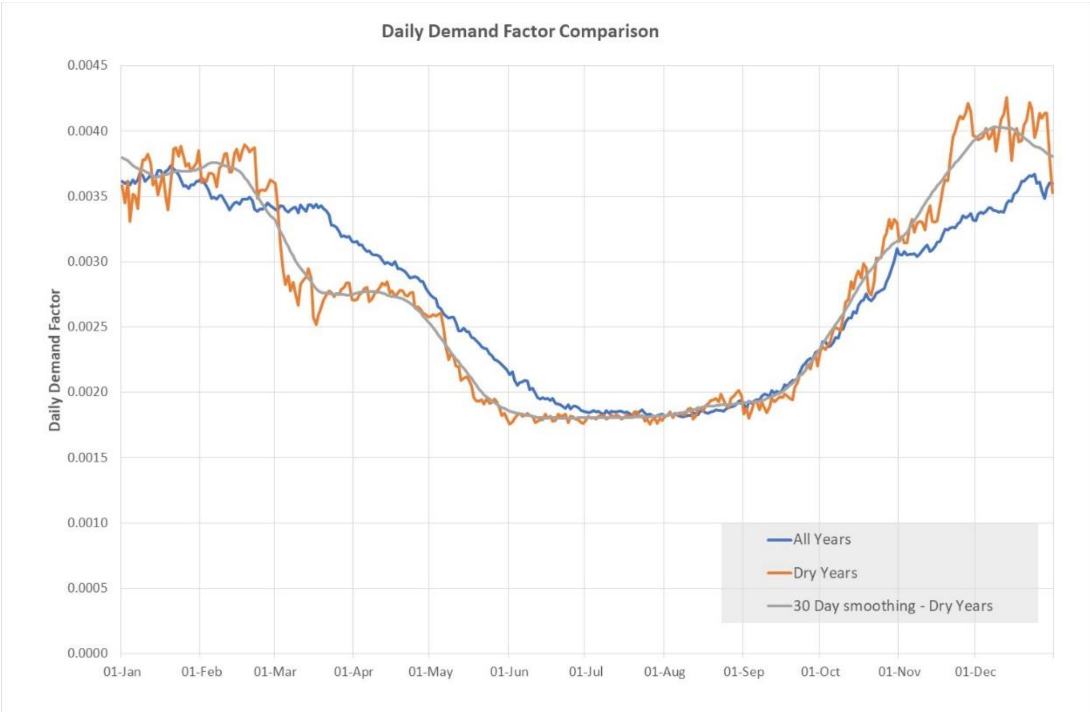


Figure 11 Daily demand factor comparison

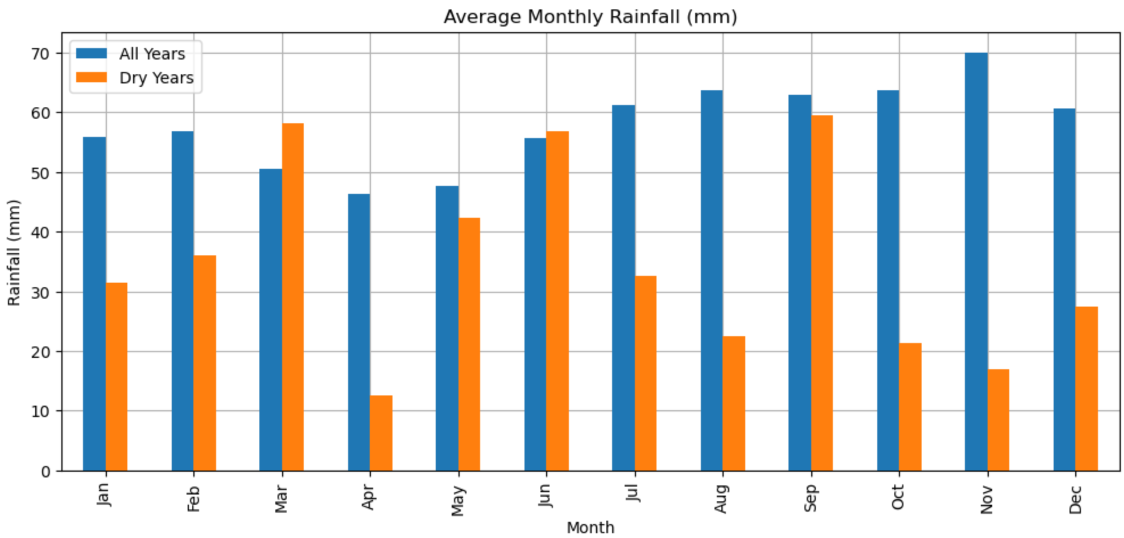


Figure 12 Average monthly rainfall patterns considering all years from 1970 – present, and the 2006,1982,1997,1980,1977 dry years

2.4.4 Daily town diversion limit

In the Upper Murrumbidgee Source model, the storage node representing Yass Dam has an imposed 10 ML/day diversion limit attached to the outlet pump that connects to the Yass demand model node. Under current conditions with an estimated supplied population of approximately 7,000 people, this limit is never reached, with peak daily demand estimated to be 5 ML/day. Testing has shown that when the population is increased to in excess of 14,000 there is the potential for the diversion limit to be triggered on any given day. This results in the demands not being met on peak demand days at population levels higher than this, even when there is water remaining in storage. Due to this, the 10 ML/day diversion limit has been removed from the models used to conduct the yield analysis.

2.5 Town water restrictions

The 5/10/10 level of service criteria was used for the yield analysis under 'x/y/z' approach as referred to in the Department's Water Security Guidance (DPE Water, 2022). Water restriction triggers are developed when applying the approach, with demand reductions under restrictions pre-defined by the method (z=10 indicating an assumed 10% reduction in demand during restrictions). For verification of the Yass Source model, and for application of the alternative yield analysis approach, water restrictions currently in operation by the Yass Valley Council have been adopted, with adjustment as required at different levels of demand in subsequent yield analysis.

The Yass supply system has a five-stage restriction policy, as defined in Yass Valley Council policy document WS-POL-11 (YVC, 2020), which was implemented on 25 March 2020. Waterwise measures are in place at all times to avoid water being wasted with inefficient water use practices. Yass Valley Council also provided a copy of its earlier four-stage restriction policy (YVC, 2012), which was in place from 13 June 2012 to 24 March 2020. Note that the demand reduction actions under the two policies are identical apart from minor wording changes. After the Yass dam wall was raised in 2013, only mild restrictions have only been implemented at Yass and Murrumbateman in 2019/20 using the previous 2012-2020 restriction policy. No restrictions have been implemented using the current restriction policy.

Table 9 Volume in Yass Dam at which restriction level is implemented (% of full supply volume)

Restriction level	Current policy	2012-2020 policy
Waterwise measures	100%	100%
Level 1	81%	99%
Level 2	74%	86%
Level 3	63%	73%
Level 4	53%	59%
Level 5	46%	45%

It was not possible to empirically estimate the demand reduction anticipated at each level of restriction, because only mild restrictions have been implemented for a short period of time with the 2012-2020 restriction policy, and no restrictions have been implemented with the current restriction policy. Instead, an end use model was used to estimate the extent to which different components of household and non-household demand would be affected by each stage of restriction, and the likely impact on each of those demand components. This was based on an interpretation of the current Yass Valley Council restriction policy. It is noted that outdoor water use is rostered, but not restricted, until Level 5 is reached, which explains the large increase in demand reduction at Level 5 relative to lower levels of restriction.

Table 10 Assumed demand reduction at each stage of restriction

Restriction level	Demand reduction (% of unrestricted demand)
Waterwise measures	0.0%
Level 1	4.9%
Level 2	6.5%
Level 3	9.1%
Level 4	11.6%
Level 5	22.9%

2.6 Rainfall-runoff modelling

There are two gauged headwater catchments and six inter-station (residual) catchments delineated in the Yass Source model. The rainfall-runoff modelling to generate time series streamflow inputs is outlined below, based on the rainfall-runoff modelling previously undertaken by the Department for the Upper Murrumbidgee Source model. This modelling is undertaken using the Sacramento rainfall-runoff model, with rainfall weightings from different rainfall stations optimised in FORS.

2.6.1 Climate data inputs

The climate data used for each rainfall-runoff model, and the weighting applied in the composite rainfall inputs for each model, are as listed in Table 11 (with weightings rounded to three decimal places – unrounded weightings are presented in Appendix A.3). The evaporation data used was Morton’s wet areal potential evapotranspiration. All data was sourced from the SILO database, with the SILO data adopted as downloaded by the Department at the time of rainfall-runoff model calibration for the regional water strategy.

Table 11 Climate data inputs for the Yass Source model rainfall-runoff modelling

Catchment	Rainfall stations (and weightings)	Evaporation station
R13a	070030 (0.409), 070233 (0.394), 070042 (0.285)	070233
R13b	070255 (0.472), 070115 (0.379), 070042 (0.170)	070042
R13c	070091 (0.345), 070042 (0.680)	070042
R13d	070091 (0.463), 070042 (0.260), 070045 (0.363)	070045
R13e	070091 (1.082)	070091
HW 410851	070233 (0.157), 070056 (0.465), 070232 (0.426)	070233
HW 410160	070042 (1.100)	070042

2.6.2 Sacramento model parameters

The Sacramento rainfall-runoff model parameters for each catchment were as provided by the Department from the Upper Murrumbidgee Source model. These model parameters are presented in Appendix A.3. These parameters were optimised by the Department to best fit the observed streamflow data. The same set of model parameters were used for residual catchments 13b to 13e, with catchment areas and climate inputs being different in each of these residual catchments.

2.6.3 Sacramento model calibration

The Sacramento models were previously calibrated by the Department, with calibration report cards for the two headwater catchments presented in Appendix A.4. The calibration period is from January 1996 to April 2020 for the Yass River above Macks Reef Road (gauge number 410851) and from February 1989 to April 2020 for Williams Creek at White Hill (gauge number 410060). Both headwater catchment rainfall-runoff models exhibit an overall mass balance without significant bias, and display a good fit to low flow behaviour. The Yass River above Macks Reef Road fits well to high flows as well, but the Williams Creek site does not fit as well to high flows, resulting in a lower overall Nash-Sutcliffe efficiency. For the purposes of estimating yield, where low to moderate flows will be of most importance, these models are considered fit for purpose.

For the residual catchments, the Sacramento model parameters were calibrated by the Department simultaneously to streamflow gauges 410176 (upstream of Burrinjuck Dam), 410026 (downstream of Yass Dam), and 410090 (at Gundaroo), after taking into account the routing along the Yass River, described in Section 2.7. The model calibration period for the residual catchments was from January 1970 to April 2020, when observed data was available at the three calibration locations. The model fit at Yass, as presented in Appendix A.4, shows a good overall fit, with model bias within ±2% of the observed flows for a range of total flow, low flow, and high flow parameters. The rainfall-runoff models were not calibrated to the volume in Yass Dam, with a river loss subsequently introduced by the Department to improve Source model calibration to the volume in Yass Dam.

2.6.4 Sacramento model verification

Prior to utilising the Sacramento rainfall-runoff models, HARC first verified that the rainfall-runoff models could re-produce the catchment runoff estimates available in the inflow time series within the Upper Murrumbidgee Source model that were previously prepared by the Department. This verification process identified a difference in estimated rainfall in the SILO rainfall data, when downloaded by HARC in 2023, relative to that obtained by the Department for model calibration in 2020. This is because the SILO database is regularly updated, with adjustments to data infilling procedures to include newly recorded rainfall data as it becomes available. These changes to data infilling procedures are backdated in the SILO database over the whole of the rainfall time series. For the purposes of verifying the Sacramento rainfall-runoff models, HARC used the SILO rainfall (and evapotranspiration) data as downloaded by the Department in 2020 when the rainfall-runoff models were calibrated. After discussion with the Department, when using the historical climate information for Source model verification purposes, HARC has used the SILO climate data as downloaded by the Department in 2020, then appended the additional climate data to early 2023, using the SILO climate data downloaded by HARC in 2023.

Table 12 Sacramento model verification (1/01/1890 – 31/12/2018)

Catchment	Mean daily runoff in Upper Murrumbidgee Source model (ML/Day)	Mean daily runoff in Yass Source model (ML/Day)	% difference
R13a	42.45	42.40	0.12%
R13b	57.18	57.15	0.05%
R13c	30.22	30.21	0.04%
R13d	38.94	38.93	0.04%
R13e	31.62	31.61	0.04%
HW 410851	2.22	2.22	0.00%
HW 410160	16.62	16.62	0.00%

2.7 River routing

River routing occurs in several river reaches along the Yass River using a relationship between flow and travel time over a given reach length. See Appendix A.5 for the details of the relationship between flow and travel time for each reach, as provided by the Department in the Upper Murrumbidgee Source model.

2.8 Rural demand modelling

There are two rural demand nodes in the Upper Murrumbidgee Source model, which have been adopted in the Yass Source model. These are a domestic and stock demand of 52 ML/annum, with an assumed even distribution of demand all year round, plus an irrigation demand.

The irrigation demand node uses the Irrigator demand model in Source. It assumes a maximum irrigated area of 1,000 ha, with a soil moisture capacity of 80%. Four crop types are used, namely fallow (no crops), vines, olives, and perennial pasture. The three active crop types have their own assumed depth of root zone (500 mm, 820 mm, and 400 mm respectively), with all having a depletion factor of 80% and an initial depletion of 20 mm. The target soil depletion is 25 mm for vines and olives, and 50 mm for pasture. Water is ordered when a soil water balance indicates that the soil moisture content is below the target depletion, after taking into consideration net evaporation and other soil moisture movements.

The daily volume that can be supplied is limited by the supply point to the irrigation demand node, which is set at a capacity of 78 ML/day, with supply only permissible when the flow in the Yass River above Gundaroo (gauge number 410090) is greater than 6 ML/day. The annual entitlement volume assigned to the irrigation demand node is 1,563 ML/annum.

The annual supply volumes over the historic climate model run period are shown in Table 13. This indicates that the maximum annual supply of 1,418 ML/annum could be increased by a further 145 ML/annum (10% of current use) until the annual licensed volume would be reached in the year of maximum water use.

The 78 ML/day maximum daily diversion threshold was reached on 0.9% of days over the 130-year period.

Table 13 Annual supply (July to June), July 1890 to June 2020, relative to licensed volume for irrigation demands

Metric	Value (ML/annum)
Annual licensed volume	1,563
Maximum annual supply	1,418
Average annual supply	652
Minimum annual supply	0

There are two irrigation licences, with a total licensed volume of 107 ML/annum, who can access water from the Yass River at Yass Dam, plus a further 6 ML/annum licence for unspecified purposes. According to the water sharing plan covering this area (NSW Parliamentary Counsel, 2020), there is no cease to divert condition on these licences because under Clause 57(2)(c) water is being taken from an in-river dam pool. These licences are also not subject to a cease to divert condition under Schedule 2 of the water sharing plan.

The total irrigation supply from Yass River upstream of Yass Dam, as modelled in Source, is not permitted during very low flow periods, consistent with the Water Sharing Plan rules operating in the catchment. This results in an intermittent pattern of irrigation supply, with sometimes long periods of no diversions followed by short periods with diversions up to the maximum diversion rate of 78 ML/day. This is shown in Figure 13 for an example year. This figure also shows how the modelled irrigation demand has often been set well above the maximum diversion rate.

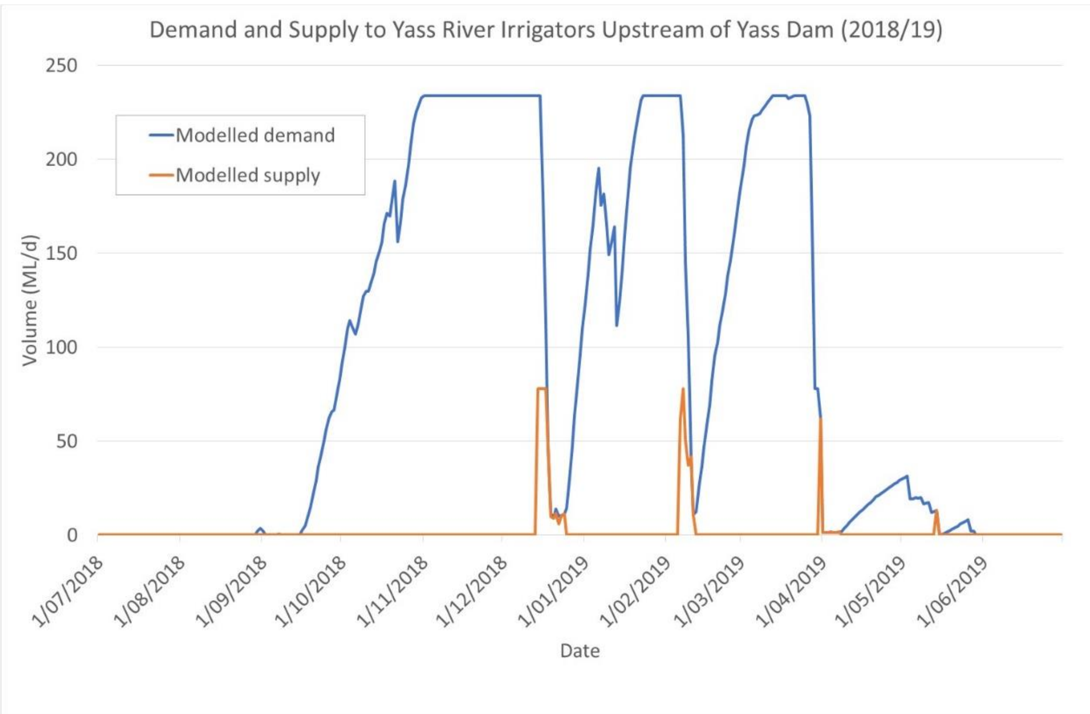


Figure 13 Modelled irrigation supply in an example year (2018/19)

2.9 River losses

During the project the Upper Murrumbidgee Source model was modified by the Department to incorporate a river loss directly upstream of Yass Dam. The purpose of this river loss was to improve the Upper Murrumbidgee Source model performance in Yass Dam, after taking into account the additional water level monitoring information provided by Yass Valley Council during this project, without compromising model goodness of fit downstream of Yass Dam. The river loss was modelled by the Department using a dummy irrigation demand node that draws water from the river when there is high cumulative net evaporation. Modelled daily losses were typically up to 50 ML/day, with a maximum daily loss (under historical climate from 1970-2023) of 276 ML/day. An illustration of the loss behaviour is shown in Figure 14 for an example period, highlighting the intermittent nature of the loss, and the range of upstream flow that is being lost. Under historical climate conditions, losses averaged 680 ML/annum, which is approximately 1% of the upstream river flow. The modelled loss resulted in an inflow to Yass Dam of a constant 3 ML/day during some extended low flow periods.

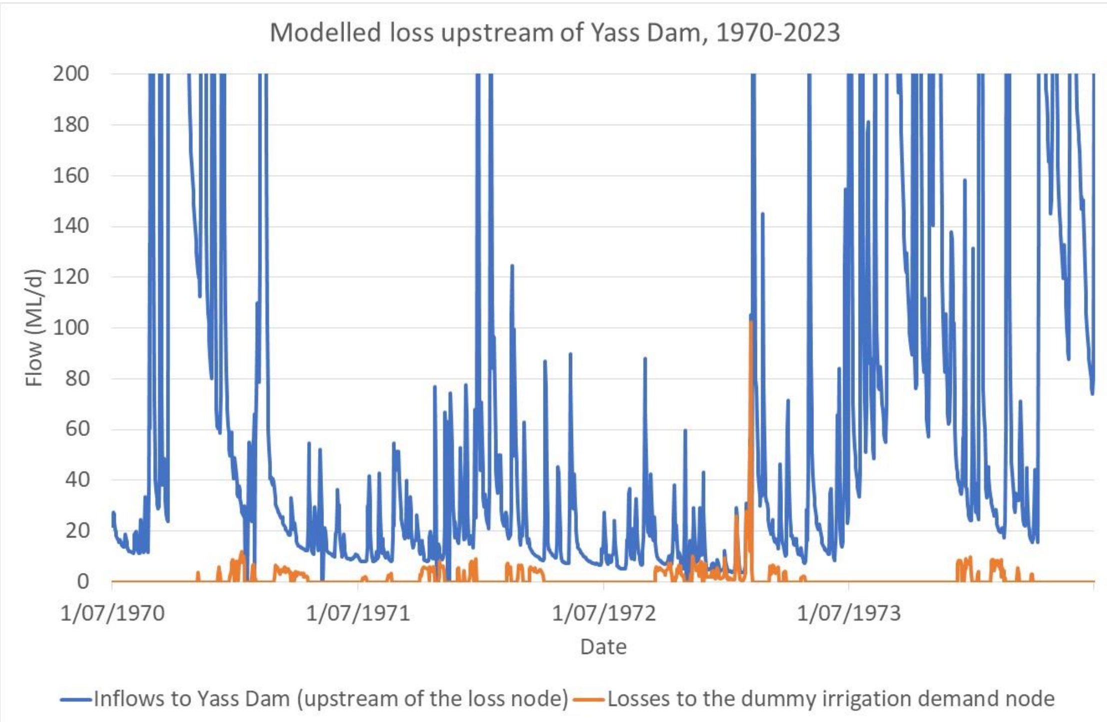


Figure 14 Modelled in-stream river losses for an example period (July 1970 – June 1974)

2.10 Yass Source model verification

The Yass Source model was verified in several steps to confirm that:

1: the Yass Source model is replicating the Upper Murrumbidgee Source model, when assuming the same climate and inflow inputs (see Section 2.10.1).

2: the Yass Sacramento models are replicating the inflow inputs into the Upper Murrumbidgee Source model (previously presented in Section 2.6.4).

3: the Yass Source model is reasonably replicating observed behaviour in Yass Dam and at the downstream flow gauge Yass River at Yass (421026) over a recent historical period (see Section 2.10.2).

4: the Yass Source model is also reasonably estimating reservoir drawdown over the Millennium Drought (see Section 2.10.3).

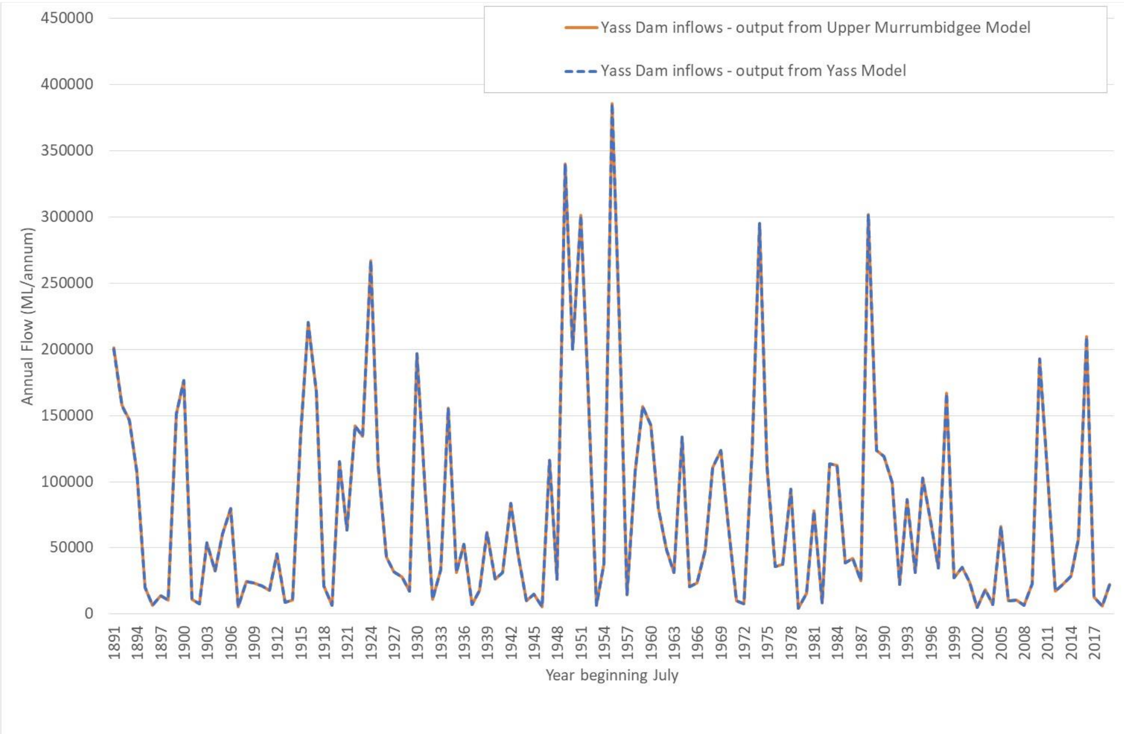
Further suggested guidance for local water utilities to consider the suitability of the Regional Water Strategy (RWS) models and datasets for local water security planning for a given town water supply system is provided in Appendix A.6. The information in this appendix was derived after the case study was completed, based on lessons learned during the case study. This includes consideration of the goodness of fit of those models to local low flow behaviour (as per items 3 & 4 above), as well as consideration of climate variability that has occurred since those models and datasets were developed in 2018. Characterising recent droughts (since 2018) and performing model verification tests using local water resource data, can be used to confirm the suitability of the RWS models and datasets for local town water security planning.

2.10.1 Yass Source model and Upper Murrumbidgee Source model

The first step was to verify that the Yass Source model was replicating the Upper Murrumbidgee Source model, and that no errors had been introduced in copying the Upper Murrumbidgee Source model when building the Yass Source model. This was done at the commencement of the project, prior to the updating of the model by including the river loss upstream of Yass Dam, and then repeated with the updated model. All results presented below are for the comparison undertaken after the inclusion of the new river loss into the Yass Source model.

The verification below assumes use of the Department's town demand model in both the Upper Murrumbidgee and Yass Source models. It also assumes that the passing flow rules at Yass Dam from the Upper Murrumbidgee Source model are used in both models (with differences in assumed passing flows in the two models explained previously in Section 2.3.4).

The inflows into Yass Dam were identical in both models, as shown in Figure 15. There were some very minor differences in dam drawdown when inflows were very low. This was due to the release of water from Yass Dam to meet private diverter demand between Yass Dam and Lake Burrinjuck within the Upper Murrumbidgee Source model (also discussed previously in Section 2.3.4). This river reach is not represented in the Yass Source model. It can be seen in Figure 16 and Figure 17 that outflows from Yass Dam and the volume in storage are near-identical, with the small differences in dam behaviour illustrated in Figure 18 for an example drawdown event. These differences emerge when inflows to Yass Dam are less than 1 ML/day, when minimum passing flow requirements at the dam are assumed to be zero (as per the Upper Murrumbidgee Source model, and as adopted in the Yass Source model for this comparison only), but releases from the dam of 1 ML/day are being made to meet downstream demands that are not represented in the Yass Source model.



Yass Dam inflows - output from Upper Murrumbidgee Model
Yass Dam inflows - output from Yass Model
Annual Flow (ML/annum)
450000
400000
350000
300000
250000
200000
150000
100000
50000
0
1891
1894
1897
1900
1903
1906
1909
1912
1915
1918
1921
1924
1927
1930
1933
1936
1939
1942
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1960
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1966
1969
1972
1975
1978
1981
1984
1987
1990
1993
1996
1999
2002
2005
2008
2011
2014
2017
Year beginning July

Figure 15 Annual inflow to Yass Dam from Upper Murrumbidgee and Yass Source models, July 1890 to June 2020

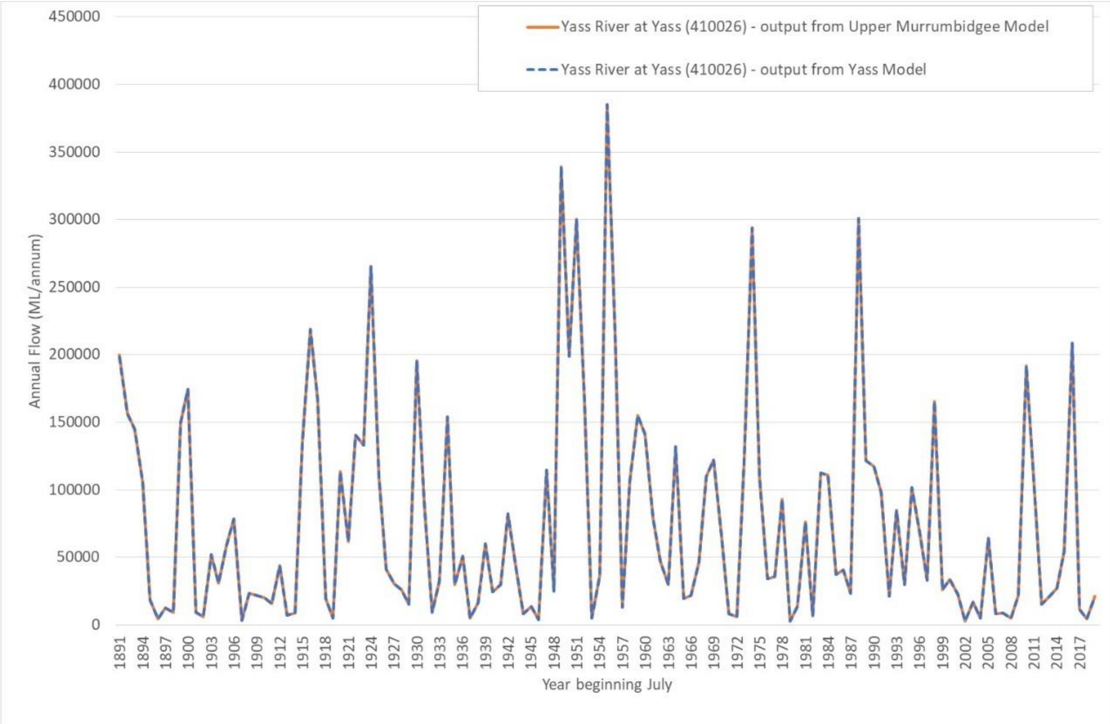


Figure 16 Annual flow in Yass River at Yass (streamflow gauge 410026) from Upper Murrumbidgee and Yass Source models, July 1890 to June 2020

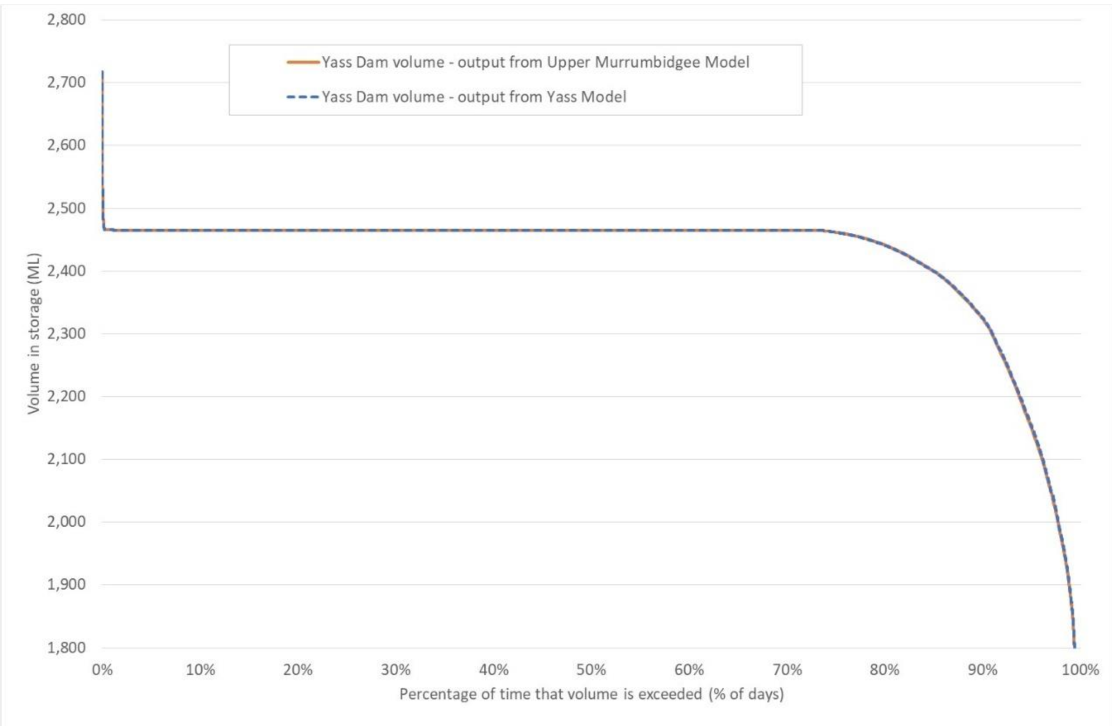


Figure 17 Volume exceedance in Yass Dam from Upper Murrumbidgee and Yass Source models, July 1890 to June 2020

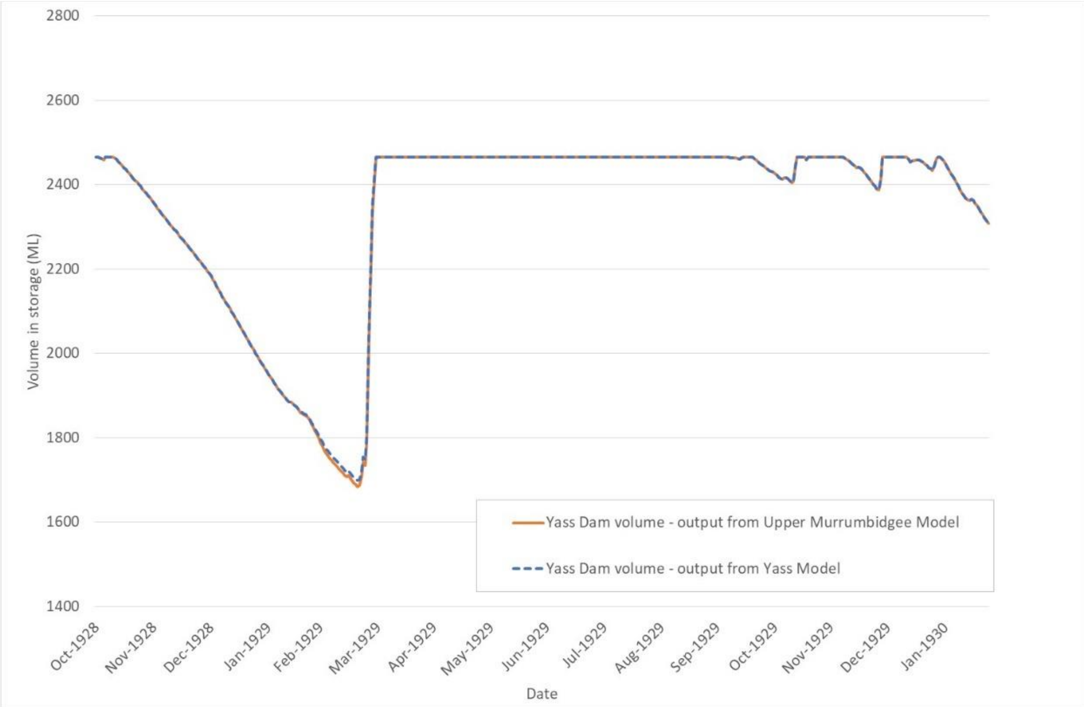


Figure 18 Volume in Yass Dam from Upper Murrumbidgee and Yass Source models, example drawdown event

The supply to the irrigation demand node in the Yass Source model was also checked and found to be identical to that in the Upper Murrumbidgee Source model, as shown in Figure 19.

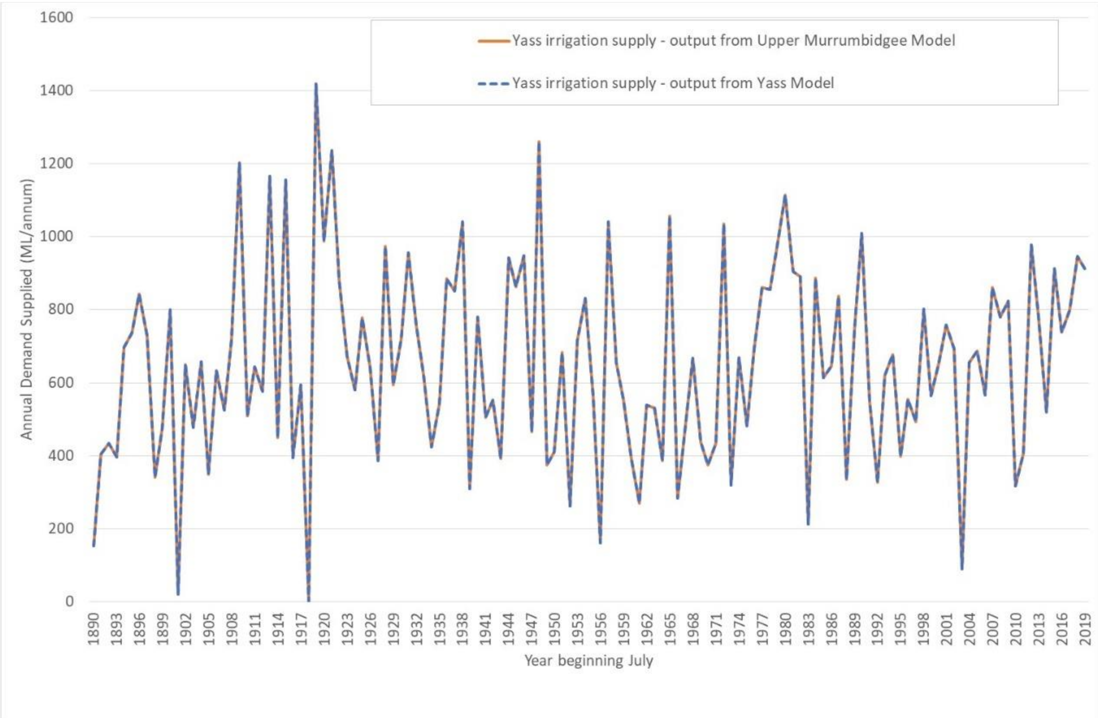


Figure 19 Annual Irrigation Supply upstream of Yass Dam from Upper Murrumbidgee and Yass Source models, July 1890 to June 2020

The conclusion from this comparison is that the Yass Source model is reproducing the behaviour from the Department's Upper Murrumbidgee Source model, when adopting the same town demand model and the same passing flow rules at Yass Dam, and that the minor differences between the two models when inflows are less than 1 ML/day can be explained by the difference in model extent, as discussed previously in Section 2.3.4.

2.10.2 Yass Source model performance over recent droughts

Once the Yass Source model had been verified against the Upper Murrumbidgee Source model, it was then verified against observed behaviour in the 2019/20 drought. The version of the Yass Source model used for this comparison includes the passing flow rules from Section 2.3.4, as well as the HARC town demand model from Section 2.4, Yass Valley Council restriction triggers from Section 2.5, and demand reductions at each stage of restriction as presented in Section 2.5.

The Yass Source model was compared against recent historical behaviour by running the model over the period July 2013 (i.e. after the Yass dam wall upgrade) to June 2023. Consistent with the observed volume in Yass Dam, there was only one significant modelled reservoir drawdown event over this period from the start of November 2019 to 7 February 2020. Both the historical and modelled volume in Yass Dam were at or near the full supply level at all other times. Modelled demands were set based on a population of 6,124, which corresponded to the estimated population as at 30 June 2019. This was based on Census data, consistent with the serviced population in Public Works Advisory (2021) *Integrated Water Cycle Management Strategy Draft Issues Paper*. A static level of demand was considered suitable for this verification given that the period of interest with historical reservoir drawdown was limited to a period of only a few months.

The Yass Source model was found to over-estimate the volume in storage, and under-estimate the drawdown during the 2019/20 historical drawdown event, as shown in Figure 20. Field measurements by Council staff were available from 1 November 2019, at which point observed and modelled behaviour were similar. From that point forward, the rate of drawdown was faster in the observed data, as shown by the steeper slope of the drawdown relative to the modelled data. The minimum volume in storage reached was 1,893 ML in the modelled data, compared to 1,591 ML in the observed data, with the modelled data under-estimating the historical drawdown during the event by ~300 ML.

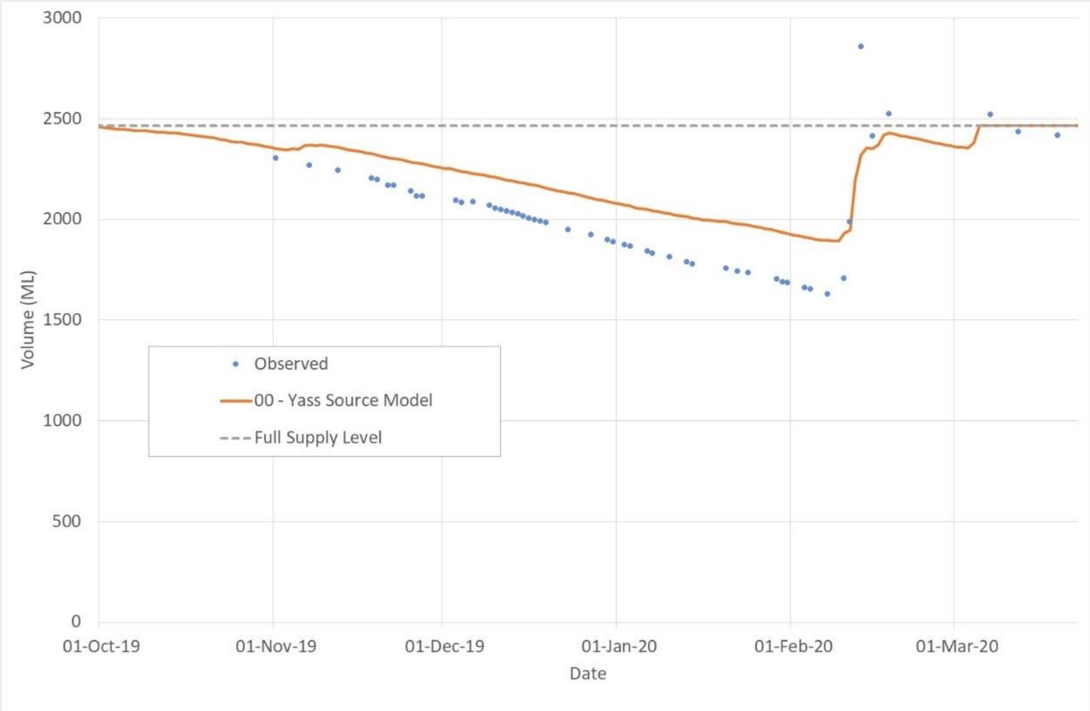


Figure 20 Observed and modelled Yass Dam storage behaviour, Oct 2019 to Mar 2020

When checking the various inflow and outflow components over this period, the observed and modelled supply to the Yass supply system were found to match well (390 ML observed versus 352 ML modelled from 1/11/2019 to 7/2/2020), and most other water balance components were either too small in magnitude or insufficient uncertainty to generate the difference in modelled and observed reservoir drawdown. Checking the upstream modelled flows, it was found that the rainfall-runoff model outputs for the two gauged headwater catchments (Yass River at Gundaroo and Williams Creek at White Hall) produced zero or near-zero flows over the period of Yass Dam drawdown, consistent with the gauged data at these two locations. This indicates that these two inflow sources are accurate during this event, and are not the source of any differences in dam behaviour downstream.

The low flow behaviour of the modelled inflows for the gauged catchments upstream of the dam, the inflows to the dam, and the river losses upstream of the dam, are presented in Figure 21 during the 2019/20 dam drawdown event. This figure shows that the river loss function introduced to the (updated) Upper Murrumbidgee Source model, and subsequently incorporated into the Yass Source model, allows a residual 3 ML/day inflow to Yass Dam. The gauged data downstream of the dam, and Council's passing flow operating rules, would suggest that there were no inflows to the dam over much of this period. This difference in very low inflows is likely to be the reason why the drawdown in Yass Dam is not as large in the model, compared to the historical observations during the 2019/20 drawdown event (i.e. an excess inflow of 3 ML/d over the ~90 day drawdown event generates an excess inflow volume of ~270 ML, which is similar in magnitude to the ~300 ML difference between the observed and modelled minimum storage volume during that event). These differences are limited to very low flow periods, with the Upper Murrumbidgee Source model calibration statistics (see Appendix A.4) indicating that modelled low flow metrics at the gauge downstream of Yass Dam (421026) are within ±2% of the observed values, suggesting that the model is overall unbiased at that location, including for low flows outside of these very low flow periods.

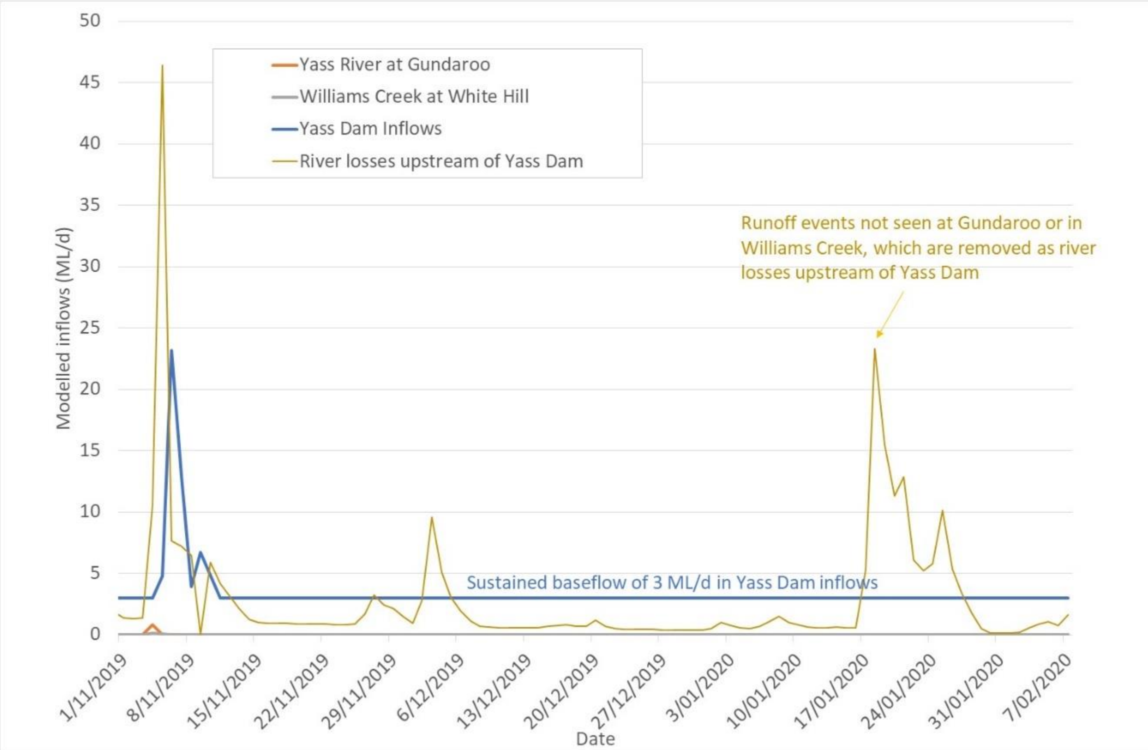


Figure 21 Modelled runoff from gauged catchments upstream of Yass Dam, net inflows to the dam and upstream river losses, during historical Yass Dam drawdown event

2.10.3 Yass Source model verification during Millennium Drought

The comments above on the Yass Source model behaviour in Yass Dam were largely based on a single drawdown event in 2019/20. After discussion with the project steering committee, further work was undertaken to estimate model performance over the Millennium Drought, prior to the dam upgrade works in 2013. It was intended that this would help to identify whether the under-estimation of drawdown in 2019/20 was an isolated occurrence as part of random variability in the model behaviour, or whether it was representative of a more systemic bias in under-estimating dam drawdown.

2.10.3.1 Changes to Yass Source model to represent Millennium Drought demands and infrastructure

The Yass Source model was adjusted to represent the infrastructure and population that existed over the Millennium Drought period. This included resetting the pre-upgrade storage capacity to 872 ML with the storage bathymetry at that time. The HARC demand model of the Yass supply system was used with input population data for Yass township only (see Table 14) linearly interpolated between census dates over the Millennium Drought. This demand model assumes that per capita water use in the pre-dam period is the same as it was over the demand model calibration period (July 2017 to June 2022), which may not necessarily be the case. This could result in an under-estimate of water use in the Millennium Drought, if that water use is currently more efficient than it has been in the past. It is also noted that the spatial boundary for the Yass township, as used in the census, was slightly different after the 2006 census. Census data for Yass population in 1996 was not readily available, so the population was linearly extrapolated prior to 2001 using the rate of change of population from 2001 to 2006.

No supply from groundwater bores during this period is assumed in the Source model. In practice, pumping from the Old Quarry and Willow Creek bores was metered as occurring from late 2008, but volumes pumped were very small relative to storage capacity, at around 1 ML per month. These bores were not operating prior to 2008. The Willow Creek bores were installed in August 2008 and the Old Quarry bore was installed in February 2009 (K. Kugaprasatham, YVC pers. comm. 4/12/2024).

The restriction policy in the model and the assumed demand reduction at each stage of restriction was assumed to be the same as it is currently. In practice, based on an interpolated log of historical restriction periods, levels of restriction were implemented at approximately the same percentage of storage capacity as they are currently, but with variation around those triggers from year to year.

Table 14 Population from ABS Census for Yass (ABS, 2023)

Year	Yass township population
2001	4,884
2006	5,333
2011	5,591
2016	5,466
2021	5,837

2.10.3.2 Yass Source model performance during Millennium Drought

The modelling over the Millennium Drought confirmed that the Yass Source model, with the same inflows and losses as the Upper Murrumbidgee Source model, was a reasonable match to the observed reservoir drawdown. This is illustrated in Figure 22 for a sample of years over the Millennium Drought. In the largest observed drawdown event in 2002/03, the modelled storage reached 540 ML, relative to an observed minimum storage volume reached of 510 ML, albeit with a two month difference in the timing of the minimum modelled and minimum observed values. In some years, drawdown was delayed by 1-2 months in the model, relative to observations, with some instances of partial or full recovery of the dam as modelled, but not as observed. The model however reasonably estimated the absence of drawdown in wetter periods over the Millennium Drought. In the largest modelled drawdown event in 2006/07, the observed data indicated storage recovery between mid-December and early January that was not replicated in the modelled behaviour, however there was an absence of recorded data from the second week of January through to the start of April, so the full extent of historical drawdown may not have been observed. The outcomes of this analysis highlight that while there is some overfitting and underfitting to individual years of historical reservoir drawdown, there is not clear evidence of systemic bias in the model fit to Yass Dam. An under-estimation of storage drawdown is more likely than an over-estimation of storage drawdown during the Millennium Drought, consistent with the 2019/20 event.

Figure 22 Modelled drawdown in Yass Dam with inflows and losses from the Upper Murrumbidgee Source model

Attempts to make use of additional Millennium Drought datasets to explain differences between modelled and observed reservoir drawdown over this period are presented in Appendix A.8, but did not generate any definitive additional insights.

3. Stochastic Data Preparation

3.1 Introduction

The approach recommended in the step-by-step guidance involved dividing the climate replicates into 130 year segments, and then performing some checks on those replicates to ensure that severe drought sequences were not being unduly divided across replicates. This section of the report presents those checks.

The application of the stochastic climate inputs was slightly different to that in the Department's high level, regional supply shortfall risk analysis (the Department, 2024). For this case study, 76 replicates of 130 years in length were used, compared to a single 10,000 year replicate used in the Department's shortfall risk analysis. This difference would have no bearing on model outcomes given the small storage capacity of Yass Dam relative to inflows, and given the way in which the 76 replicates were divided to avoid splitting severe droughts, as described in Section 3.3.

3.2 Should stochastic data be used to assess yield for Yass?

The Department's optional how-to guidance on understanding water security (DPE Water, 2022a) provides a decision flow chart for identifying when stochastic data may be of higher value for understanding water supply risks. Following this flow chart in Figure 23, it is understood that:

1. Yass is a regional centre, with the Yass supply system servicing a population of around 7,000 people, and acting as a commercial centre for surrounding small towns. Running out of water in this supply system would affect thousands of people, and the consequences of this could be regarded as high.

2. Whilst the Yass supply system has access to groundwater bores, and the Yass Valley Council has demand reduction measures available to implement, there are no large-scale, low-cost contingency supply measures readily available to implement at short notice.

3. GHD (2022) previously identified the water supply risks for the Yass supply system in light of projected population growth and potentially much drier conditions under projected climate change.

4. With the exception of the groundwater bores, the Yass supply system relies on inflows to Yass Dam, which are an entirely climate dependent source of water.

This suggests that the stochastic data is likely to be of higher benefit for the Yass supply system, relative to other supply systems with different supply system characteristics.

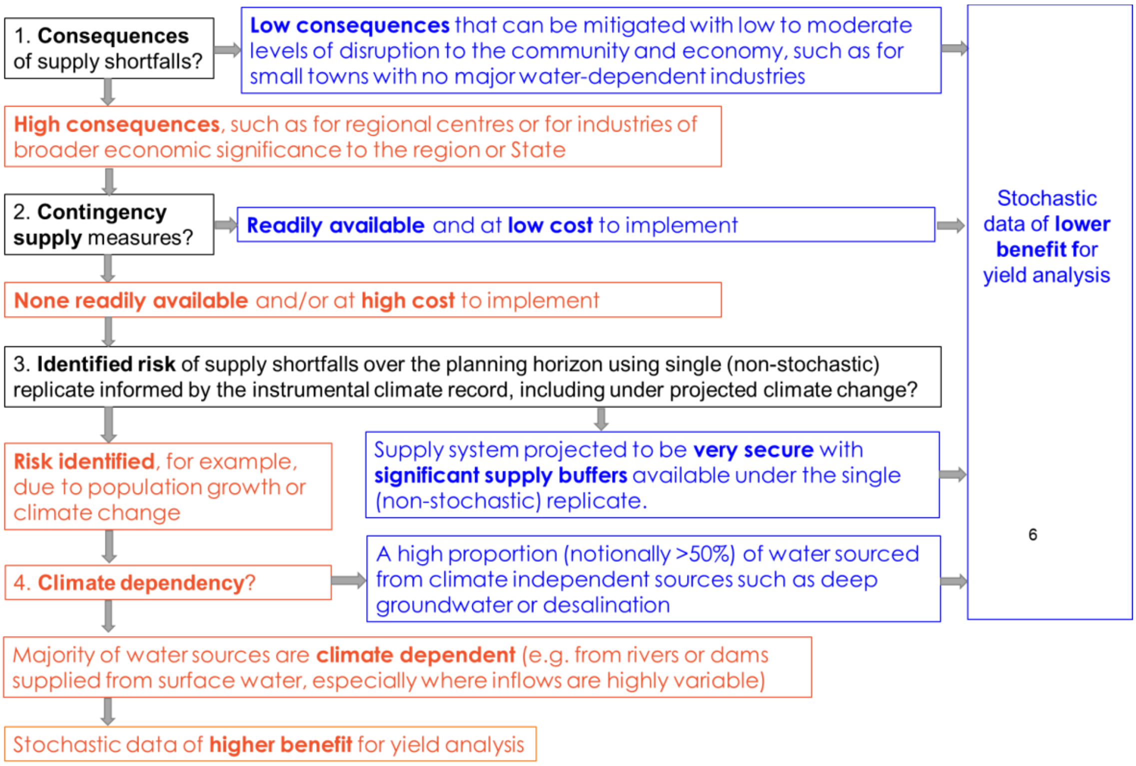


Figure 23 Guide to assessing when stochastic data provides higher benefit for yield analysis by local water utilities (DPE Water, 2022a)

3.3 Division of the stochastic data into replicates

Following the first three steps of the step-by-step guidance in DPE Water (2022a):

Step 1: The stochastic climate data was downloaded from the Department's website (located online at https://datasets.seed.nsw.gov.au/dataset/water-modelling-stochastic-climate-data).

Step 2: The 10,000 year sequence of stochastic data was divided into 130 year replicates, starting from year zero.

Step 3: The daily cumulative deviation from average rainfall was plotted over the whole 10,000 year sequence, as shown in Figure 24. Rainfall station 070042 (Gundaroo) was used for this purpose. Figure 24 identified firstly that there was significant serial correlation across replicates, with a run of drier than average conditions spanning 2-3 replicates (i.e. spanning 200-300 years) in some periods of the dataset. The daily cumulative deviation from average rainfall (when calculated across all replicates) was then plotted for each individual replicate, as shown in Figure 25. This identified that the driest climate replicate (and the next two driest replicates) where being divided prior to the end of the dry sequence within that replicate, as shown in Figure 26 for the driest replicate. In order to ensure that the whole of the dry sequence within this driest replicate was fully contained within the replicate, the division of the data was shifted by ten years. That is, the division of replicates commenced from year 10 rather than year zero. The period covered by this driest replicate after shifting the division of the data is shown in Figure 27, which now shows a period of above average rainfall at the end of the replicate.

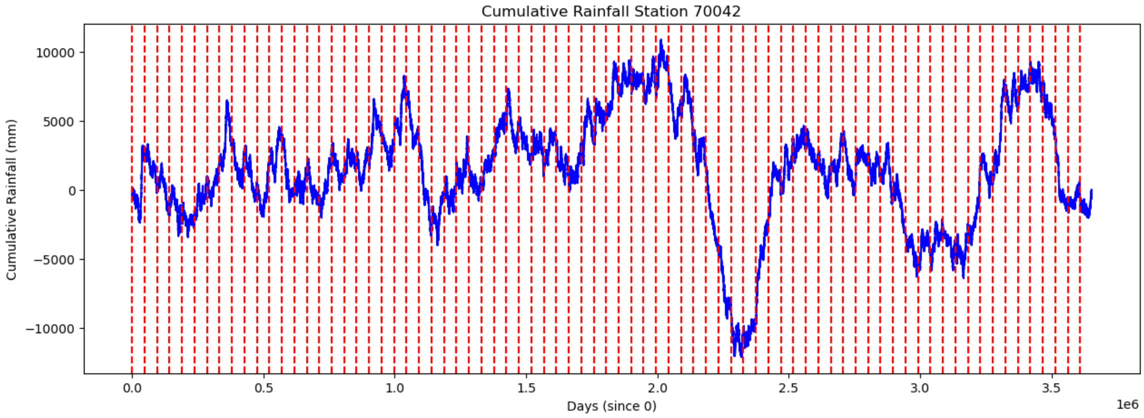


Figure 24 Cumulative deviation from mean annual rainfall for stochastic rainfall at representative rainfall station 070042 (each of the intervals between the vertical red dashed lines is a single 130 year period)

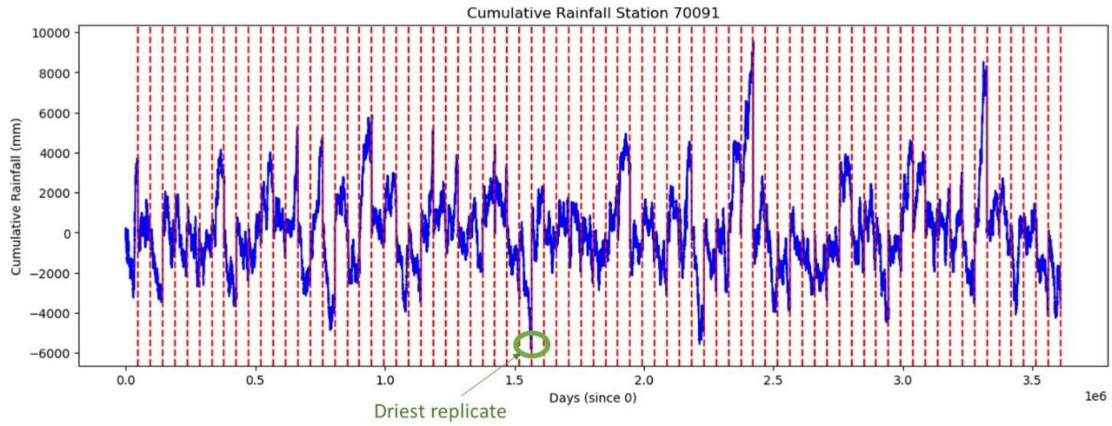


Figure 25 Cumulative deviation from mean annual rainfall for stochastic rainfall at representative rainfall station 070042 (each of the intervals between the vertical red dashed lines is a single 130 year period). Each replicate restarts at zero deviation.

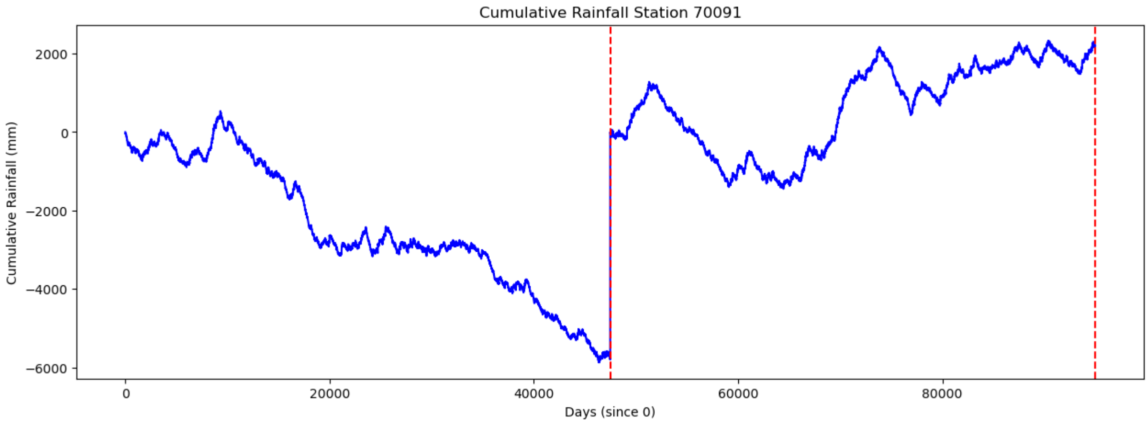


Figure 26 Cumulative deviation from mean annual rainfall (across all replicates) for the driest stochastic replicate when dividing the replicates from year zero

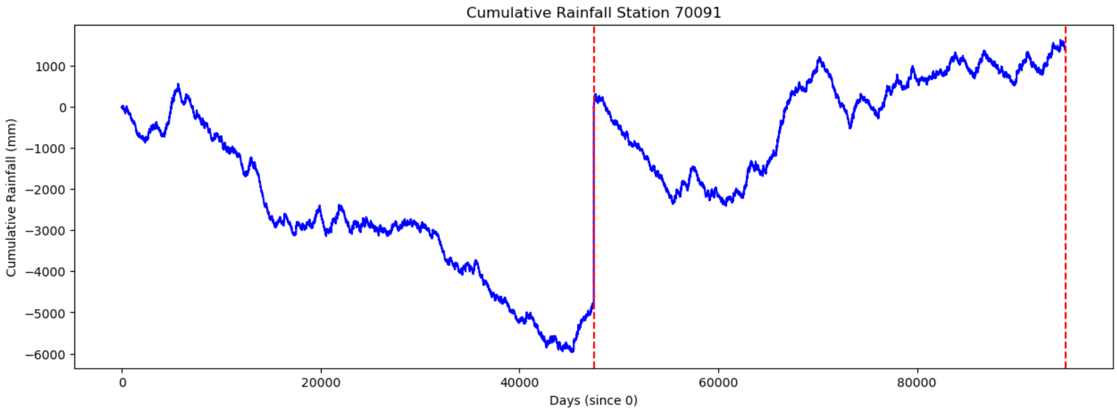


Figure 27 Cumulative deviation from mean annual rainfall (across all replicates) for the driest stochastic replicate when dividing the replicates from year ten

4. Climate change projections and higher irrigation demands

4.1 Climate change projections

Climate change projections for climate stations in the Upper Murrumbidgee River catchment were provided by the Department. Different adjustment factors were provided for each month of the year to capture seasonal differences in projected climate. The projections were the average of outputs from three regional climate models driven by the CSIRO Mk3 global climate model, consistent with the Department's RWS climate change assessments. These are from the NARCliM 1.0 projections based on the SRES-A2 emissions scenario. This is a high emissions scenario, equivalent to the more recent SSP5-8.5 scenario. The projections used in the Yass case study are for the years 2060-2079 (centred on 2070) relative to the years 1990-2009 (centred on the year 2000).

The scaling factors for rainfall and potential evapotranspiration are shown in Table 15 and Table 16. These scaling factors highlight that across the Yass catchment, by the year 2070 relative to the year 2000, it is projected under this climate change scenario that:

- There would be less rainfall in most months of the year, but with higher rainfall from January to March and (for all but one rainfall station) in September; and
- Evaporation and evapotranspiration would be 4-6% higher in any given month, with no clear seasonal pattern to that increase.

For example, for the site at Yass (Linton Hostel), rainfall is projected to be 37% lower on average in June, but 17% higher on average in February.

In applying this climate change scenario it is recognised that other projections are also possible and plausible, including other scenarios available from the NARCliM project that are both wetter and drier than the projection adopted. As such, the climate change projection adopted should be regarded one potential alternative climate future, but that other climate futures are also possible. A broader range of climate change projections, such as all of the projections available from NARCliM 2.0 (or at least the range of those projections), would enhance the understanding of the likely timing of required actions at different levels of climate change risk.

The climate change projections have been incorporated into the inflows, net evaporation from storages, and modelled demand patterns in the Yass Source model when undertaking the yield analysis in Section 5. The potential effect of climate change on demand is also incorporated into the demand projections sourced from Public Works Advisory (2021b), which includes an 11% increase in average year demand for Yass and a 9% increase for Murrumbateman per degree of global warming.

Table 15 Rainfall scaling factors for the assumed climate change scenario in the year 2070 relative to the year 2000

Site Number	**70030**	**70042**	**70045**	**70056**	**70091**	**70115**	**70232**	**70233**	**70255**
Site Name	**Bungendore (Douglas)**	**Gundaroo (Bairnsdale)**	**Hall (Lochleigh)**	**Kowen Forest**	**Yass (Linton Hostel)**	**Collector (Lerida)**	**Sutton (Uba)**	**Sutton The Anchorage**	**Mitchell (Exhibition Park)**
Month									
Jan	97%	105%	99%	103%	106%	103%	102%	102%	101%
Feb	106%	114%	117%	110%	117%	111%	113%	113%	117%
Mar	101%	103%	108%	103%	106%	105%	104%	104%	103%
Apr	87%	89%	86%	94%	87%	84%	91%	90%	89%
May	71%	70%	65%	67%	71%	70%	67%	68%	64%
Jun	67%	69%	65%	64%	63%	66%	65%	65%	62%
Jul	85%	87%	88%	89%	84%	83%	88%	88%	88%
Aug	93%	90%	88%	95%	87%	95%	92%	92%	90%
Sep	107%	103%	106%	111%	98%	104%	109%	108%	109%
Oct	80%	72%	77%	72%	79%	83%	74%	74%	75%
Nov	89%	88%	90%	92%	82%	89%	92%	91%	91%
Dec	87%	82%	85%	86%	84%	88%	87%	87%	86%

Table 16 Potential evaporation and evapotranspiration (ET) scaling factors for the assumed climate change scenario in year 2070 relative to the year 2000. Applicable to FAO56, Morton's shallow lake evaporation, and Morton's wet environment areal potential ET over land

Site Number	70042	70045	70091	70233
Site Name	Gundaroo (Bairnsdale)	Hall (Lochleigh)	Yass (Linton Hostel)	Sutton The Anchorage
Month				
Jan	105%	105%	105%	105%
Feb	104%	104%	103%	104%
Mar	103%	103%	103%	103%
Apr	105%	105%	105%	105%
May	104%	104%	104%	104%
Jun	104%	104%	103%	104%
Jul	104%	104%	104%	104%
Aug	104%	104%	104%	104%
Sep	104%	104%	104%	104%
Oct	104%	104%	104%	104%
Nov	106%	105%	105%	105%
Dec	104%	104%	104%	104%

4.2 Higher irrigation demand

As noted in Section 2.8, the maximum modelled annual irrigation supply in the Upper Murrumbidgee Source model (and therefore in the Yass Source model) is 1,418 ML/annum. This compares to a licence volume of 1,563 ML/annum. For the yield analysis with the higher irrigation demand scenario, irrigation demands were increased by 10% to bring the year of maximum use from the river up to the licensed volume. The adjusted crop areas used in Source to achieve this are listed in Table 17.

Table 17 Change in modelled crop area (ha) at full uptake of irrigation licences

	Vines	Olives	Pasture	Fallow
Current	100	100	100	700
Full uptake	110	110	110	770

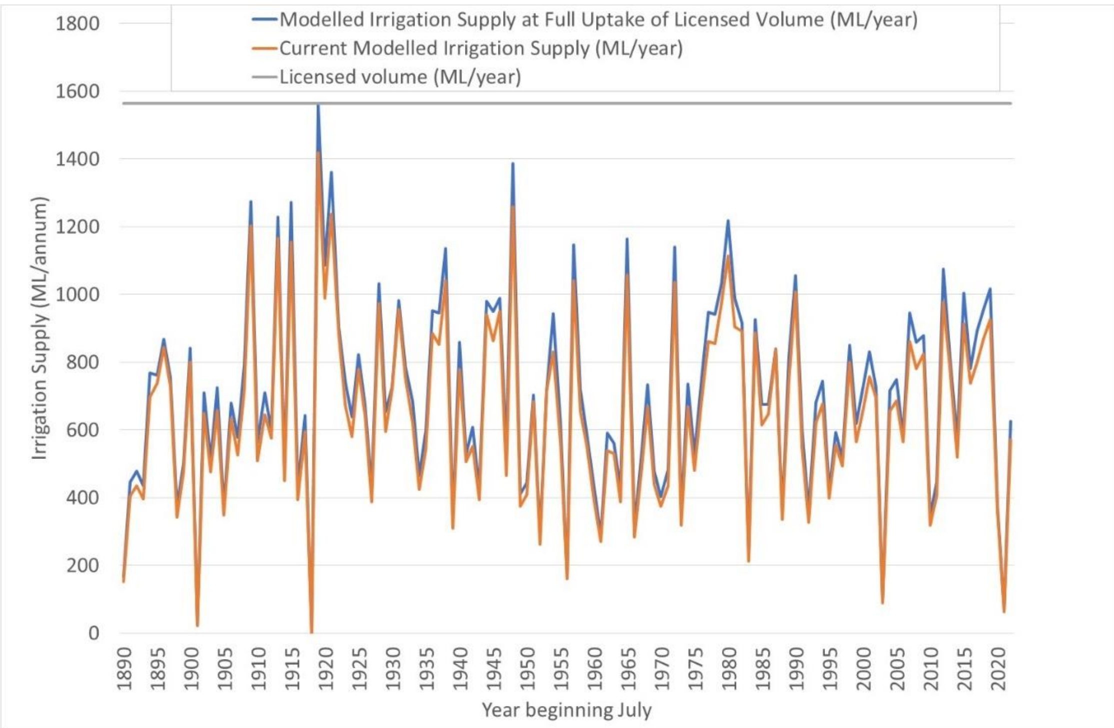


Figure 28 Annual irrigation supply at current demand and full uptake of licensed volume

5. Yield estimates

5.1 Introduction

The following yield estimates were prepared for this case study:

- Yield under the instrumental climate record;
- Yield under climate variability beyond the instrumental climate record, using the RWS stochastic climate data;
- Yield under a projected climate change scenario;
- Yield under a higher irrigation demand scenario;
- Sensitivity of results when using the x/y/z performance-based approach relative to the alternative performance based approach;
- Sensitivity of results to alternative restriction triggers; and
- Sensitivity of results to different level of service objectives.

These are listed in Table 18, along with the relevant section in this chapter of the report which presents each type of yield estimate. A summary of all results in presented at the end of this chapter in Section 5.11. As noted in Table 18, the yield analysis scenarios in this report are all with the current Yass supply system configuration and do not include any potential future water security improvement options.

Table 18 List of yield analysis scenarios

	Using instrumental climate record	Using stochastic data	Applying x/y/z approach	Applying alternative approach	Section in this report
Historic climate	✓	✓	✓	✓	5.3
Climate change	✓	✓	x	✓	5.5
Higher irrigation demand	✓	✓	✓	✓	5.6
With Yass Valley Council's current restriction triggers	✓	✓	x	✓	5.7
Alternative restriction triggers	✓	✓	x	✓	5.7
Alternative level of service objectives	✓	✓	x	✓	5.8
Water security improvement options	x	x	x	x	N/a

The "alternative" yield analysis approach is informed by methods adopted in other jurisdictions of Australia. It is labelled "alternative" not because it is new or innovative, but rather simply because it makes different assumptions to the Department's x/y/z approach to reflect local conditions for inter-annual variability in demand, water savings under restrictions, restriction triggers, and storage buffers set aside for unforeseen events.

For all scenarios, yield was defined as the highest modelled demand that meets all of the nominated performance criteria. In this case study, demands were adjusted in increments of 1,000 people, which was equivalent to increments of average annual demand of approximately 160 ML/annum. For yield assessments where restriction triggers were varied for each climate replicate, this was done in increments of 1% of storage capacity over the range from 40-100% of storage capacity. Other increments of demand or population could have been adopted, and slightly larger increments (say up to 5-10% of storage capacity) could have been adopted when varying the restriction triggers. In practice these increments would be informed by the sensitivity of yield analysis results to the adopted increments. For the purposes of presenting results, all yields have been rounded to the nearest 100 ML/annum, noting that the limit of accuracy of any yield estimate from this case study is at least ±80 ML/annum based on the 160 ML/annum increment of demand adopted when searching for the maximum yield for any given replicate. As indicated previously, unless otherwise stated, all of the following yield assessments have been undertaken using either a 130 year instrumental historic climate period, or 76 replicates of 130 years of length for the stochastic datasets.

The results in this case are all presented as box plots, which were considered the most readily interpretable and informative. The box plots indicate both the median value and the spread of yield results across the stochastic replicates.

5.2 Level of service objectives

Supply system yield for town water security is the volume of water that can be delivered from a supply system without breaching the level of service objectives for that supply system.

The x/y/z approach for assessing yield is outlined in the Department's guidance on strategic planning outcome – understanding water security (DPE Water, 2022a). It is referred to as an "x/y/z" approach indicating three different level of service objectives. The 5/10/10 design rule, which has commonly been applied in yield analysis in NSW to date, is an example of the x/y/z approach. The level of service objectives of this design rule are that:

- the total time spent with water use restrictions (x) should be no more than 5% of the time;
- the percentage of years with restrictions (y) should not be more than 10% of years; and
- when restrictions are applied the water supply system should be able to provide 90% of the unrestricted water demand (i.e. an assumed 10% reduction (z) in demand) through a repeat of the worst recorded drought, without reaching the minimum operating level. It is recommended that the seasonal pattern from a dry year or dry years be used for this worst drought analysis.

Under an x/y/z approach, these design criteria can be adjusted to other values, with 5/10/10 being historically the most common design criteria recommended by the Department and adopted by local water utilities across New South Wales. Yield under the x/y/z approach is the maximum average annual demand that meets all of these three criteria.

Level of service objectives are assumed to be derived through customer consultation, using a transparent process to determine what level of service is acceptable to customers, and their willingness to pay for that level of service, consistent with the Department's guidance on understanding water security (DPE Water, 2022a). This discussion occurs not only in the context of climate variability, climate change, and the supply system configuration, but also takes into account the nature of readily available contingency supply options, enduring supply availability, lead times to implement demand reduction and supply enhancement options, capital and operating costs, operating rules (drought response triggers, triggers for switching supply sources, contingency supply buffers in storage, etc.), and any other relevant performance metrics. Each of these considerations are specific to the local supply system, and collectively, they inform the level of service that customers deem satisfactory. This level is service is typically expressed as:

- A minimum level of service to maintain critical human water needs; and
- An agreed level of service for the avoidance of water supply restrictions, additional costs, and any other agreed thresholds for poor performance.

The Department's guidance on understanding water security (DPE Water, 2022a) states that it is critical to understand and determine the level of service and/or risk approach for a utility's water supply systems in consultation with customers and the community. This is formulated within the context of an x/y/z yield analysis approach like the 5/10/10 design rule, but the Department's guidance also allows for the adoption of any other credible and robust approach, provided there is clear justification for its application. This could, for example, involve using other performance measures unrelated to water restrictions. As such, both the x/y/z approach and the alternative approach align with the Department's current guidance within the regulatory and assurance framework for local water utilities (DPE Water, 2022c), provided that the adopted approach reflects the outcomes of consultation with customers and the community on their preferred level of service objectives.

It was beyond the scope of the Yass case study to engage with Council or customers about level of service objectives for the supply system, and the rationale for existing operating rules such as Council's drought response triggers and actions. HARC has therefore adopted the following level of service objectives and other operating rule assumptions for the alternative yield assessment approach. For ease of comparison with the 5/10/10 design rule, we have adopted a level of service objective for duration (x) and frequency (y) as 5/10, unless otherwise stated. These were:

- the total time spent with water use restrictions should be no more than 5% of the time (consistent with the 5/10/10 design rule);
- restrictions should not be applied in more than 10% of years (consistent with the 5/10/10 design rule). This corresponds to a 10% likelihood of restrictions in any given year; and
- the minimum operating level plus any contingency storage buffer are not reached during the most severe modelled drought.

The operating rule assumptions used during the alternative yield assessment were:

- a contingency storage buffer of zero (because without a detailed understanding of contingency supply risks for the Yass supply system, and customer risk appetite, we could not justify a non-zero buffer); and
- Council's drought response triggers and an estimated demand reduction at each level of restriction based on interpretation of the actions undertaken at each level of restriction (as previously presented in Section 2.5).

There were some further differences in method between the two approaches. These included:

- the use of a climate dependent demand model in the alternative approach, which includes inter-annual climate variability. The x/y/z approach uses a fixed seasonal pattern of demand in every year; and
- the use of the whole storage capacity in the alternative approach to assess drawdown to minimum operating levels. This is done as part of a continuous simulation that includes periods when the storage recovers to above restriction trigger levels, up to the full supply level. In contrast, the x/y/z approach "assumes that the storage is already drawn down [to the Level 1 restriction trigger] before the start of drought, providing an additional storage buffer (that is, factor of safety)" (DPE Water, 2022a). Whilst any buffer can be adopted using the alternative approach, in the Yass case study no storage buffer was adopted, consistent with Yass Valley Council's current operation.

Other specific level of service objectives introduced as part of sensitivity testing are outlined in Section 5.8.

5.3 Uncertainty in yield due to climate variability beyond the instrumental climate record

The distribution of yields when applying the stochastic replicates for the x/y/z approach is illustrated in Figure 29. The stochastic replicates generated a range of yields that included results that were both much higher (up to 33% higher) and much lower (up to 33% lower) than the yield estimated using the instrumental climate record alone. Median stochastic values were similar to (but in this case 7% higher than) those generated using the instrumental climate record. Note that all of these yield estimates are not constrained by Yass Valley Council's water access licence entitlement volume, which is 1,700 ML/annum.

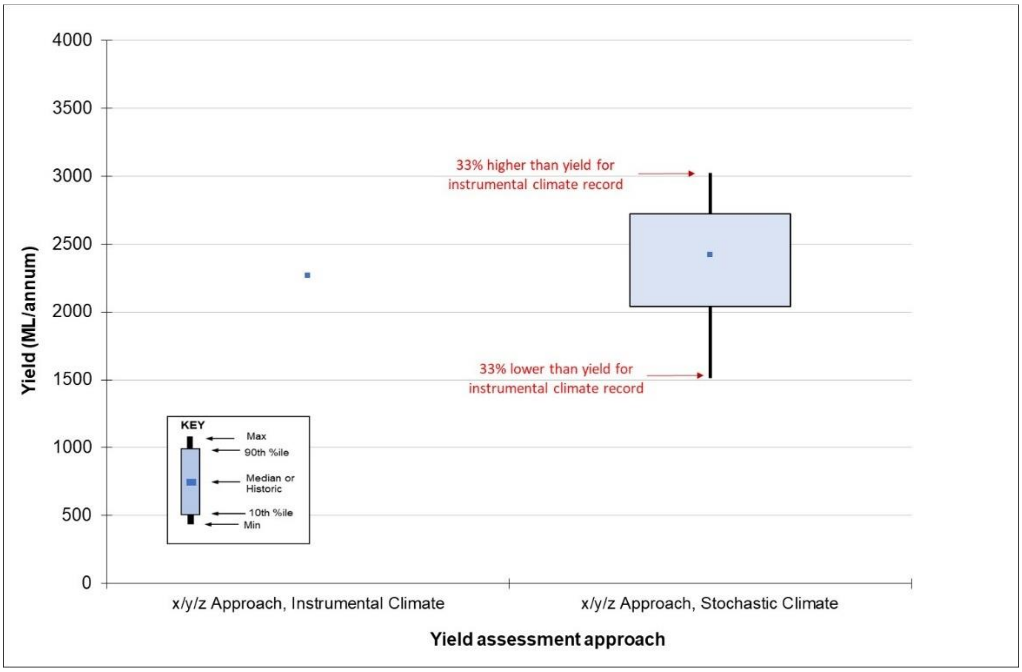


Figure 29 Distribution of yields (max, min, 90^{th}, 10^{th} percentile and median) from the 76 stochastic replicates using the x/y/z approach relative to the instrumental (historic) yield estimate

5.4 Differences in estimated yield due to yield analysis approach

The yield estimates using the alternative approach were consistently higher than those generated using the x/y/z approach, as shown in Figure 30. The spread of results was also greater when using the alternative approach relative to the x/y/z approach.

For the alternative approach, when optimising trigger levels, the Level 2 to 5 restriction triggers were reduced by the same volume as the Level 1 restriction trigger. That is when the Level 1 restriction trigger was reduced by say 10% of storage capacity, then the triggers for Levels 2 to 5 were also reduced by 10% of storage capacity. This preserves the duration of supply under Levels 1 to 4 restrictions, for a given level of demand, and reduces the duration of supply under Level 5. This method was adopted over the different method of shrinking all of the restriction triggers proportionally, which would not have preserved the duration of supply under any level of restriction, for a given level of demand. The consequence of the adopted method was that it placed a lower bound on the restriction triggers that could be modelled with five levels of restriction. This is because the storage available below the Level 5 trigger started to compress to near zero when the Level 1 restriction trigger was below 40% of storage capacity. The spread of higher yielding results for the alternative approach would arguably have been higher for the 90^{th} percentile and maximum values (i.e. for the wetter replicates) if the Level 1 restriction trigger were lowered below 40% of storage capacity.

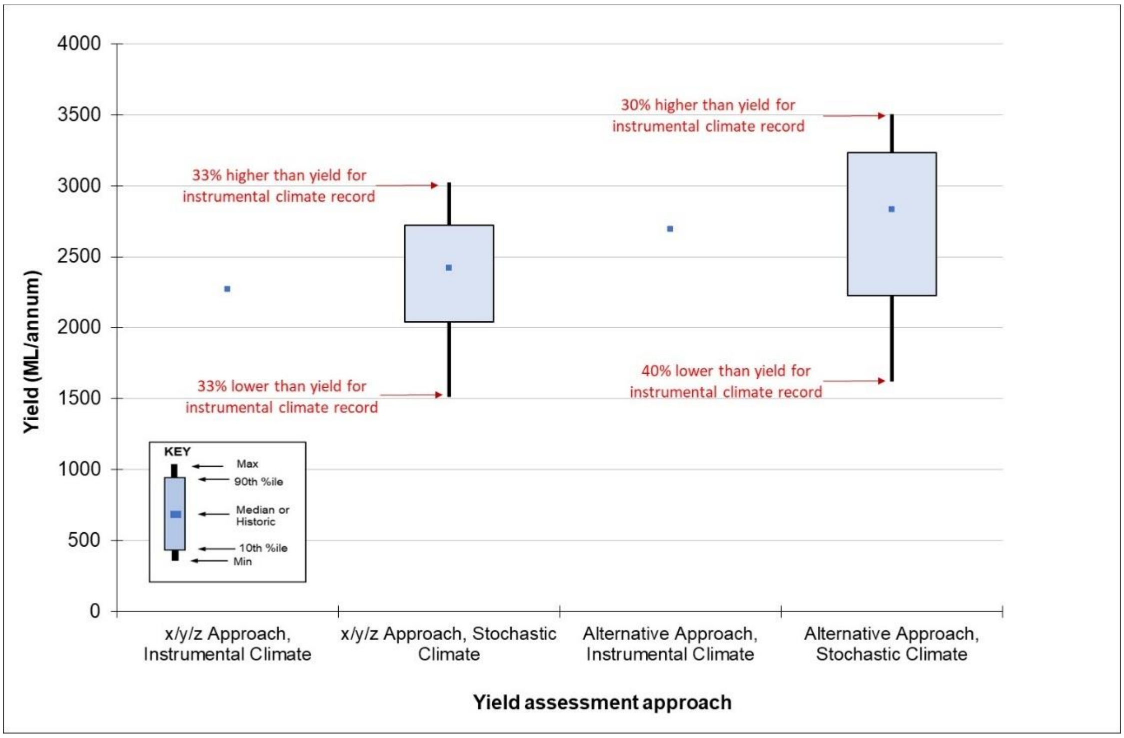


Figure 30 Distribution of yields (max, min, 90th, 10th percentile and median) from the 76 stochastic replicates using the x/y/z approach relative to the alternative yield analysis approach

The reason for the higher yield from the alternative approach is that there is an implicit allowance of a storage buffer (or reserve volume) in the x/y/z approach, whereas the alternative approach assumes an explicit allowance, which in this case study was assumed to be zero. This was previously explained in HARC (2022).

The results of the Yass case study also indicate that there is less difference between the results from the two methods for the drier (lower yielding) replicates, relative to the wetter (higher yielding replicates). This was traced back to the influence of different demand patterns assumed in the two methods. The x/y/z approach assumes the same pattern of demand in each year, based on the average behaviour from five recent dry years, with no inter-annual variability in that demand pattern. In contrast, the alternative approach uses a demand model that includes different seasonal and inter-annual patterns of demand based on the prevailing climate conditions, as estimated by the demand model. In very dry years within the stochastic data, it is possible to generate a pattern of demand from the demand model that results in demands that are higher than those generated when using the average dry-year demand pattern from the x/y/z approach. This higher demand results in the storage being drawn down faster in those very dry years, which reduces the supply system yield. An example period within the stochastic data where this was observed for the same level of population in the two demand models is shown in Figure 31 and Figure 32. This reduction in yield for the alternative approach, due to higher demands in the drier replicates, partially offsets the increase in yield associated with having an explicit storage buffer of zero, relative to the implicit non-zero storage buffer when using the x/y/z approach.

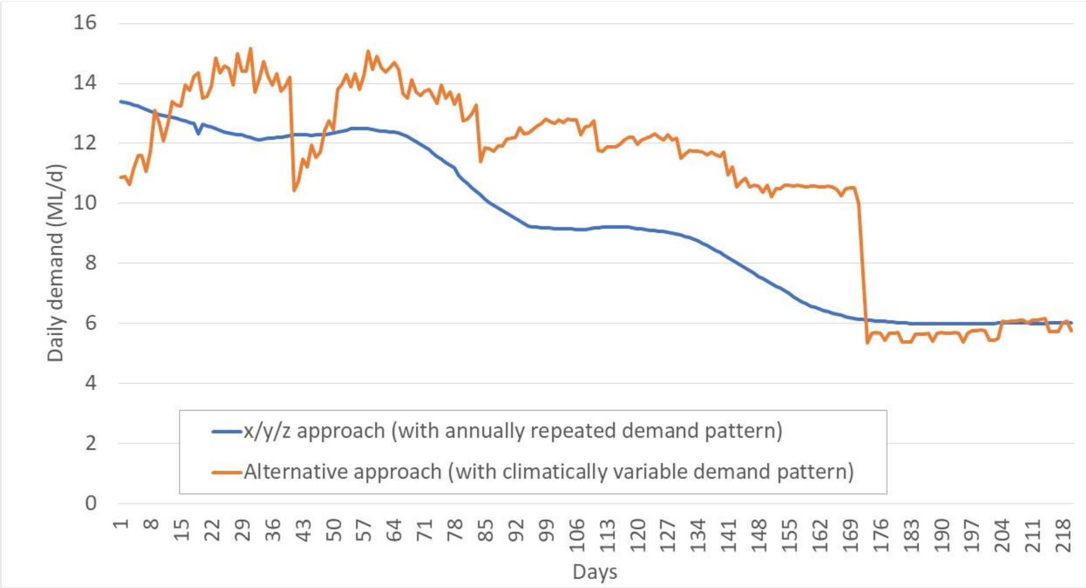


Figure 31 Yass supply system demand, at the same average annual level of demand, for the x/y/z approach and the alternative approach in an example storage drawdown event in a dry period for an example replicate

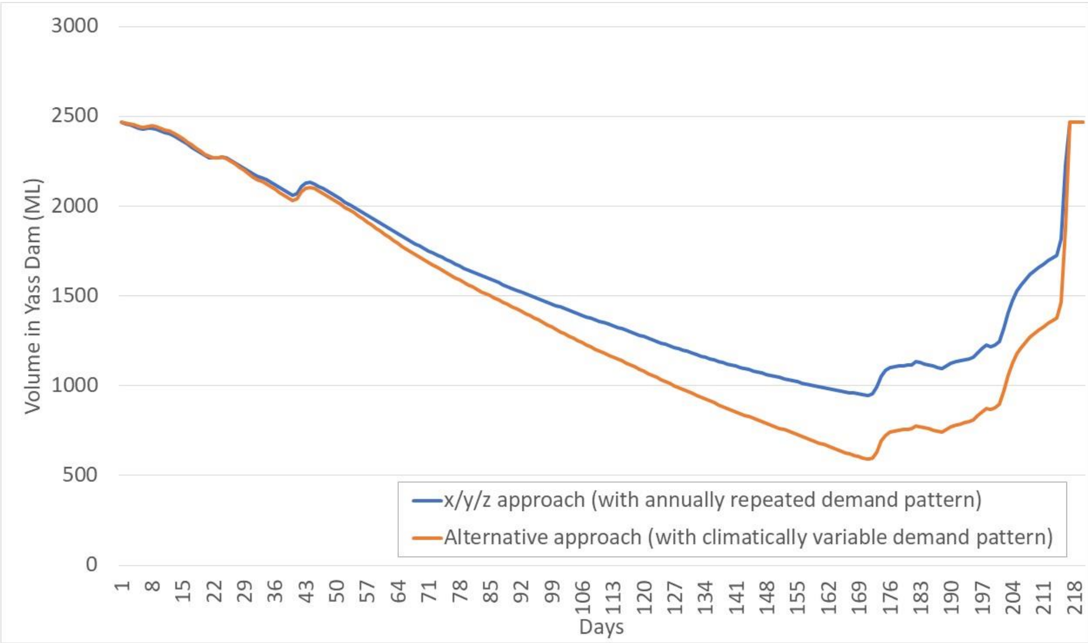


Figure 32 Drawdown in Yass Dam, at the same average annual level of demand, for the x/y/z approach and the alternative approach in an example storage drawdown event in a dry period for an example replicate

These results illustrate the risks in both demand modelling approaches. For the demand modelling adopted in the x/y/z approach, the storage buffer embedded within the approach can be diminished by climate variability for climate conditions drier than those observed in the instrumental climate record, whilst for the alternative approach, there is a need to check the voracity of the climate dependent demand model, when that model is applied well outside of the range of conditions over which it was calibrated, as can occur in some much drier stochastic replicates.

5.5 Yield under a projected climate change scenario

The climate change adjustment factors outlined previously in Section 4.1 were applied to the input climate variables in the Yass Source model. This provided an estimate of the effect of one climate change projection on supply system yield for the year 2070. This is one of many plausible climate change projections, and should therefore be regarded as a demonstration of the ability to apply climate change projections to the stochastic datasets, rather than a definitive statement of the effect of projected climate change. Consistent with the scope of work for this project, this analysis has been undertaken using the alternative yield assessment approach only.

Figure 33 illustrates that under a drier climate change projection, yield could be substantially (~27-42%) lower than under historical climate conditions. For example, the range of yields under this projected climate change scenario would reduce from 1,600-3,500 ML/annum down to 900-2,600 ML/annum, with the median yield reducing from 2,800 ML/annum down to 1,800 ML/annum.

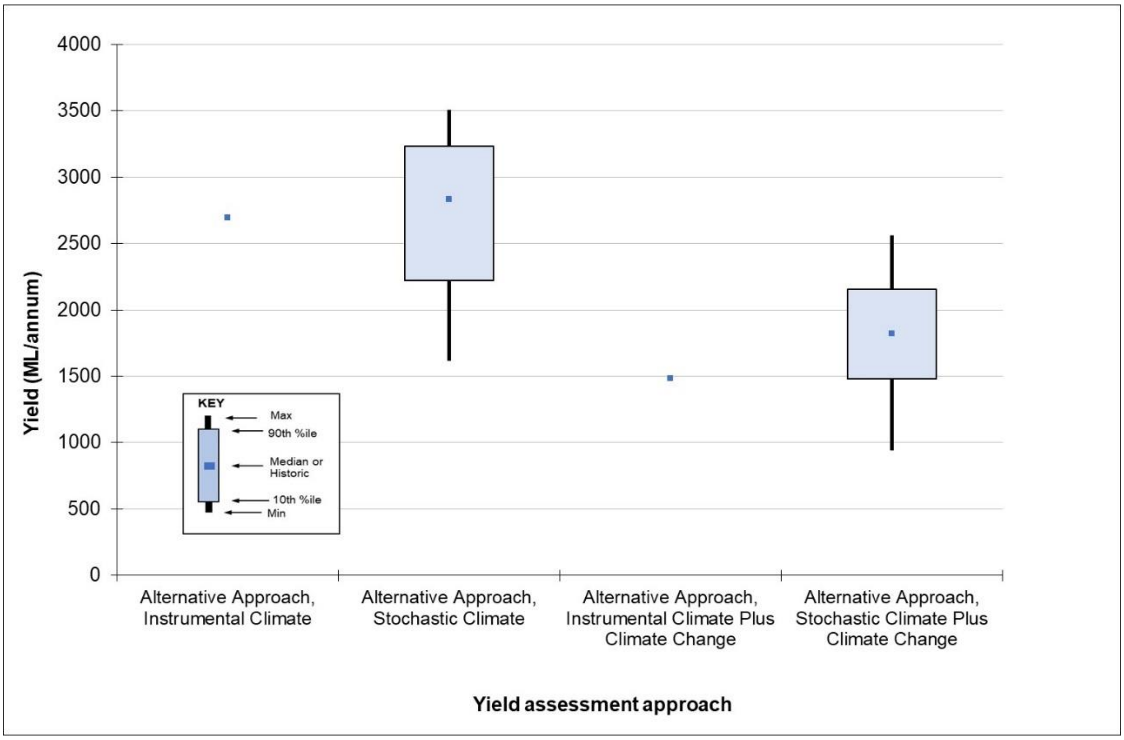


Figure 33 Distribution of yields (max, min, 90th, 10th percentile and median) from the 76 stochastic replicates under a projected year 2070 climate change scenario using the alternative yield analysis approach

These results are not directly comparable with the climate change impacts on yield previously presented in Public Works Advisory (2021b). This is because the underlying assumptions of the climate change scenario were different, with the assessment in Public Works Advisory (2021b) based on an assumed 1°C, whilst the scenario presented by HARC in this current project is based on a specific year (2070) rather than an assumed increment of global warming. Neither approach presents the full range of plausible future climate change possibilities, and should therefore be regarded as one such possibility. In both studies, a drier climate future was modelled, indicating lower yields for the Yass supply system under this drier future.

5.6 Yield under a higher irrigation demand scenario

For this scenario, the irrigation demands in the catchment upstream of Yass Dam were set equal to the irrigation licence volume in the year of maximum demand, as outlined previously in Section 4.2. These demands were set 10% higher than they are under current water use conditions.

The yield analysis results, shown in Figure 34, indicated that there was no change in the estimates of yield in this figure, when assuming full uptake of irrigation licences, with only a minor reduction for a small number of the wetter replicates (not evident in this figure). This result is considered to be partly a consequence of the cease to divert rules in the Water Sharing Plan. During very low flow periods, when supply to irrigators is not permitted by Water Sharing Plan rules, there are long periods of up to several weeks with no diversions, followed by a short period when diversions can resume. This means that on most days, the higher irrigation demand is having no effect on available inflows to Yass Dam. Small changes in town supply system yield were only evident in some of the wetter replicates, presumably when these cease-to-divert rules were in place less often.

These results are quite different to those previously presented in Public Works Advisory (2021b). It is noted that there are some differences in approach, notably that the x/y/z approach was used to estimate yield in Public Works Advisory (2021b) and the alternative yield assessment approach was used in the current work by HARC. The assumptions around the limits on future extraction were also different. Whilst Figure 34 indicates no significant change in yield with the higher irrigation demand upstream, the previous work presented in Public Works Advisory (2021b) indicated a reduction in yield of 37% (from 1,900 ML/annum down to 1,200 ML/annum). If current maximum annual water use is as indicated by the Upper Murrumbidgee Source model, then the maximum additional future uptake of water for irrigation would be 145 ML/annum, as previously indicated in Section 4.2. In this context, the reduction in yield of 700 ML/annum under higher irrigation demands in Public Works Advisory (2021b) appears overly high. The current estimate by HARC of negligible change could nevertheless be under-stated if the irrigation demand model over-estimated current annual irrigation supply. It could also be under-stated if the maximum allowable water use were assumed to be provided in multiple years, rather than a single year, because of access to on-farm storage or other water sources by irrigators.

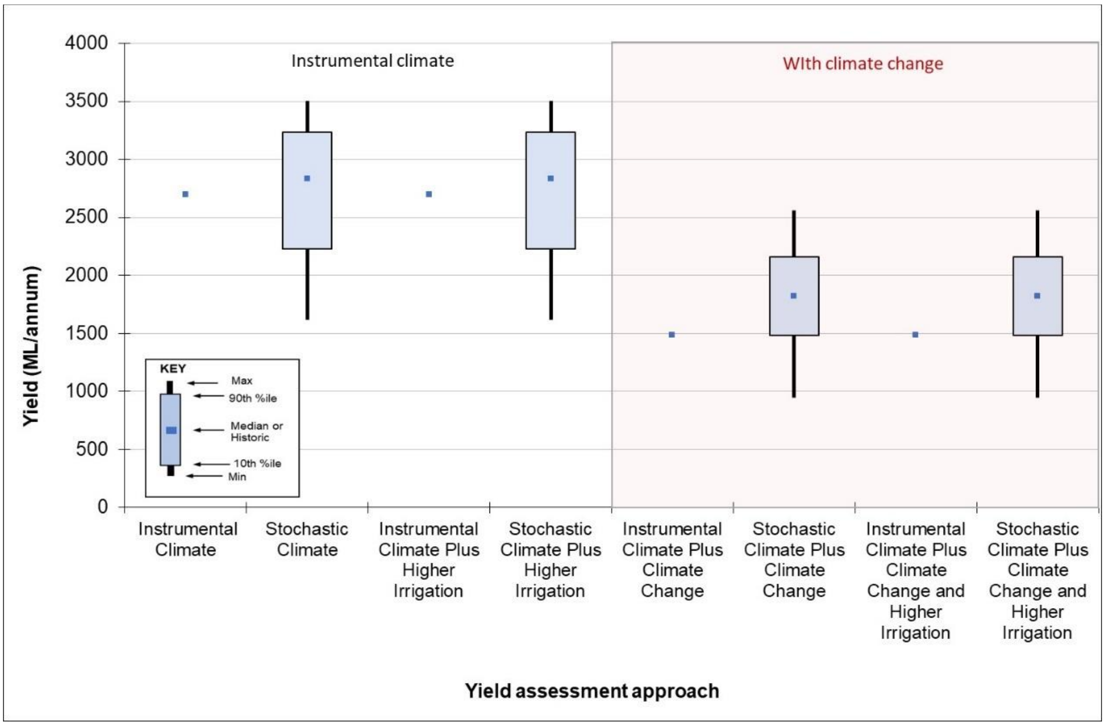


Figure 34 Distribution of yields (max, min, 90th, 10th percentile and median) from the 76 stochastic replicates under higher irrigation demands using the alternative yield analysis approach, with and without climate change

Results were also generated for the combination of higher climate change and higher irrigation demand, which led to the same conclusion, namely that the increase in irrigation demand up to the licensed volume had negligible impact on yield to Yass township, with only the wetter replicates displaying minor differences in yield.

5.7 Sensitivity to restriction trigger assumptions

When restriction triggers were not fixed across replicates, both the x/y/z and the alternative approach resulted in higher restriction triggers for lower yielding, drier climate replicates, as would be expected if needed to avoid storages reaching minimum operating levels during these drier sequences. In both cases, a Level 1 restriction trigger was adopted for the drier climate replicates that was lower than Yass Valley Council's current 81% restriction trigger for Level 1. This is illustrated in Figure 35 and Figure 36 for the two yield analysis approaches using the stochastic data. Figure 36 also suggests that for some higher yielding (wetter) replicates, a restriction trigger below 40% of storage capacity could be the optimal trigger when using the alternative approach. However, inspection of the failure criteria for many of these wetter replicates indicated that yield was being limited by both the restriction frequency and the minimum volume in storage, and that relaxing the trial values of restriction trigger to include lower values would not have increased yield for many of these wetter replicates.

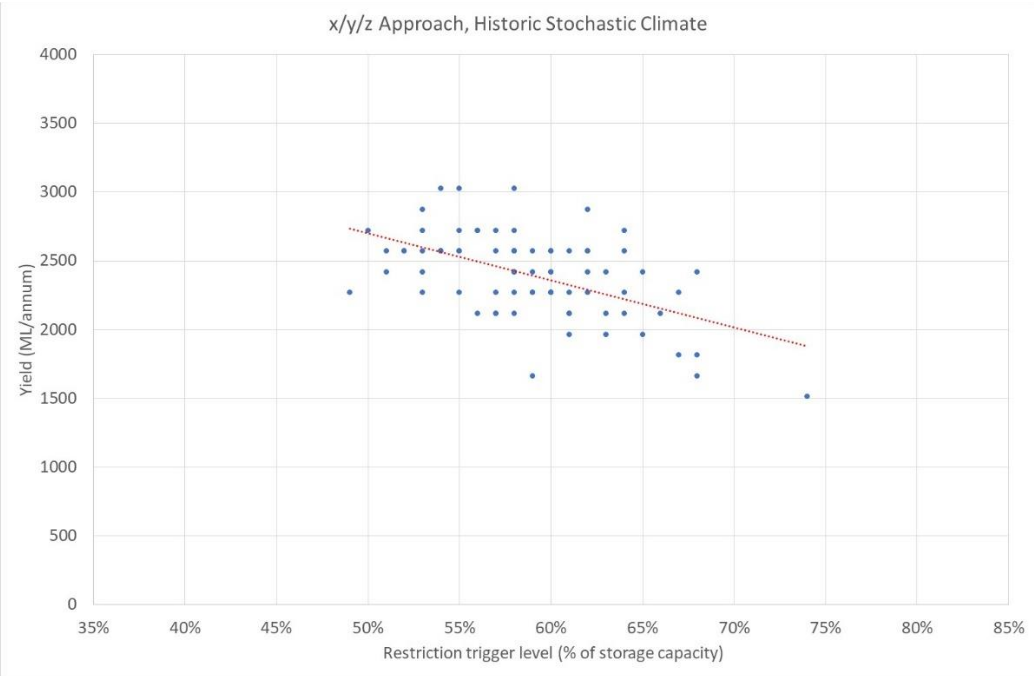


Figure 35 Relationship between yield and restriction trigger level across different climate replicates for the x/y/z approach

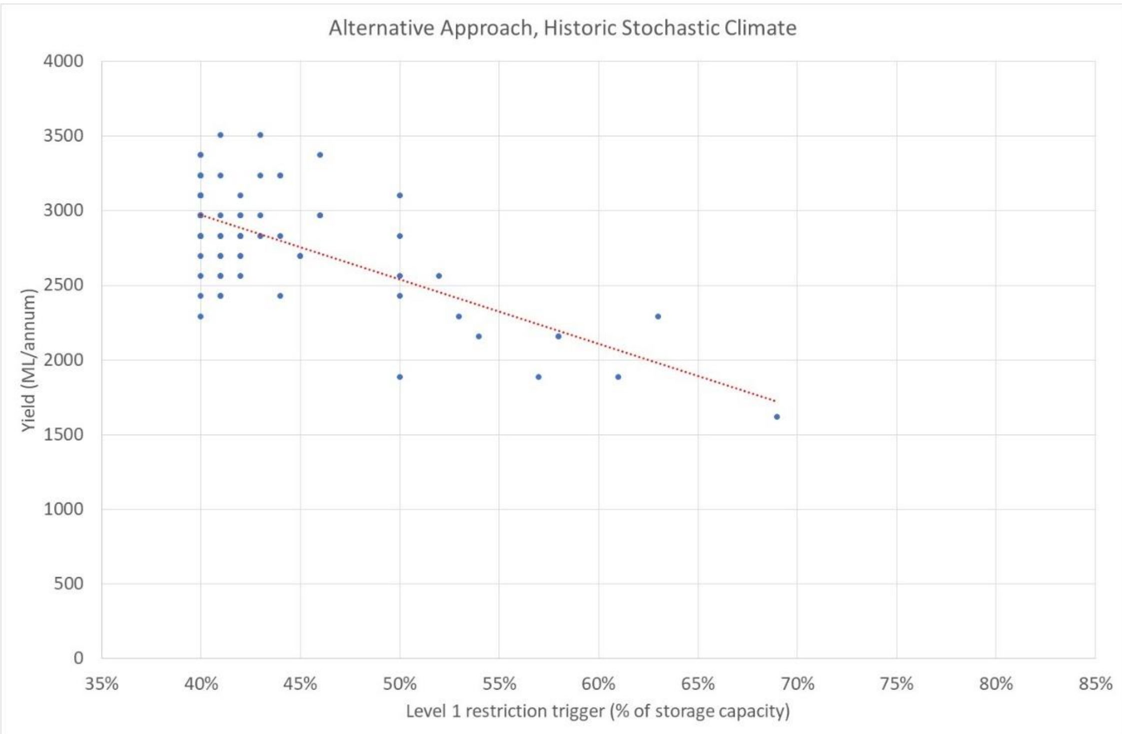


Figure 36 Relationship between yield and restriction trigger level across different climate replicates for the alternative yield analysis approach

In practice, a local water utility will not know what climate conditions are about to unfold, and therefore cannot optimise the restriction trigger level for future climate conditions. Therefore, the setting of restriction trigger levels should be a risk-based decision that considers the restriction trigger level that provides a robust estimate of yield across all climate possibilities, but not necessarily the optimum yield for each climate possibility. The resulting yield using a fixed restriction trigger will always be lower than when the restriction trigger is tailored to the climate conditions within each replicate.

To test this for the Yass case study, the Yass Valley Council's current restriction triggers were adopted across all climate replicates (i.e. Level 1 at 81% of storage capacity, as per Table 9 in Section 2.5). The results are shown in Figure 37. These results are generated using the alternative yield assessment approach only, because the x/y/z approach sets restriction trigger levels as part of the yield assessment method, and not as an input assumption for the yield analysis.

Figure 37 shows that the estimated yield using the instrumental climate record is considerably lower when using Yass Valley Council's current restriction triggers. Yields reduced from 2,700 ML/annum (with triggers optimised to maximise yield only, without consideration of any other risks) to 800 ML/annum (with the Level 1 trigger at 81% of storage capacity). In each case, yield was driven by the need to keep the annual likelihood of restrictions below 10%. This outcome suggests that the current restriction triggers may be too high to avoid an annual likelihood of restrictions of more than 10% under drier climate sequences, if demands were to increase beyond their current levels.

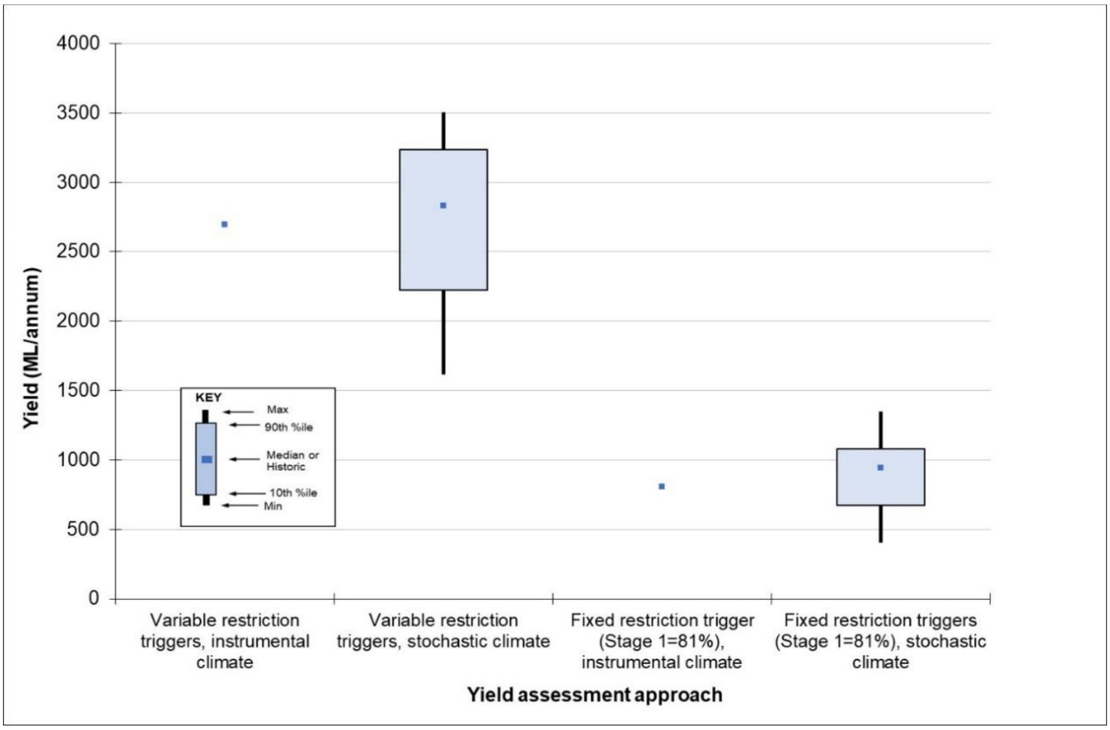


Figure 37 Distribution of yields (max, min, 90th, 10th percentile and median) from the 76 stochastic replicates with Council's current restriction triggers (Level 1 at 81% of storage capacity) using the alternative yield assessment approach

5.7.1 Testing alternative restriction triggers

To test the potential for higher yields with different fixed restriction triggers, two additional sets of restriction triggers were trialled. These were a designated “lower risk” and “higher risk” set of restriction triggers. The lower risk triggers were those assessed as likely to increase yield (by reducing the frequency at which the Level 1 restriction trigger would be reached) without increasing the risk of reaching the minimum storage level at yield due to climate variability. The higher risk triggers were those assessed as likely to increase yield, as above, but with a higher potential for yield to be limited by the minimum storage volume being reached. This is illustrated in Figure 38, which includes the first 8 (of 76) replicates, plus three of the lowest yielding replicates. This figure shows that at Level 1 restriction triggers above ~72%, yield is directly proportional to the restriction trigger value. However, when the restriction trigger is set around 63%, the yield for some of the drier replicates starts to become independent of the restriction trigger level. This is because when the restriction triggers are lowered, the minimum volume in storage becomes the limiting factor on yield for the drier replicates, not the restriction frequency. When the Level 1 restriction trigger was below ~63%, the number of replicates under which minimum volume in storage became the limiting factor on yield started to increase.

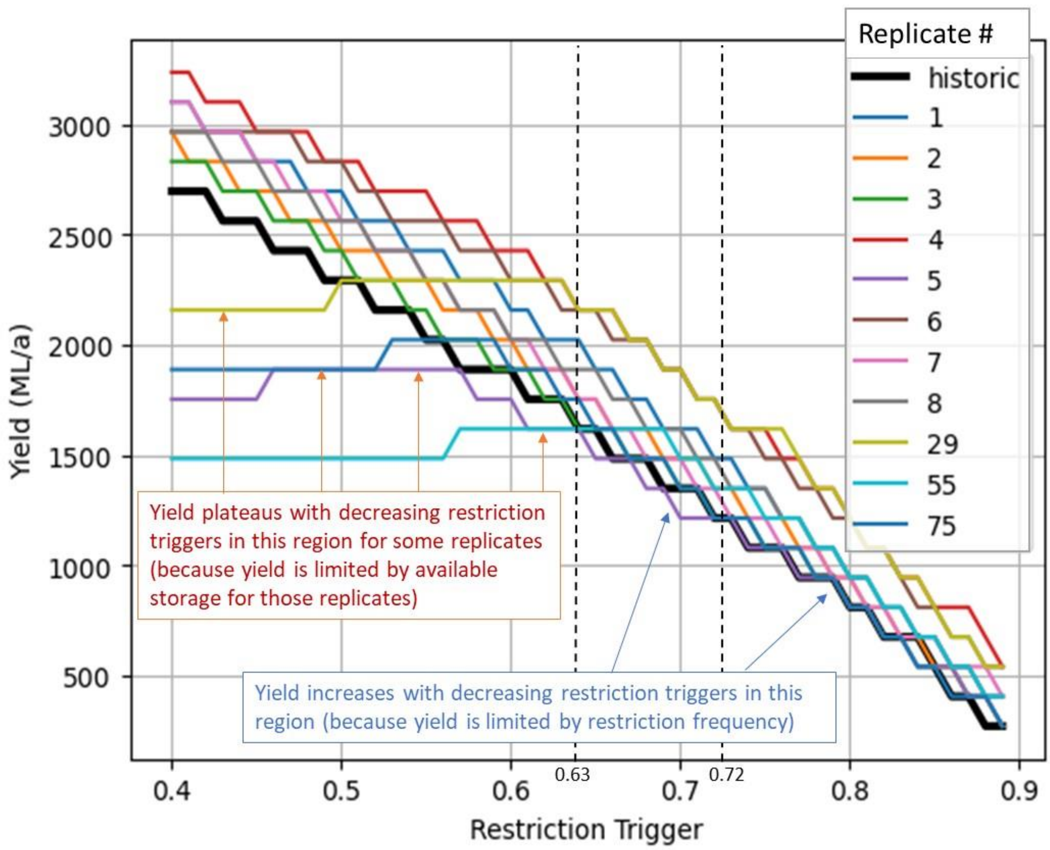


Figure 38 Yield at different restriction trigger levels for a selection of climate replicates

For the purposes of this analysis, the Level 1 restriction triggers that were adopted for the testing are as listed in Table 19. These alternative triggers also have the advantage that they are evenly spaced (i.e. 9% of storage capacity apart) to identify any non-linearity in yield with respect to linear reductions in the Level 1 restriction trigger. The levels 2 to 5 triggers were reduced by the same volume as the Level 1 restriction trigger. That is when the Level 1 restriction trigger was reduced by 9% of storage capacity, then the triggers for Levels 2 to 5 were also reduced by 9% of storage capacity. This preserves the duration of supply under Levels 1 to 4 restrictions, for a given level of demand, and reduces the duration of supply under Level 5.

Table 19 Lower and Higher Risk Restriction Triggers for Sensitivity Testing

Restriction Trigger Type	Level 1 restriction level trigger (% of storage capacity)
Current Council Policy	81%
Lower Risk Alternative Triggers	72%
Higher Risk Alternative Triggers	63%

The results of this analysis are shown in Figure 39, which illustrate how yield for the Yass supply system increases as the restriction triggers are lowered. For example, the median stochastic yield increases from 900 ML/annum to 1,300 ML/annum to 1,900 ML/annum as the Level 1 trigger is lowered from 81% to 72% to 63% of storage capacity respectively.

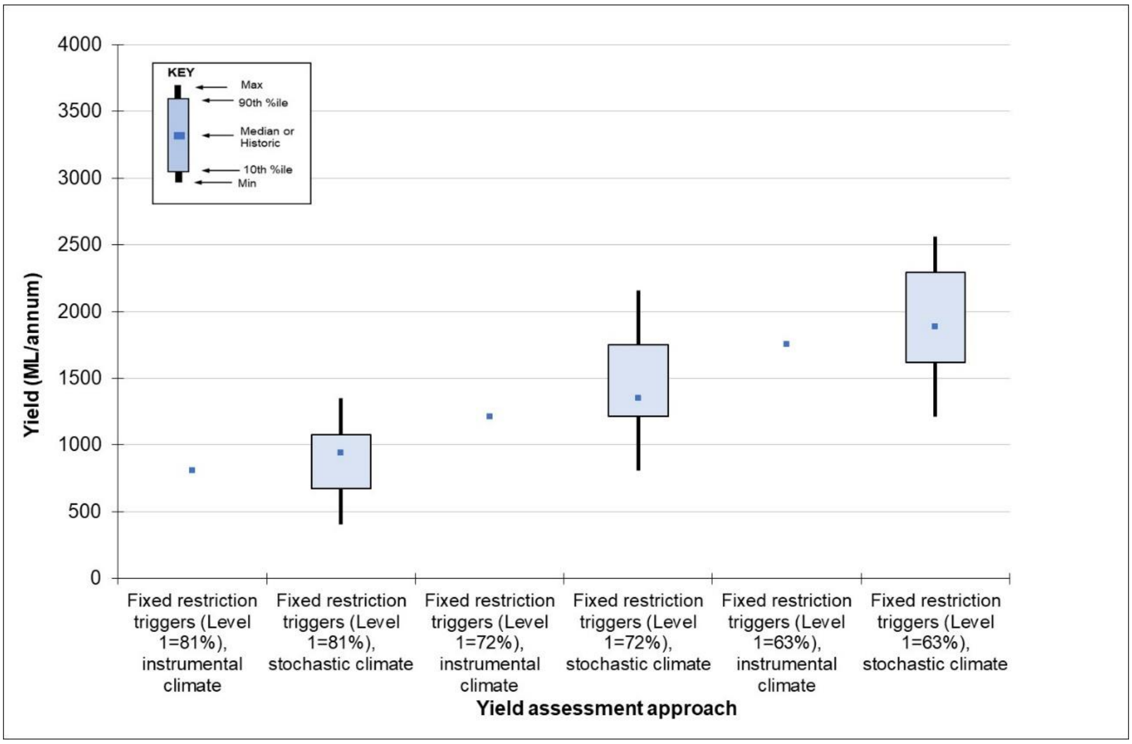


Figure 39 Distribution of yields (max, min, 90^{th}, 10^{th} percentile and median) from the 76 stochastic replicates under different fixed restriction triggers

This result is achieved because the yield is always limited by the annual frequency of restrictions under Council's current restriction policy. The failure mode that limits yield was classified as being the minimum storage volume when the minimum volume reached was less than 160 ML (i.e. the next increment of demand between adjacent yield estimates for this particular case study would result in the storage being drawn down by ~160 ML to the minimum operating level). If the minimum storage reached was above 160 ML, then the failure mode that limits yield was classified as being the annual frequency of restrictions, because increasing the yield by one increment of demand would be unlikely to result in the minimum operating level being reached. The duration criterion that limits restrictions to less than 5% of the time was never the limiting criterion.

The proportion of replicates for which yield was limited by each failure mode is shown in Figure 40. Changes in failure mode from the annual frequency of restrictions to the minimum storage volume occurred for only the two driest replicates (i.e. 3% of replicates) when the Level 1 restriction trigger was set at 63% of capacity.

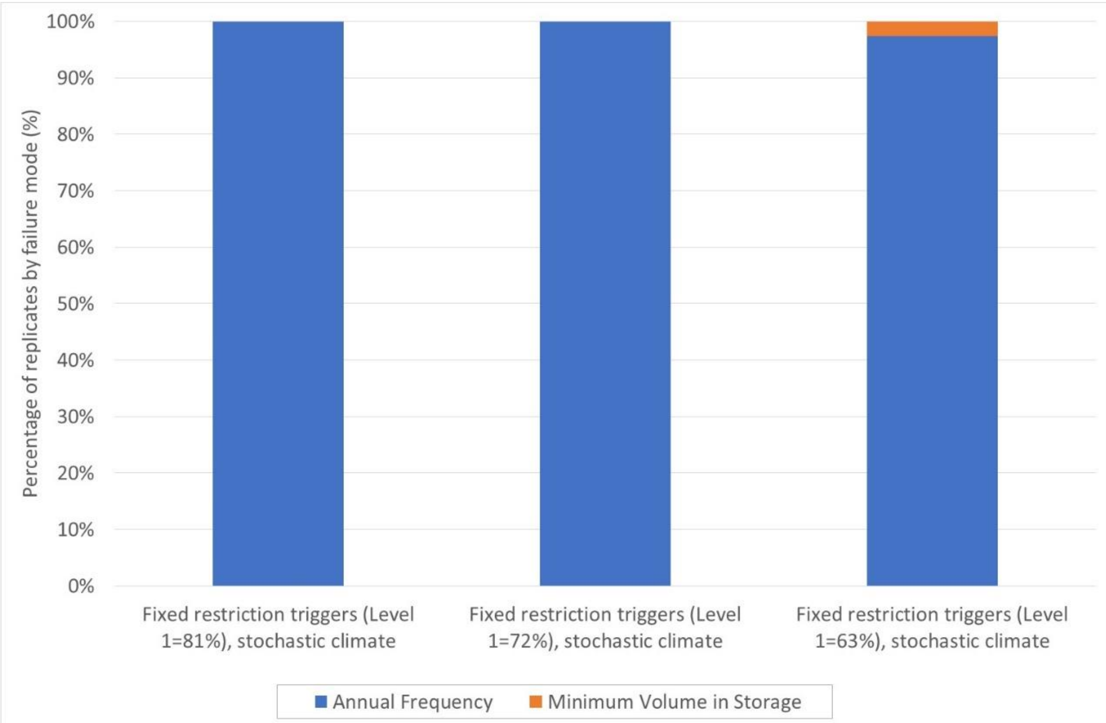


Figure 40 Level of service objective criterion that limits yield for each replicate, for three different sets of fixed restriction triggers

The minimum volume reached across the 76 replicates is shown in Figure 41. This shows that for the majority of replicates, the minimum volume in storage when demand is at yield is well above the minimum operating level, with minimum storage volumes approaching the minimum operating level in a small number of replicates when the restriction triggers are lowered.

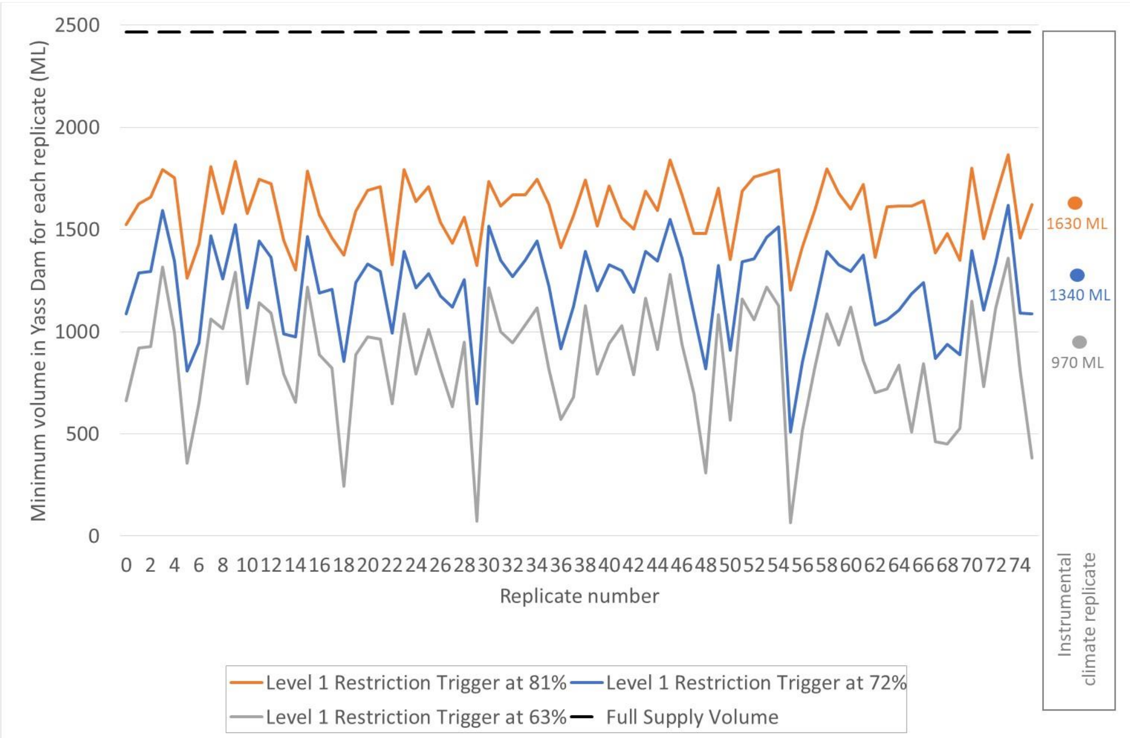


Figure 41 Minimum volume in Yass Dam at yield for each replicate with different fixed restriction triggers

5.8 Sensitivity to level of service objectives

Level of service objectives for the above yield assessment results were outlined in Section 5.2. To test the sensitivity of yield to level of service objectives, a different level of service objective was trialled, as shown in Table 20. The different (lower) level of service objective relaxes the criteria that limit the frequency of restrictions at yield. For the base case level of service objectives (assuming the Level 1 restriction trigger is at 72% of storage capacity), the limiting criterion was always the percentage of years spent in restrictions.

This sensitivity test was undertaken using the alternative yield assessment approach, with the Level 1 restriction trigger set at 72% of storage capacity.

Table 20 Different level of service (LOS) objectives for sensitivity testing

Assessment criteria	Base case LOS objectives	Lower LOS objectives
Time spent in restrictions	5%	10%
Years spent in restrictions (aka annual likelihood of restrictions)	10%	20%
Minimum storage volume reached	0 ML	0 ML

The results of this analysis are illustrated in Figure 39. These results show that lowering the level of service objective increases the yield, as expected, but that the benefits of this diminish under a drier climate future. Under historic climate, lowering the level of service reduced the minimum volume in storage reached within each replicate, but the annual frequency of restrictions (20%) still remained the limiting constraint on yield for almost all (97%) replicates, with the yield of the other 3% of replicates limited by reaching the minimum operating level in Yass Dam.

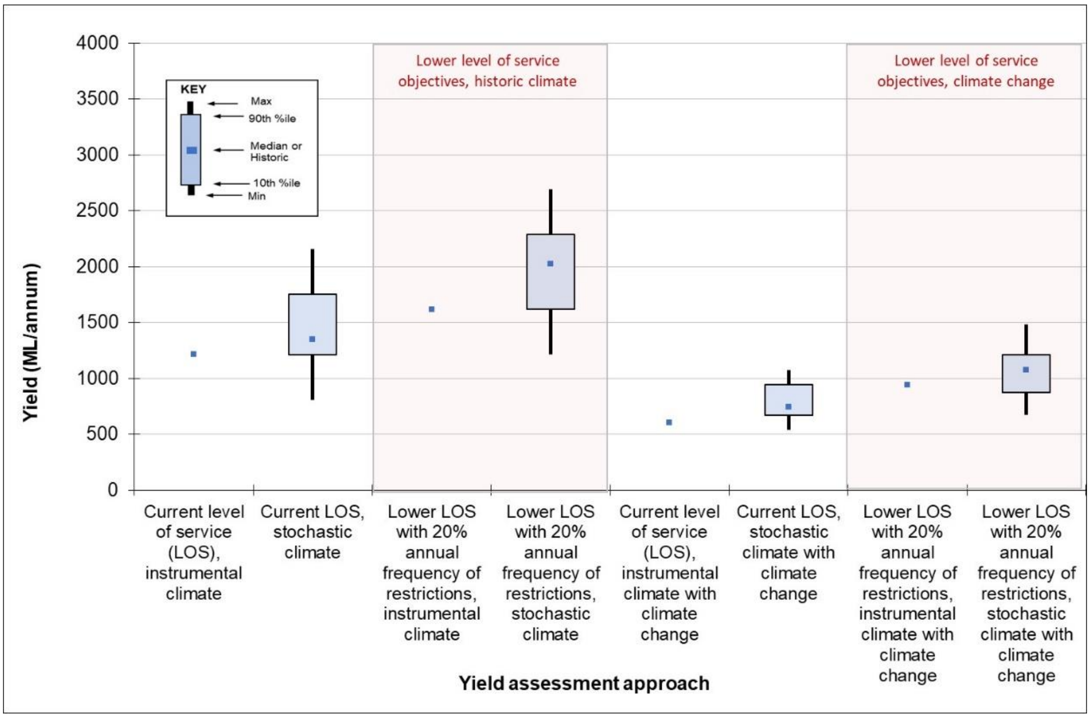


Figure 42 Distribution of yields (max, min, 90th, 10th percentile and median) from the 76 stochastic replicates under different level of service objectives

5.9 Other checks on the yield analysis results

When examining these results, it is important to question the veracity of the extreme values in yield, given that the stochastic datasets are generated from a mathematical model rather than a process-based model and because there are various processing steps involved to generate yield, all with the potential for data processing errors. The following checks relate to Steps 6 to 8 of the Department's step-by-step guidance for water security analysis using stochastic data (DPE Water, 2022a). In this case study, it was found that the critical drawdown period was in the order 6 to 24 months, depending on the climate replicate. Minimum inflows over these durations were typically lower when sampling from the stochastic data, as shown in Table 21 for an example drier climate replicate, but with reductions in those inflows that were plausible, relative to say reductions in minimum accumulated flows in the instrumental climate record before and after the Millennium Drought across the region. After allowing for the benefits provided from having water in storage leading into the drought period, a yield that is ~33% lower than historic is not inconsistent with inflows that are up to ~10-60% lower over the periods listed in Table 21.

Table 21 Inflow metrics from the stochastic data relative to the historical instrumental period for a sample drier climate replicate that generated one of the lowest yields

Inflow metric	Stochastic replicate* generating one of the lowest yields as a % of the instrumental climate replicate
Minimum monthly	89%
Minimum 3 month	86%
Minimum 6 month	86%
Minimum annual	54%
Minimum 18 month	39%
Minimum 24 month	44%
Minimum 36 month	38%

*Replicate #75;

The replicates generating the lowest yield estimates were generally consistent for different scenarios when using the same inflow assumptions (i.e. a lower yielding replicate for one scenario was also a lower yielding replicate across all other scenarios).

Checks on the drivers of demand model behaviour for drier climate replicates were previously discussed in Section 5.4.

5.10 Level of effort in undertaking yield analysis with stochastic data

The additional level of effort involved in preparing, applying and post-processing stochastic data, relative to using the single instrumental climate replicate, includes additional skill requirements, as well as additional setup and processing time. On a single PC, run times for a yield analysis of a given scenario were up to around 3-4 days for the Yass case study (using a daily time step model).

Run times for processing the stochastic data would be considerably less for a monthly time step model. It became clear from the Yass case study that for daily time step models more complex than the Yass Source model, either:

(i) optimisation techniques; and/or

(ii) more powerful computers; and/or

(iii) replicate thinning; and/or

(iv) a hybrid daily/monthly time step modelling framework

would be required to reduce run times to a workable duration. Replicate thinning involves the selection of a sample of replicates based on initial exploration of the replicates that generate a representative range of yields, but has the drawback that it reduces the information available from the stochastic dataset, particularly when different types of scenarios are affected in different ways by different input climate sequences (i.e. when the ranking of outcomes by replicate number is not preserved across scenarios).

The option of using a simpler monthly time step model to explore the solution space, prior to employing the daily time step model, would help to generate more information relevant to decision making in a shorter space of time, particularly if a large number of scenarios are being considered, and where reservoir drawdown occurs over periods much longer than one month. To use the Yass supply system as an example, this could involve:

1. Fitting a monthly time step rainfall-runoff model to total inflows to Yass Dam, and fitting a monthly time step demand model to the observed consumption data;

2. Developing a monthly time step Source model of the Yass water supply system that only models inflows to the dam (i.e. not the upstream catchment);

3. Aggregating the daily stochastic climate data to a monthly time step;

4. Using the monthly time step model to explore sensitivities to climate change (i.e. more than just a single representation of climate change), potential supply re-configuration options, different inflow assumptions, different yield analysis techniques, etc.; and

5. Confirming outcomes from the monthly time step modelling using the daily time step model, but only for a subset of scenarios of most interest to decision-making (e.g. current conditions and the preferred future demand and supply strategy), as informed from the monthly time step modelling.

The modelling strategy for daily time step water supply system models that have a similar level of complexity or which are more complex than the Yass Source model, will need to be assessed on a case by case basis.

5.11 Summary of results

A summary of the yield analysis results presented in this chapter is tabulated in Table 22 and illustrated in Figure 44. These yield analysis results compare to recent historical raw water withdrawal from the dam of ~800-1,000 ML/annum in the Yass supply system.

Table 22 Summary of yield analysis results (bold font highlights the distinguishing feature of each scenario)

Yield method	Climate and inflow data	Yield (ML/annum)	Level 1 restriction trigger (% of storage capacity)*	Level of service objectives for annual frequency of restrictions
x/y/z	**Historic instrumental**	2,300	60%	10%
x/y/z	**Historic stochastic**	1,500-3,000	Various	10%
Alternative	**Historic instrumental**	2,700	42%	10%
Alternative	**Historic stochastic**	1,600-3,500	Various	10%
Alternative	Historic instrumental with **higher upstream irrigation**	2,700	41%	10%
Alternative	Historic stochastic with **higher upstream irrigation**	1,600-3,500	Various	10%
Alternative	**Climate change** instrumental	1,500	47%	10%
Alternative	**Climate change** stochastic	900-2,600	Various	10%
Alternative	**Climate change** instrumental with **higher upstream irrigation**	1,500	47%	10%
Alternative	**Climate change** stochastic with **higher upstream irrigation**	900-2,600	Various	10%
Alternative	Historic instrumental	800	81%#	10%
Alternative	Historic stochastic	400-1,300	81%#	10%
Alternative	Historic instrumental	1,200	72%	10%
Alternative	Historic stochastic	800-2,200	72%	10%
Alternative	Historic instrumental	1,800	63%	10%
Alternative	Historic stochastic	1,200-2,600	63%	10%
Alternative	Climate change instrumental	600	72%	10%
Alternative	Climate change stochastic	500-1,100	72%	10%
Alternative	Historic instrumental	1,600	72%	20%
Alternative	Historic stochastic	1,200-2,700	72%	20%
Alternative	Climate change instrumental	900	72%	20%
Alternative	Climate change stochastic	700-1,500	72%	20%

*The 10% demand reduction trigger for the x/y/z approach, and the Level 1 restriction trigger for the alternative approach.

Yass Valley Council's current restriction policy

HARC's view is that the yield of 400-1,300 ML/annum with Council's current restriction triggers represents the best estimate of current supply system yield under historic climate conditions, however this yield could be different with changes in operating rules for restriction triggers, and could change under projected climate change. In the absence of a single definitive yield estimate into the future in Table 22 and Figure 44, collectively the estimates point toward the value of robust and adaptable supply enhancement and demand reduction strategies for the Yass supply system over the coming years and decades. It is not possible to assign a precise likelihood to the various yield estimates. This means that any risk-based decision-making using these yields would be informed by qualitative rather than quantitative likelihoods for any given yield estimate. This could include statements such as:

- An example risk-avoidance approach, based on planning for minimum yields: *With the current restriction triggers in place, the Yass supply system cannot be guaranteed to generate a yield of more than 400 ML/annum*. Such an approach would most likely result in strategies that seek other water supplies to meet most of the Yass water supply needs, but investment in these may come with higher regret (i.e. under-utilised water sources) if average to wetter climate conditions were to prevail; or
- An example risk-averse approach, based on planning for the 10th percentile yield and an adjustment to restriction triggers, with consideration of contingency measures if drier climate conditions eventuate: *With an adjustment to current restriction triggers (Level 1 set at 72% of capacity), the Yass supply system could yield 1,200 ML/annum under 90% of current climate scenarios, but this would reduce under a projected drier climate change scenario. Contingency supply measures (e.g. existing groundwater bores) could be used under drier climate scenarios in the near-term, with supply enhancement measures likely to be required if demand for water grows as anticipated*. Such an approach adopts a conservative yield estimate with a very high likelihood that this yield would be available without breaching level of service objectives. It would most likely result in strategies that place higher value on the readiness and adaptability of other supply options and the ability to defer options.
- An example risk-balanced approach, based on planning for near-median yields and an adjustment to restriction triggers, but with consideration of contingency measures if drier climate conditions eventuate: *With an adjustment to current restriction triggers (Level 1 set at 72% of capacity), the Yass supply system could generate over 1,300 ML/annum under the majority of current climate and inflow conditions, with contingency supply measures (e.g. existing groundwater bores) available to use under drier climate possibilities. This would reduce under a projected drier climate change scenario.* Such an approach would most likely result in strategies that seek other water supplies to supplement the existing Yass water supply, or to defer investment in those supplies beyond making them ready to implement at short notice. It could also result in the current supply system being used as an opportunistic source of water, with an enduring supply available to provide restricted demands when needed. Note that for the Yass supply system, there was relatively little difference (rounded to 100 ML/annum) between the yield assumed to be available for the example risk-averse versus the example risk-balanced approach, but this may not be the case for other scenarios or other supply systems.

An example supply-demand projection derived from this information for an example scenario (Level 1 restriction triggers set at 72%, alternative yield analysis approach) is shown in Figure 43. This is based on a simple linear climate change projection from 2020 to 2070 for only one such projection, and assumes the growth in demand in Public Works Advisory (2021b). Under this scenario, there is a 98% likelihood that level of service objectives could be met in the year 2020, reducing to zero likelihood between 2045-2050, depending on growth assumptions, assuming a relatively dry climate change projection. To obtain a more complete picture of the likely timing of required actions at different levels of risk, a broader range of climate change projections would be required.

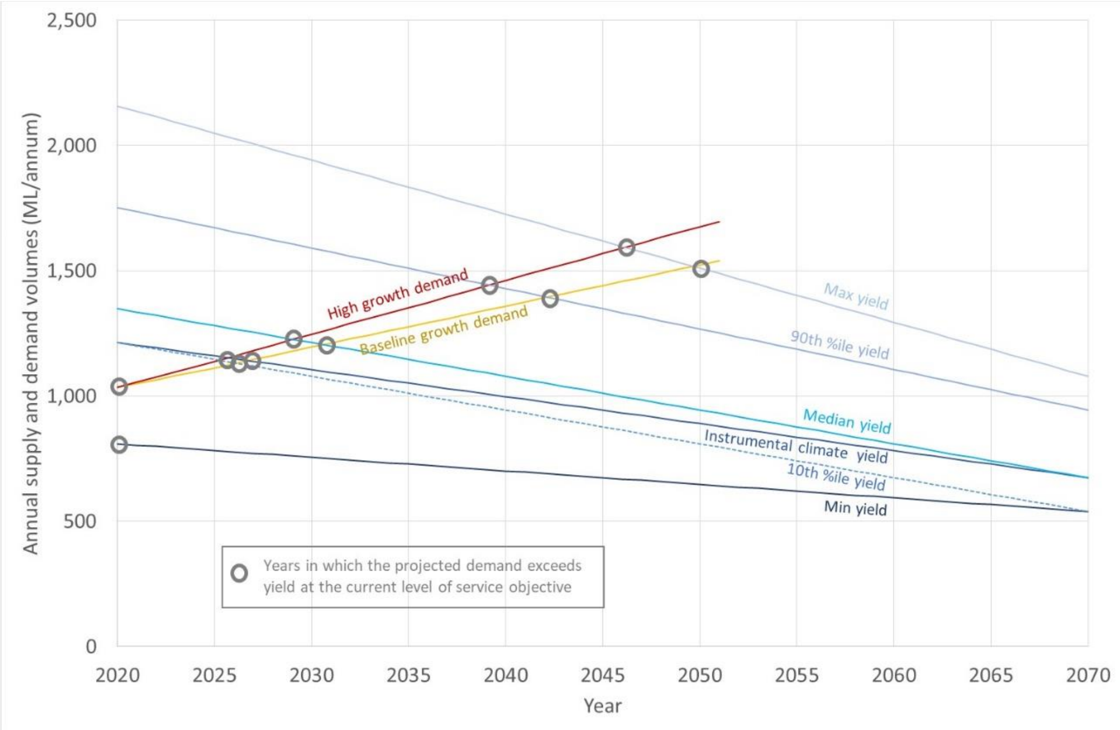


Figure 43 Example supply-demand projection for the Yass supply system, with Level 1 restriction triggers set at 72% of storage capacity, alternative yield analysis approach

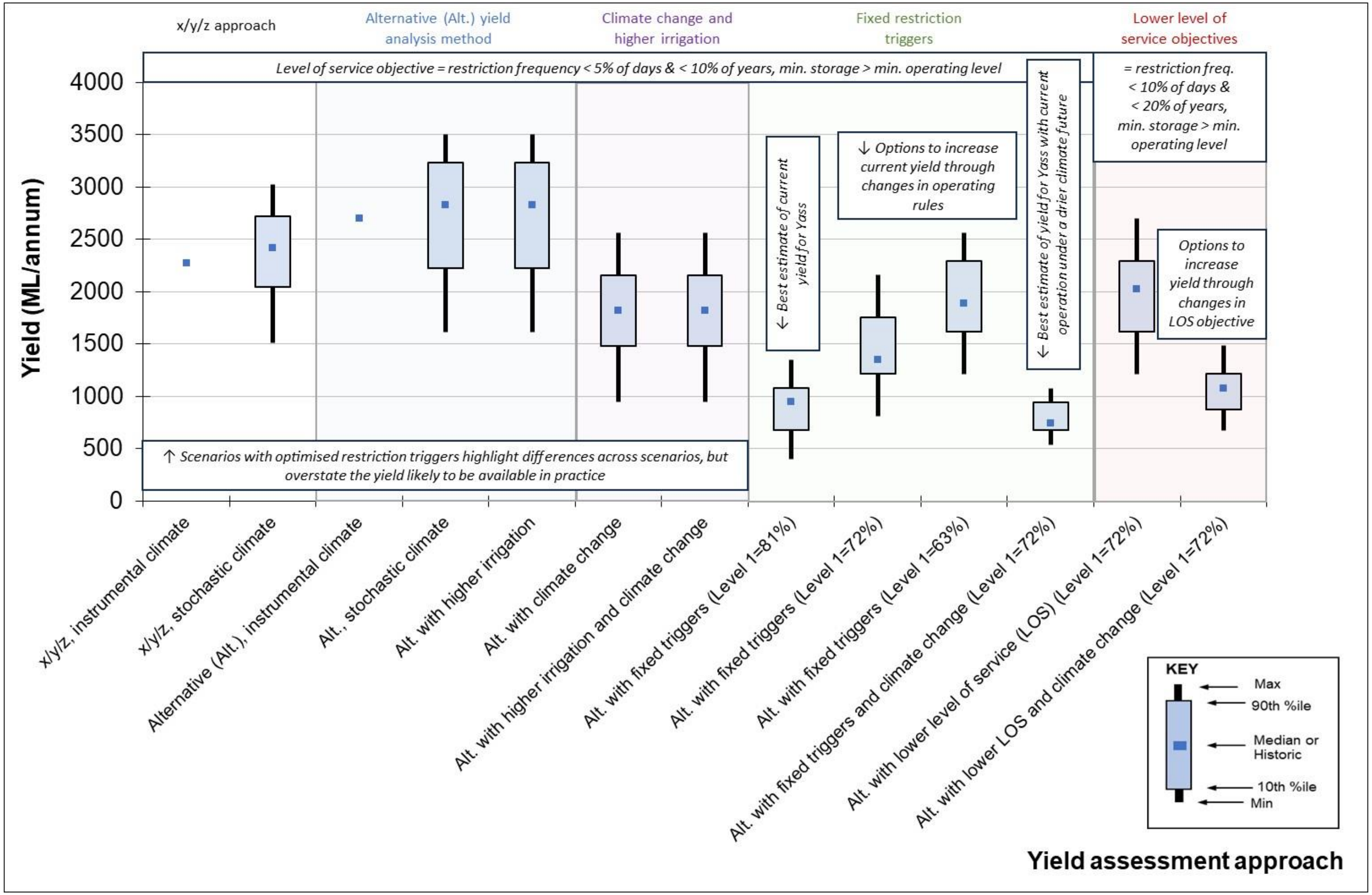


Figure 44 Overview of yield estimates using different input assumptions and assessment techniques

6. Conclusions

Conclusions are presented in three areas, namely with regards to the methods to use the RWS stochastic datasets, Yass water resource model, and the estimate of yield for the Yass supply system.

Methods to use the RWS stochastic datasets

- This study demonstrated how the Department's Regional Water Strategy stochastic data can be used to better understand uncertainty in yield estimates and inform water security risks for a real-world town water supply system.
- The previously developed step-by-step procedure in Appendix A of the Department's Water Security Guidance was able to be successfully applied to this case study.
- A cumulative rainfall deviation check (where the cumulative deviation is reset to zero at the start of each replicate, and the deviation is measured from the mean of the whole 10,000 year sequence) was helpful for dividing the stochastic replicates into 130 year sequences. This check is in addition to the steps in Appendix A of the Department's current Water Security Guidance.
- The median yield from the stochastic climate data was found to sometimes differ from the yield estimated using the instrumental climate data, indicating that they cannot automatically be assumed to be the same.
- The stochastic data was readily adjusted to estimate yield under projected climate change using one NARCliM climate projection.
- The stochastic data was readily applied when adopting alternative inflow assumptions, alternative non-urban demand assumptions, alternative yield assessment techniques, different restriction trigger rules, and different level of service objectives.
- The assumed demand patterns associated with the x/y/z approach (which assumes a fixed dry-year demand pattern applied each year) relative to the alternative yield approach (which assumes the demand pattern can vary from year to year based on prevailing climate conditions) can influence the yield assessment outcomes.
- The suite of optimised restriction triggers that maximise yield for each climate replicate can help inform the design of a single set of restriction triggers for operational purposes and for yield analysis across all replicates that is consistent with water utility operations.
- When updating its Water Security Guidance on the use of Regional Water Strategy models and datasets, the Department may include additional advice for local water utilities to consider climate variability that has occurred since the Regional Water Strategy models and datasets were developed. It may also include considering the suitability of those models and datasets at a local scale, for water security planning for town water supplies.

Yass water resource model

- There is considerable information uncertainty with regards to modelling the Yass supply system.

- This uncertainty manifest as uncertainty in the estimate of inflows to Yass Dam and an under-estimation of drawdown in Yass Dam by the Yass Source model during the 2019/20 drought.
- This highlights the benefit of ensuring that the supply system model used to estimate town water supply yield is well calibrated and informed by good quality, long-term monitoring data, prior to using stochastic climate inputs.
- Yass Valley Council has started addressing data uncertainty issues by installing a radar sensor for improved measurement of dam water levels in April 2022.
- Subject to advice from a hydrographer about site suitability, monitoring inflows and/or outflows at the dam over a concurrent period during drought, with at least one of these monitored indefinitely, would provide valuable information for future yield assessment. Yass Valley Council has indicated that monitoring outflows at the dam wall is likely to be difficult due to the nature of the weir structure.

Yield estimate for the Yass supply system

- The outcomes of this case study highlight that a range of yields from the Yass supply system are possible due to climate variability, climate change, assumed operating rules, assumed level of service objectives, and the yield assessment method. Yield estimates generated from this study ranged from a low of ~400 ML/annum to a high of ~3,500 ML/annum, with these reducing further under a drier climate change scenario.
- The yield assessed using the x/y/z approach was lower than the equivalent yield using the alternative approach.
- The lower yield distribution resulting from adopting the same restriction triggers across all climate replicates is considered by HARC to reflect the yield which a local water utility could expect in practice.
- On that basis, the current yield estimate for Yass is 400-1,300 ML/annum assuming Council's current restriction triggers (Level 1 restrictions at 81% of storage capacity). This yield was limited by the 10% annual likelihood of restrictions. The range of current yield estimates reflects the range of possible climate variability using 76 stochastic streamflow sequences of 130 years in length, for comparison against the yield of 800 ML/annum using the single streamflow sequence from the 130 year instrumental climate record.
- Lowering storage level triggers for introducing restrictions increased yield, without resulting in minimum operating levels being reached at yield in all but the driest stochastic replicates. When the triggers were lowered (Level 1 = 72% or 63% of storage capacity), yield increased significantly, and approximately doubled to tripled for the drier replicates. Setting restriction triggers should however be informed not only by yield analysis considerations, but also by the likely time available for customers to respond to different restriction levels, the lead time required to implement contingency supply measures and/or the next supply system augmentation, and any desire for consistency with water restrictions in the surrounding region (Canberra).
- A lower level of service objective for the annual likelihood of restrictions (20% annual likelihood instead of a 10% annual likelihood) would also increase the yield for Yass.

- In the absence of a single definitive yield estimate, all of the above point toward the value of robust and adaptable supply enhancement and demand reduction strategies for the Yass supply system over the coming years and decades. In the short-term, subject to further consideration of lead times for contingency supply measures and the insurance value provided by the current water restrictions (e.g. for risks unrelated to climate, such as unforeseen pipe bursts), supply system yield could be increased by lowering restriction triggers. This is estimated to be associated with low risk of reaching minimum operating levels due to climate variability, when demands are at that yield.
- It is not possible to assign a precise likelihood to the various yield estimates across different scenarios. This means that any risk-based decision making using these yields would be informed by qualitative rather than quantitative likelihoods for any given yield estimate.
- A broader range of climate change projections, such as all of the projections available from NARCliM 2.0 (or at least the range of those projections), would enhance the understanding of the likely timing of required actions at different levels of climate change risk.

7. References

Beatty, RJ (2009) *Water Demand and Wastewater Flow Trend Tracking and Climate Correction Using a Short Baseline Calibration Methodology*. Hydrology and Water Resources Symposium. Newcastle.

Department of Climate Change, Energy, the Environment and Water (the Department) (2022) *Water Modelling – Paleo Stochastic Climate Data – Murrumbidgee*. Available online at https://datasets.seed.nsw.gov.au/dataset/water-modelling-stochastic-climate-data-murrumbidgee

Department of Climate Change, Energy, the Environment and Water (the Department) (2024) *Draft Regional Water Strategy. Murrumbidgee: Shortlisted Actions – Consultation Paper*. May 2024.

Department of Planning and Environment (DPE Water) (2022a) *Guidance on strategic planning outcome – Understanding water security. Regulatory and assurance framework for local water utilities*. December 2022.

Department of Planning and Environment (DPE Water) (2022b) *Draft NSW Murray and Murrumbidgee Regional Water Strategies. Climate and Hydrological Modelling*. December 2022.

Department of Planning and Environment (DPE Water) (2022c) *Regulatory and assurance framework for local water utilities*. July 2022.

GHD (2022) *Yass Valley Water Source Strategy. Options Assessment and Strategy Report*. Prepared for Yass Valley Council. 18 October 2022.Rev 4.

HARC (2022) *Modelling Town Water Supply Security Using NSW RWS Climate Data. Project Report*. Final. 1 December 2022.

NSW Parliamentary Council (2020) *Water Sharing Plan for the Murrumbidgee Unregulated River Water Sources 2012*.

Public Works Advisory (2021a) *Sediment Accumulation Estimates*. Draft.

Public Works Advisory (2021b) Integrated Water Cycle Management Strategy. Draft Issues Paper. June 2021. Prepared for Yass Valley Council.

Yass Valley Council (YVC) (2019) *Yass Valley Settlement Strategy 2036*. August 2019 Version.

Yass Valley Council (YVC) (2012) *WS-POL-11 Water Supply Restrictions.* Date of Issue: 13 June 2012.

Yass Valley Council (YVC) (2020) *WS-POL-11 Water Supply Restrictions.* Approved: 25 March 2020.

Appendix A Additional information

This appendix presents additional information from Yass Valley Council, and the pre-treatment of that information (where required) by HARC, as referred to in the main text of the report.

A.1 Yass Dam inlet levels

Table 23 Yass Dam inlet levels

Valve	Label at Switchboard	Valve RL
IIV1	Actuator 1	498.526 m
IIV2	Actuator 2	496.026 m
IIV3	Actuator 3	493.526 m
IIV4	Actuator 4	491.026 m
SV1	Actuator 5	486.774 m

A.2 Yass Dam historical water levels

HARC received Yass water level data from Yass Valley Council (via the Department) in April 2023. This section outlines how the data has been treated for use in the daily time step Source model of the Yass water supply system and catchment, and the conclusions drawn from it for the purposes of subsequent Source model verification.

The data was provided covering two separate historical periods, from August 2014 to December 2018, and from January 2019 to April 2023. The data from these two time periods was merged by HARC into a single datafile.

The data was provided from two gauges, as a dam operational level (for water levels below spillway) and as a dam safety level (for water levels above spillway). HARC's focus for the study is on water supply reliability during periods of reservoir drawdown, not short-term surcharging of the dam above full supply level during high inflow periods. HARC also does not have a dam spillway/crest rating table for the dam. For these reasons, HARC has focussed on the dam operational level data, and only used the dam safety level data to visually verify some periods of reservoir drawdown in the operational level data, and to confirm when the water level was at or above the full supply level.

The data was provided on a sub-daily time step, with readings typically around every 30-40 minutes. This data was visually inspected for any potential anomalies. It was found that there were several periods of rapid drawdown of the storage, with ~7 metre drawdown (i.e. significantly emptying the storage) over the course of an hour or two. For the operational water level data, these periods are shown by the red circles in Figure 45. It was assumed that these periods of rapid drawdown are monitoring errors, as confirmed by Yass Valley Council. These six instances of rapid drawdown were re-set to full supply level. Similarly, any readings where the operational level data was above the full supply level, such as the value in early 2017 highlighted by the orange circle in Figure 45, were re-set to the full supply level.

The combined operational and dam safety water level data is shown in Figure 46 after removing any data anomalies and then converting each dataset to a mean daily water level value. For the purposes of this project, the focus is on periods of reservoir drawdown. After resetting any water level readings above the full supply level to the full supply level, and applying the reservoir rating table to convert the water levels to a volume in storage, the resulting historical volume in storage from 2014 to 2023 is shown in Figure 47.

Yass Valley Council (YVC) (K. Kugaprasatham, YVC pers. comm. 23/5/2023) confirmed that there was a significant drawdown event from November 2019 to February 2020, but that the magnitude of that drawdown was better estimated using the YVC's field measurements. YVC advised that none of the other two minor drawdown periods represented in the operational data were supported by the downstream river flow information, and it should therefore be assumed that the dam remained at its full supply level during these periods.

The field measurements showed that the water level in the dam dropped to a minimum level of 1.39m below the crest level on 7 February 2020, as shown in Figure 48. This corresponds to a volume in storage of 64% of the full supply volume.

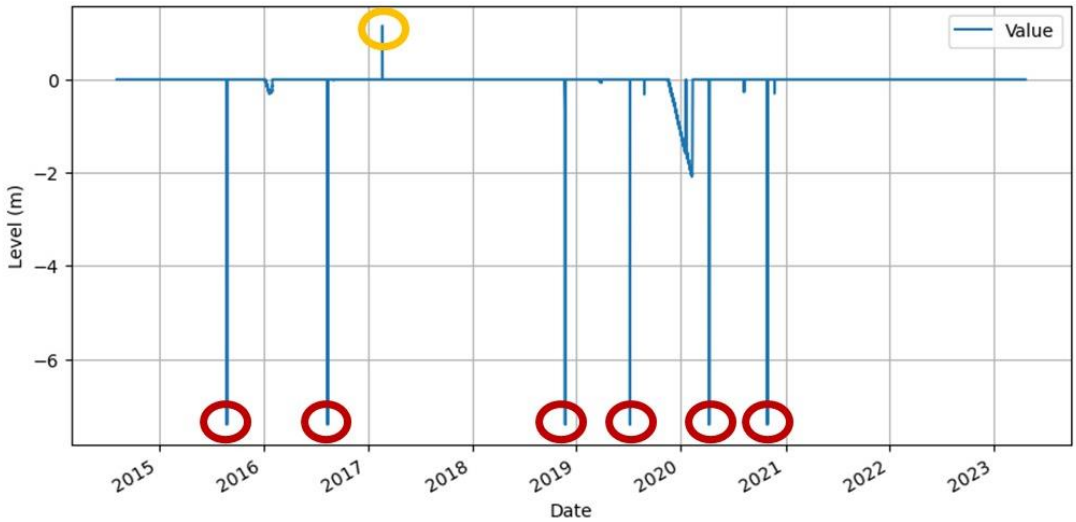


Figure 45 Raw sub-daily operational level data with assumed data anomalies circled in red and orange

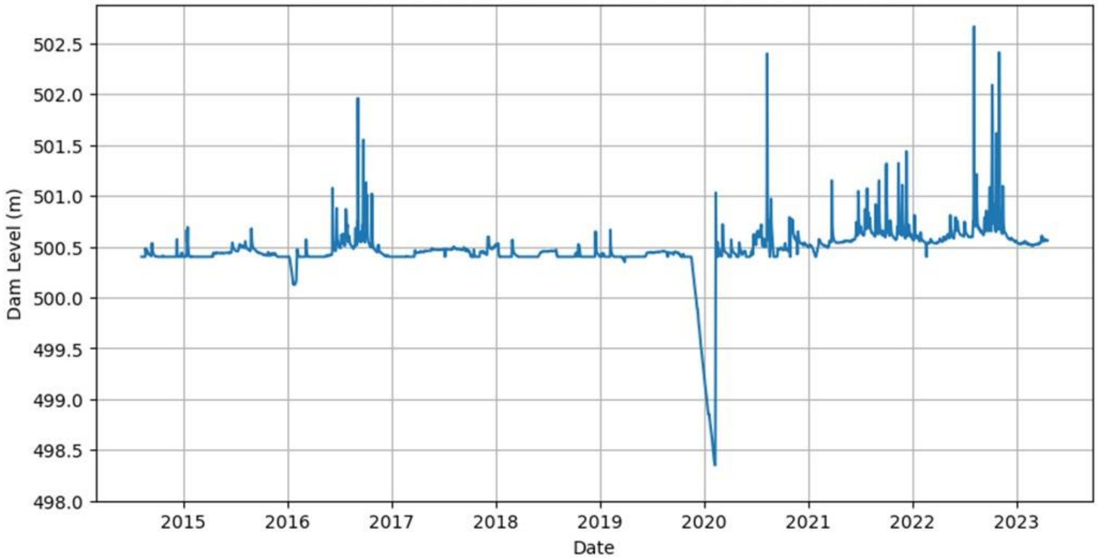


Figure 46 Raw mean daily operational and safety water level data after removing data anomalies

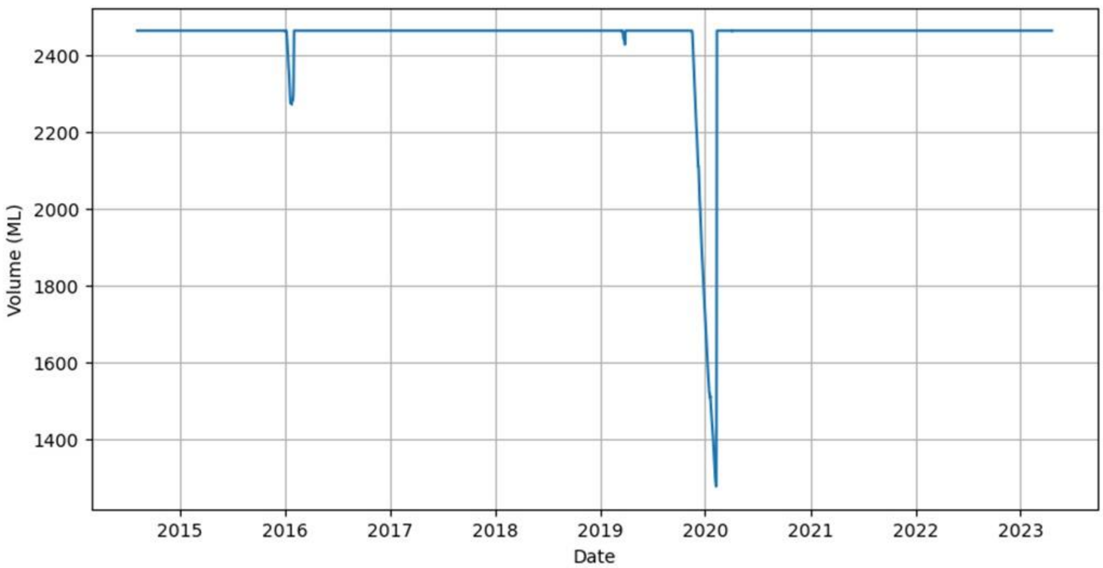


Figure 47 Monitored historical periods of reservoir drawdown in Yass Dam from sub-daily operational data

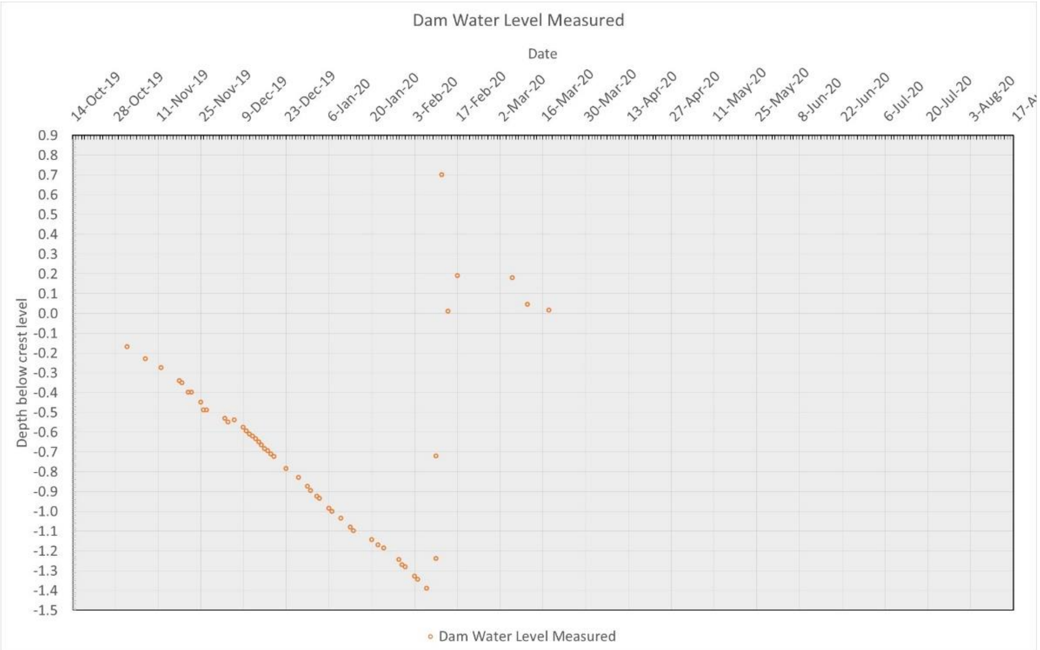


Figure 48 Monitored historical period of reservoir drawdown in Yass Dam from spot field measurements, October 2019 to August 2020

Yass Valley Council also provided dam water level readings over the Millennium Drought, as monthly spot readings from January 1998 to May 2006, and quarterly spot readings from May 2006 to October 2007. The full set of readings is presented in Figure 49. Storage bathymetry in the pre-dam upgrade period (prior to 2013) is shown in Table 24.

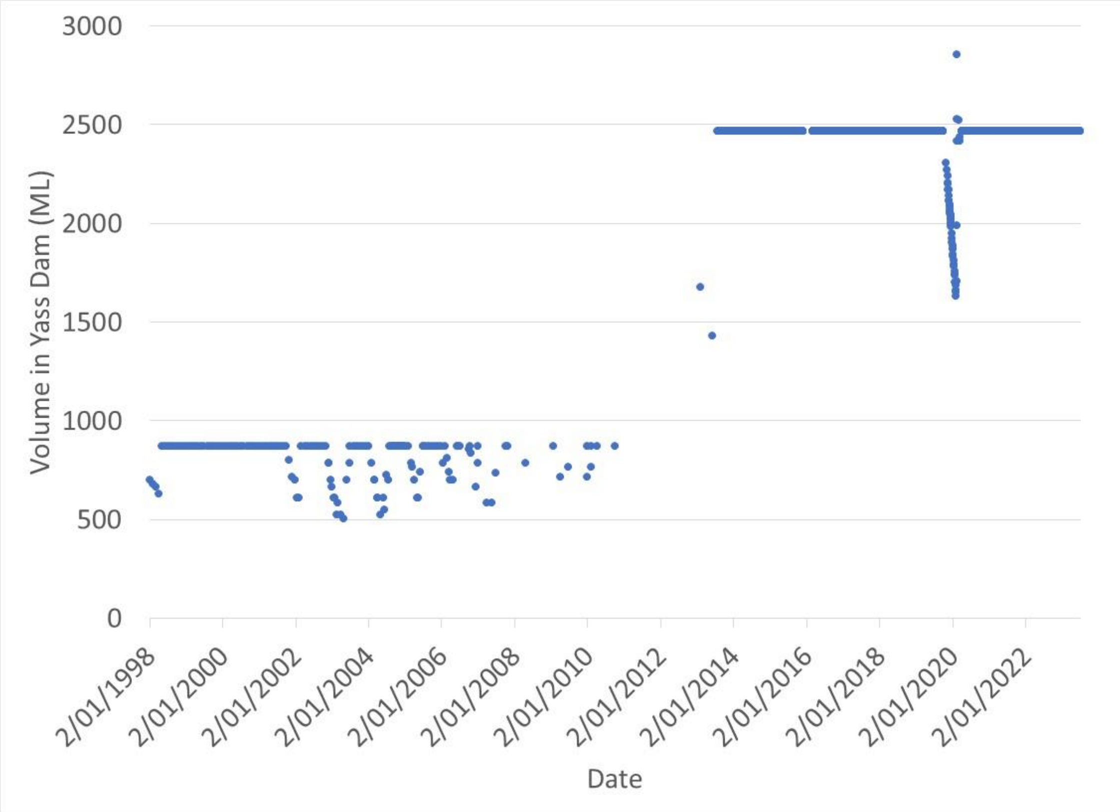


Figure 49 Available spot readings of the volume in Yass Dam

Table 24 Storage bathymetry prior to dam upgrade (Public Works Advisory, 2021a)

Water Depth	Storage Capacity m3	Surface Area m2
Zero	872 247	324 554
0.5	716 548	299 531
1.0	574 595	270 614
1.5	446 239	242 532
2.0	332 482	211 330
2.5	235 033	178 546
3.0	155 136	140 639
3.5	92 691	109 852
4.0	45 313	78 994
4.5	15 968	40 238
5.0	3 671	9 946
5.5	951	2 570
6.0	267	451
6.5	82	229
7.0	9	60

A.3 Rainfall-runoff model parameters

Rainfall-runoff model parameters for the headwater catchments are listed in Table 25 and for the residual catchments in Table 26.

Table 25 Rainfall-runoff model parameters for the headwater catchments (from Upper Murrumbidgee Source model)

Parameter	Catchment HW 410851	Catchment HW 410160
Area (km^2)	85.57005	9.9178
Rfsum	0.157492370906185*70233 + 0.464612491389916*70056 + 0.425899667956875*70232	1.09999982292999*70042
Lztwm (mm)	152.963702650129	76.3518558891716
Lzfpm (mm)	2.63817686403346	2.27143144751205
Lzfsm (mm)	11.5910633578414	77.3161073462429
Total Lower Storage (mm)		
Uztwm (mm)	23.9269662325832	47.7884933961453
Uzfwm (mm)	16.946736281238	15.0015364272415
Total Upper Storage (mm)		
uzk	0.251690011481833	0.36813450894103
Lzsk	0.334205604624649	0.0327298383272164
Lzpk	0.0251069176947313	0.00163781946058799
Impervious area:		
Adimp	0.026006838860684	0.149994946345392
Pctim	0.00012366926435726	0.00211091645929795
Infiltration:		
Rexp	5.12101862560986	5.99135643857977
Zperc	98.9824380269003	61.9271934368838
Pfree	0.0308215047376545	0.0145673841536367
Routing:		
Uh0	0.779601673998834	0.663314158982789
Uh1	0.220398326001166	0.336685841017211
Uh2	0	0
Uh3	0	0
Loss:		
Sarva	8.17260762646636E-05	0.000328778373874362
Side	7.05287213729282E-05	0.00148745058489743
Ssout	0.000941266988719185	0.0062861131880919

Table 26 Rainfall-runoff model parameters for the residual catchments (from Upper Murrumbidgee Source model)

Parameter	Catchment R13a	Catchment R13b	Catchment R13c	Catchment R13d	Catchment R13e
Area (km^2)	254.52	321.23	227.76	190.21	151.86
Lztwm (mm)	211.8126	135.7416	135.7416	135.7416	135.7416
Lzfpm (mm)	5.32629	18.2687	18.2687	18.2687	18.2687
Lzfsm (mm)	18.68213	68.63999	68.63999	68.63999	68.63999
Total Lower Storage (mm)					
Uztwm (mm)	23.98221	24.29899	24.29899	24.29899	24.29899
Uzfwm (mm)	20.15431	20.04431	20.04431	20.04431	20.04431
Total Upper Storage (mm)					
uzk	0.182776	0.737133	0.737133	0.737133	0.737133
Lzsk	0.123126	0.034257	0.034257	0.034257	0.034257
Lzpk	0.007542	0.001322	0.001322	0.001322	0.001322
Impervious area:					
Adimp	8.17E-05	0.000516	0.000516	0.000516	0.000516
Pctim	0.000309	0.006769	0.006769	0.006769	0.006769
Infiltration:					
Rexp	2.919448	3.048273	3.048273	3.048273	3.048273
Zperc	52.7862	189.9861	189.9861	189.9861	189.9861
Pfree	0.032245	0.016765	0.016765	0.016765	0.016765
Routing:					
Uh0	0.706095	0.192168	0.192168	0.192168	0.192168
Uh1	0.293905	0.807832	0.807832	0.807832	0.807832
Uh2	0	0	0	0	0
Uh3	0	0	0	0	0
Loss:					
Sarva	7.49E-06	9.64E-06	9.64E-06	9.64E-06	9.64E-06
Side	0.028061	0.000643	0.000643	0.000643	0.000643
Ssout	0.002997	0.00063	0.00063	0.00063	0.00063

Table 27 Rainfall-runoff model parameters for the residual catchments (from Upper Murrumbidgee Source model)

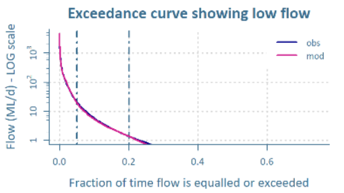
Catchment	Rainfall contribution (weighting and rainfall gauging station number)
13a	0.409471232522706*70030 + 0.394215443755358*70233 + 0.284693182971096*70042
13b	0.471614310333749*70255 + 0.379358639874551*70115 + 0.17018222447896*70042
13c	0.344737386625721*70091 + 0.680323589590516*70042
13d	0.462682835428134*70091 + 0.259781188531666*70042 + 0.363031055426585*70045
13e	1.08169742783802*70091

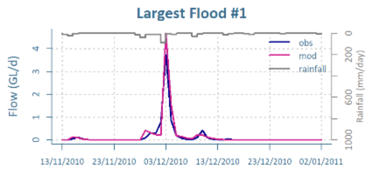
A.4 Rainfall-runoff model calibration

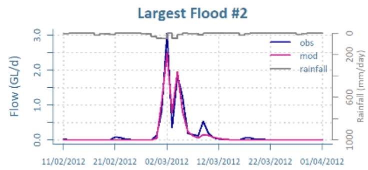
These are the rainfall-runoff model calibration goodness of fit information for the two headwater catchments, as determined by the Department. The Yass River above Macks Reef Road fits well to high flows as well, but the Williams Creek site does not fit as well to high flows, resulting in a lower overall Nash-Sutcliffe efficiency at that site. Both models exhibit an overall mass balance without significant bias, and display a good fit to low flow behaviour. For the purposes of estimating yield, low to moderate flows will be of most importance.

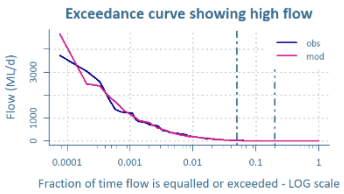
410851 Report Card

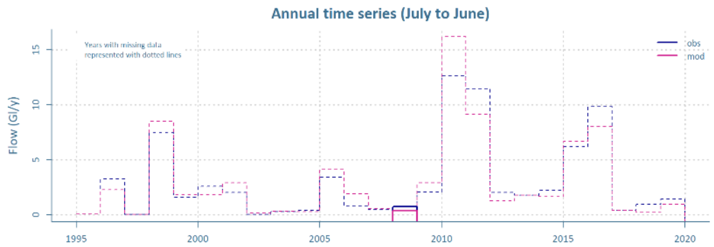
Period of analysis: 26/1/1996 to 29/4/2020
(observed flow is available for 89.2% of days in this period)











Univariate Statistic	Observed Flow	Modelled Flow Bias	Classification#
Total Flow Volume (ML)	73,983	0.4%	★★★★☆
Total Low Flow Volume (ML)*	1,079	7.0%	★★★☆☆
Total Medium Flow Volume (ML)*	6,615	-6.9%	★★★☆☆
Total High Flow Volume (ML)*	66,289	1.1%	★★★★☆
Mean Flow Volume (ML/d)	9	0.4%	★★★★☆
Driest 3 Year Mean (ML/d)	1	58.4%	★☆☆☆☆
Zero Flow Days (%)+	77.0%	0.6%^	★★★★☆
Standard Deviation (ML/d)	85	5.1%	★★★☆☆

Bivariate Statistic	Value	Classification#
Nash-Sutcliffe Efficiency(NSE)	0.82	★★★★☆
Non-matching Zero Flow Days	22.0%	★★★☆☆

Number of stars ranges from 1 (Very Poor) to 5 (Excellent)
* Low flow = flow in the 0.2 to 1 exceedance probability range
* Medium flow = flow in the 0.05 to 0.2 exceedance probability range
* High flow = flow in the 0 to 0.05 exceedance probability range
\+ Zero flow in this case refers to flow < 1ML/d
^ This is an absolute difference in percentage between observed and modelled

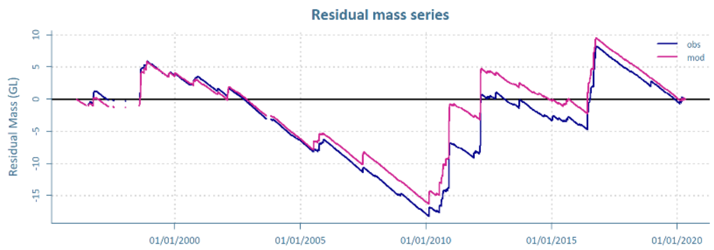
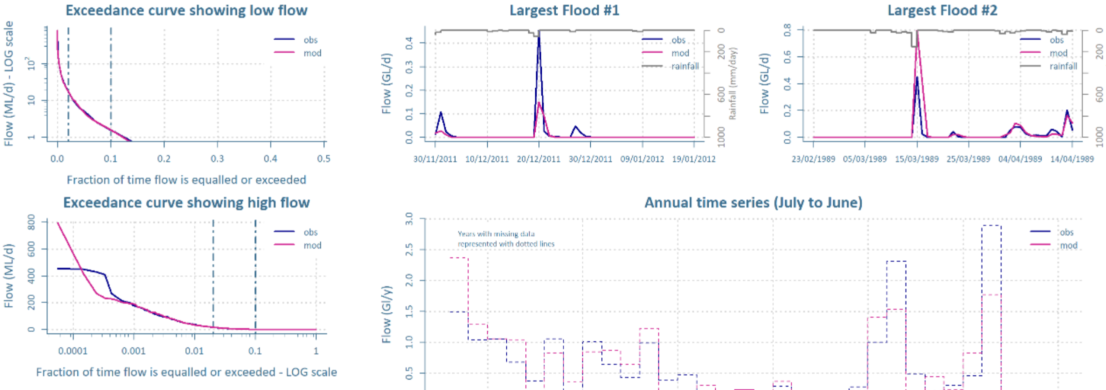


Figure 50 Rainfall-runoff model calibration for site 410851 Yass River above Macks Reef Road

410160 Report Card

Period of analysis: 3/2/1989 to 29/4/2020

(observed flow is available for 95.8% of days in this period)



Univariate Statistic	Observed Flow	Modelled Flow Bias	Classification#
Total Flow Volume (ML)	18,722	-0.2%	★★★★☆
Total Low Flow Volume (ML)*	949	-1.1%	★★★★☆
Total Medium Flow Volume (ML)*	4,471	1.2%	★★★★☆
Total High Flow Volume (ML)*	13,303	-0.5%	★★★★★
Mean Flow Volume (ML/d)	2	-0.2%	★★★★☆
Driest 3 Year Mean (ML/d)	0	11.8%	★★☆☆☆
Zero Flow Days (%)+	87.5%	0.2%^	★★★★☆
Standard Deviation (ML/d)	13	4.3%	★★★★☆

Bivariate Statistic	Value	Classification#
Nash-Sutcliffe Efficiency(NSE)	0.43	★★☆☆☆
Non-matching Zero Flow Days	25.8%	★★☆☆☆

Number of stars ranges from 1 (Very Poor) to 5 (Excellent)
* Low flow = flow in the 0.1 to 1 exceedance probability range
* Medium flow = flow in the 0.02 to 0.1 exceedance probability range
* High flow = flow in the 0 to 0.02 exceedance probability range
+ Zero flow in this case refers to flow < 1ML/d
^ This is an absolute difference in percentage between observed and modelled

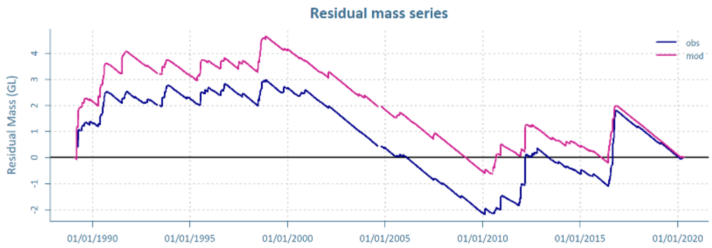
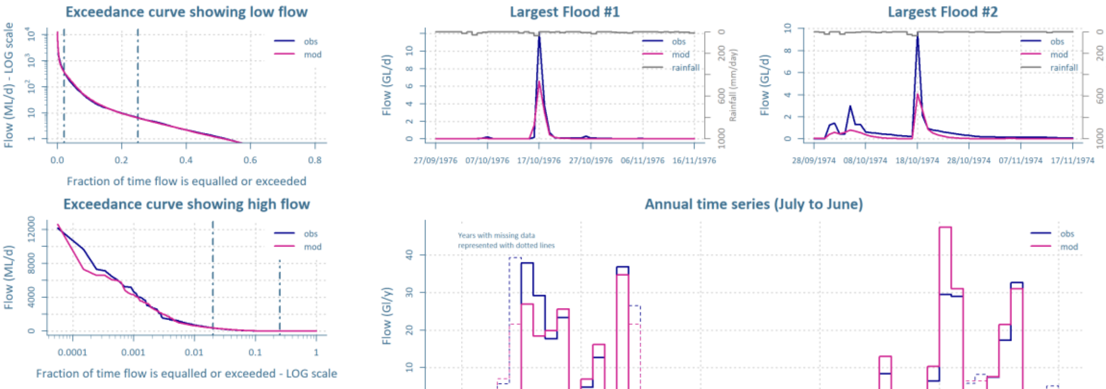


Figure 51 Rainfall-runoff model calibration for site 410160 Williams Creek at White Hill

410090 Report Card FORS model

Period of analysis: 3/1/1970 to 29/4/2020

(observed flow is available for 58.2% of days in this period)



Univariate Statistic	Observed Flow	Modelled Flow Bias	Classification#
Total Flow Volume (ML)	402,894	-0.7%	★★★★☆
Total Low Flow Volume (ML)*	9,218	-0.6%	★★★★★
Total Medium Flow Volume (ML)*	120,865	8.6%	★★★☆☆
Total High Flow Volume (ML)*	272,811	-4.8%	★★★★☆
Mean Flow Volume (ML/d)	38	-0.7%	★★★★☆
Driest 3 Year Mean (ML/d)	19	29.2%	★☆☆☆☆
Zero Flow Days (%)+	47.7%	0.5%^	★★★★☆
Standard Deviation (ML/d)	287	-4.9%	★★★★☆

Bivariate Statistic	Value	Classification#
Nash-Sutcliffe Efficiency(NSE)	0.63	★★★☆☆
Non-matching Zero Flow Days	24.9%	★★★☆☆

Number of stars ranges from 1 (Very Poor) to 5 (Excellent)
* Low flow = flow in the 0.25 to 1 exceedance probability range
* Medium flow = flow in the 0.02 to 0.25 exceedance probability range
* High flow = flow in the 0 to 0.02 exceedance probability range
+ Zero flow in this case refers to flow < 1ML/d
^ This is an absolute difference in percentage between observed and modelled

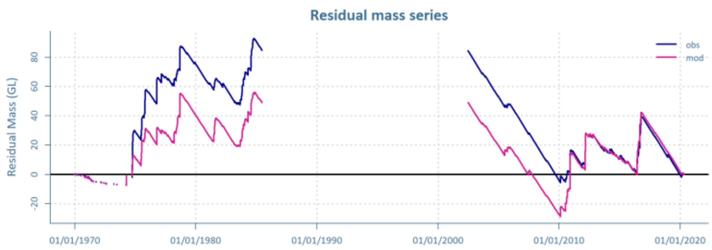
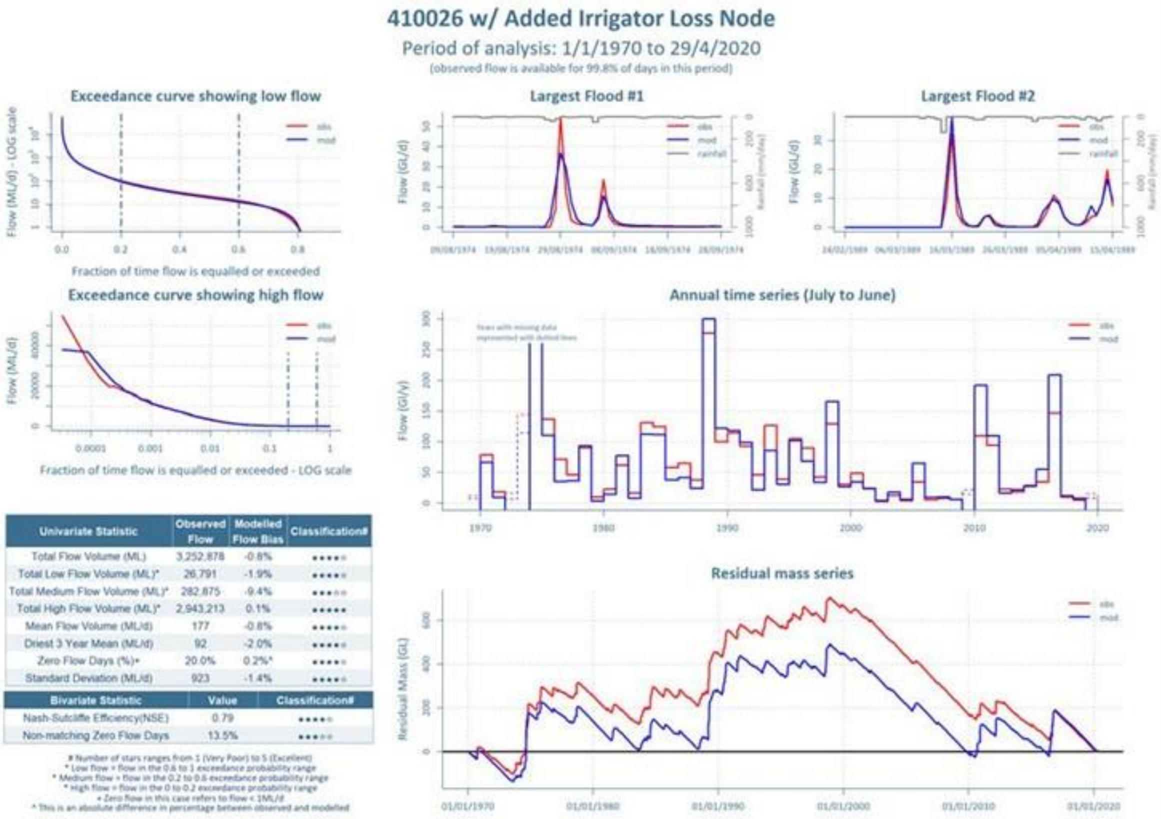


Figure 52 Rainfall-runoff model calibration for site 410090 Yass River at Gundaroo

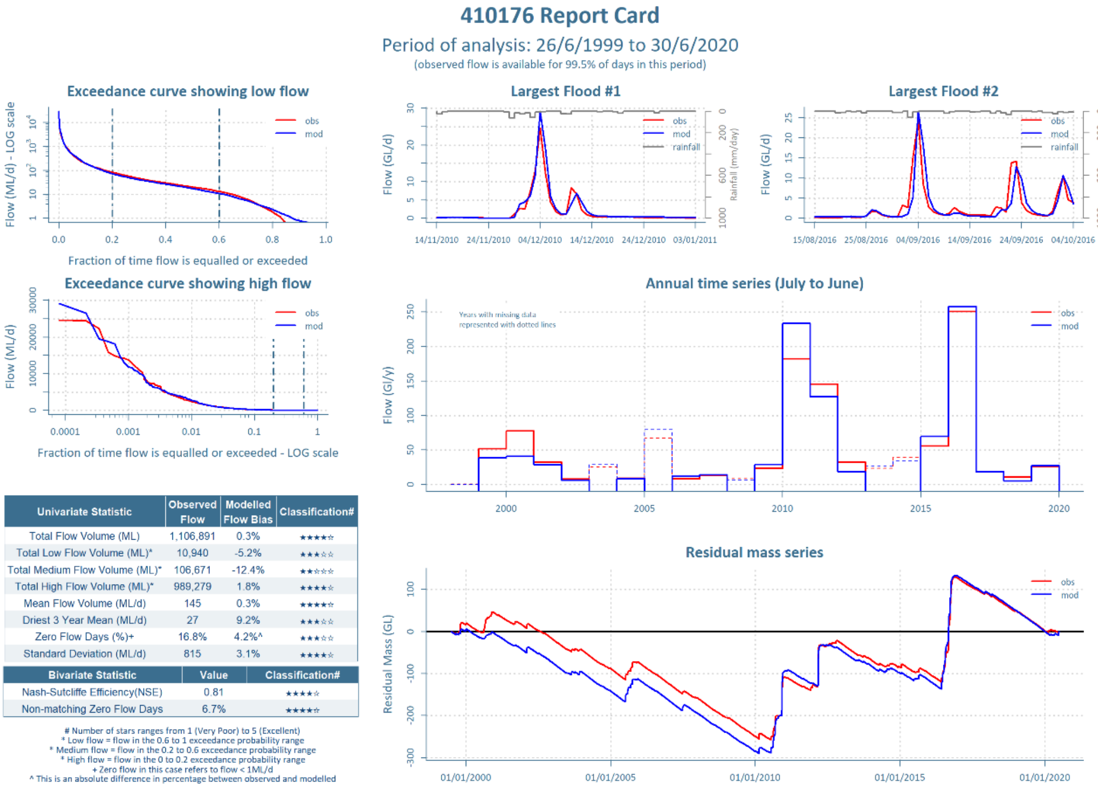


Univariate Statistic	Observed Flow	Modelled Flow Bias	Classification#
Total Flow Volume (ML)	3,252,878	-0.8%	●●●●○
Total Low Flow Volume (ML)*	26,791	-1.9%	●●●●○
Total Medium Flow Volume (ML)*	282,875	-9.4%	●●●○○
Total High Flow Volume (ML)*	2,943,213	0.1%	●●●●●
Mean Flow Volume (ML/d)	177	-0.8%	●●●●○
Driest 3 Year Mean (ML/d)	92	-2.0%	●●●●○
Zero Flow Days (%)+	20.0%	0.2%^	●●●●○
Standard Deviation (ML/d)	923	-1.4%	●●●●○

Bivariate Statistic	Value	Classification#
Nash-Sutcliffe Efficiency(NSE)	0.79	●●●●○
Non-matching Zero Flow Days	13.5%	●●●○○

Number of stars ranges from 1 (Very Poor) to 5 (Excellent)
* Low flow = flow in the 0.6 to 1 exceedance probability range
* Medium flow = flow in the 0.2 to 0.6 exceedance probability range
* High flow = flow in the 0 to 0.2 exceedance probability range
+ Zero flow in this case refers to flow < 1ML/d
^ This is an absolute difference in percentage between observed and modelled

Figure 53 Rainfall-runoff model calibration for site 410026 Yass River at Yass



Univariate Statistic	Observed Flow	Modelled Flow Bias	Classification#
Total Flow Volume (ML)	1,106,891	0.3%	★★★★☆
Total Low Flow Volume (ML)*	10,940	-5.2%	★★★☆☆
Total Medium Flow Volume (ML)*	106,671	-12.4%	★★☆☆☆
Total High Flow Volume (ML)*	989,279	1.8%	★★★★☆
Mean Flow Volume (ML/d)	145	0.3%	★★★★☆
Driest 3 Year Mean (ML/d)	27	9.2%	★★★☆☆
Zero Flow Days (%)+	16.8%	4.2%^	★★★☆☆
Standard Deviation (ML/d)	815	3.1%	★★★★☆

Bivariate Statistic	Value	Classification#
Nash-Sutcliffe Efficiency(NSE)	0.81	★★★★☆
Non-matching Zero Flow Days	6.7%	★★★★☆

Number of stars ranges from 1 (Very Poor) to 5 (Excellent)
* Low flow = flow in the 0.6 to 1 exceedance probability range
* Medium flow = flow in the 0.2 to 0.6 exceedance probability range
* High flow = flow in the 0 to 0.2 exceedance probability range
+ Zero flow in this case refers to flow < 1ML/d
^ This is an absolute difference in percentage between observed and modelled

Figure 54 Source model calibration for site 410176 Yass River upstream of Burrinjuck Dam

A.5 Yass River routing parameters

The routing parameters in Source, as developed by the Department, are presented in the following tables. All routing reaches use a relationship between flow and travel time over a given reach length with two divisions and an inflow bias of 1.

Table 28 Yass River from 410851 (Yass River at Above Macks Reef Road) to residual catchment 13a inflow (Reach length 16.330 km)

Inflow	Travel time (d)
0	0.8
0	0.79778
9.7	0.538883
52.2	0.430777
120.2	0.36759
350.5	0.293238
1100	0.218856
2453.5	0.172134
5352.3	0.132631
14606	0.140584
21300	0.118819
29000	0.106149

Table 29 Yass River from Gundaroo to residual catchment 13b inflow (Reach length 23.057 km)

Inflow	Travel time (d)
0	1.129553
0	1.126418
9.7	0.760871
52.2	0.608231
120.2	0.519015
350.5	0.414035
1100	0.309012
2453.5	0.243043
5352.3	0.187268
14606	0.198497
21300	0.167766
29000	0.149876

Table 30 Yass River from Williams Creek to residual catchment 13c inflow (Reach length 38.555 km)

Inflow	Travel time (d)
0	1.888794
0	1.883551
9.7	1.272298
52.2	1.01706
120.2	0.867876
350.5	0.692333
1100	0.516717
2453.5	0.406407
5352.3	0.313141
14606	0.331918
21300	0.280531
29000	0.250616

Table 31 Yass River from residual catchment 13d inflow to residual catchment 13e inflow (Reach length 15.55 km)

Inflow	Travel time (d)
0	0.761788
0	0.759674
9.7	0.513143
52.2	0.410201
120.2	0.350032
350.5	0.279232
1100	0.208402
2453.5	0.163912
5352.3	0.126296
14606	0.133869
21300	0.113144
29000	0.101078

A.6 Considerations for the Department's guidance for understanding water security

As a result of undertaking this case study, the Department can consider whether to update its guidance for understanding water security. This is a non-urgent priority. The additional advice that could be included in the guidance is to:

a) Clarify at Step 3 in the guidance that there is value in plotting both the cumulative deviation from mean rainfall conditions across all replicates, as well as cumulative deviation from mean rainfall conditions within each replicate.

b) Provide advice on stochastic modelling approaches for more complex supply systems, where model run times using a daily time step model are much higher. These include optimisation, more powerful computers, replicate thinning, and a hybrid daily/monthly time step modelling framework.

c) At Step 5, also record the criterion within the level of service objectives that limits yield for each replicate, and the minimum volume in storage reached, which were helpful for identifying why yields were different for different scenarios and across different replicates.

The reference historic climate information used to derive the stochastic data spanned the period 1 January 1880 to 31 December 2018. Data preparation in central and northern NSW also incorporated paleoclimate knowledge over the last 500 years about the persistence of the Interdecadal Pacific Oscillation (IPO), a known driver of rainfall variability in those regions. The observed climate since 2018 will not have been considered in the derivation of the Department's stochastic climate datasets, the calibration of its rainfall-runoff models, or the calibration of its water resource models. With respect to rainfall, which is the main driver of water security for local water utilities with climate-dependent water sources, most of the rainfall information collected since 2018 will fall within the range of observed variability in the 1880-2018 period upon which these models have been based. However, if a drought has occurred since 2018 that is locally more severe than that over the preceding 1880-2018 period, then that drought will not be represented in the derivation of the Department's stochastic datasets and will not have been considered in the Department's rainfall-runoff model and water resource model calibrations. If this is the case then local water utilities should:

- Characterise the nature of the more recent drought in terms of its duration and severity, relative to droughts over the 1880-2018 period, to confirm its uniqueness historically; and
- Check the characteristics of the more recent drought, relative to droughts represented within the stochastic data, to identify whether similar droughts are already represented within the stochastic datasets or not.

Local water utilities can use the Regional Water Strategy models and instrumental and paleo-stochastic streamflow sequences to assess water security for towns. It is important to consider the suitability of these models and datasets for this application given the primary purpose of these models and datasets is to support regional water planning rather than water security planning for town water supplies. Several adverse situations can potentially arise:

1. The Department's paleo-stochastic climate data, whilst accurate at the time it was derived, has since become biased because the climate data collected since 2018 includes unique or substantially different climate behaviour to that collected up to 2018.
2. The Department's rainfall-runoff models or water resource models, from which the historic and paleo-stochastic streamflow data were derived, do not perform well in verification tests since 2018 because the climate data collected since 2018 includes unique or substantially different climate behaviour to that collected up to 2018.
3. The Department's rainfall-runoff models or water resource models, from which the historic and paleo-stochastic streamflow data were derived, do not perform well in verification tests at a local catchment scale (as opposed to performance at a regional scale), including but not limited to the period since 2018.

In the above situations, the local water utility can consider the benefits of continuing to make use of the existing stochastic data, and the Department's calibrated rainfall-runoff and water resource models, or whether alternative approaches could be required, as described below:

- To address Point 1 above, the local water utility could bias-correct the paleo stochastic climate sequences, to better reflect the change in observed reference climate data relative to the reference data used to train the stochastic model. This can be a technically complex task with many different bias-correction techniques available, and the potential to inadvertently introduce other biases at different time scales. Alternatively, the Department could re-derive its paleo-stochastic data after incorporating the more recent climate data into the reference dataset used to train the stochastic model. Re-deriving the paleo-stochastic data is also a technically complex task; or
- To address Points 2 & 3 above, the local water utility could re-calibrate the rainfall-runoff model and water resource model to provide updated streamflow data to the current year. This is a relatively simple task for headwater catchments, but can be technically more complex for downstream locations with inflows derived by reach balances. Alternatively the Department, at the request of the local water utility, could re-calibrate the rainfall-runoff and water resource models to include the 2018-2020 drought and any subsequent droughts, as well as considering any additional local information that might support model calibration (e.g. monitoring by the local water utility that was not available at the time the RWS models were calibrated). The Department would then provide updated models and/or instrumental streamflow sequences.

A.7 Study findings from the first hypothetical case study (HARC, 2022)

The first hypothetical case study (HARC, 2022) explored the potential use of the Department's Regional Water Strategy paleo-stochastic datasets to assess water security for town water supplies. It utilised a supply system in northern NSW whose climate, inflow, and infrastructure characteristics were adjusted to create a "hypothetical" case study that was not directly linked to any particular supply system. The outcomes of the first hypothetical case study were used to develop the step-by-step "how-to" guidance for using these datasets in Appendix A of the Department's Water Security Guidance. The study findings were:

1. This study demonstrated how the Department's Regional Water Strategy stochastic data can be used to better understand uncertainty in yield estimates for water supply systems. It

highlighted the potential for supply system yield to be much lower or much higher than estimated using the historic climate record alone. This potentially provides local water utilities with greater insights about their water supply system risks in the context of a broader understanding of climate variability. In our case study, when applying the x/y/z approach, yield determined using the stochastic data ranged from 27% lower to 40% higher than yield estimated using the historic climate record only. This is illustrated in Figure E-1, with the yield distribution in this figure based on 76 climate and streamflow replicates of 130 years in length, for direct comparison against the supply system yield over the 130 year period using the recorded historic climate information.

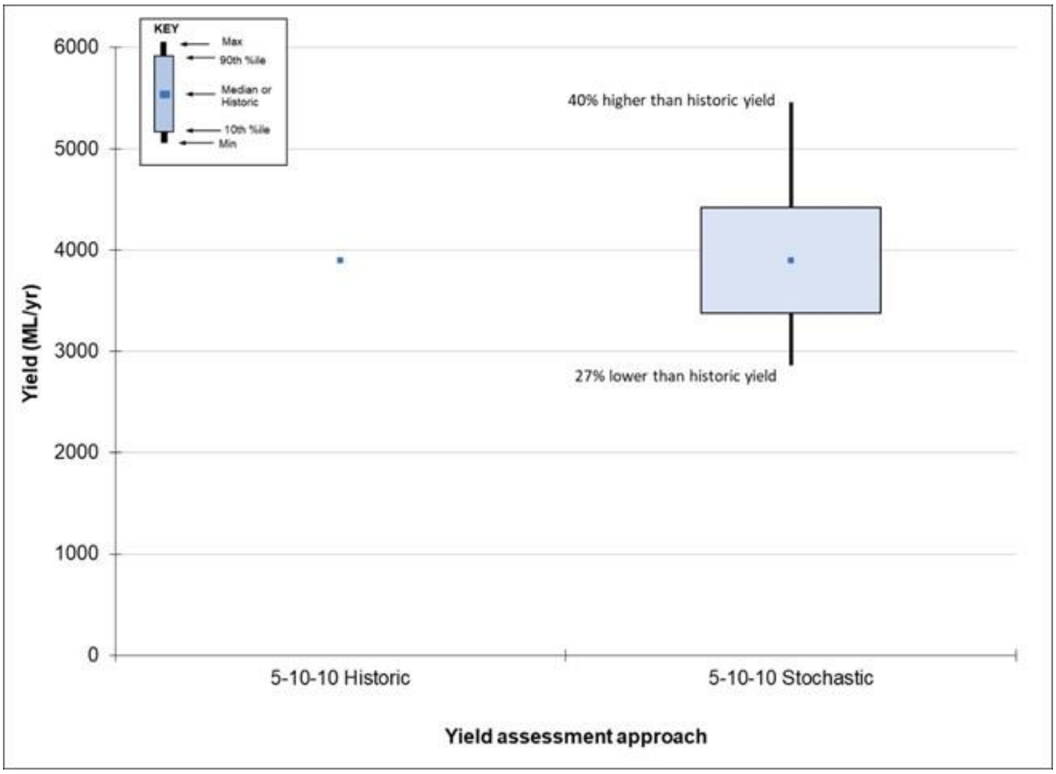


Figure 55 Distribution of yields (max, min, 90th, 10th percentile and median) from the 76 stochastic replicates using the x/y/z approach (with 5/10/10 design rule from the x/y/z approach) relative to the instrumental (historic) yield estimate

2. Slicing the stochastic data into replicates of length equal to the historic instrumental record (130 years) allowed direct comparison of yields from the stochastic data with that from the historic record. This allows uncertainty around the historic yield estimate to be quantified. Whilst not tested in the case study, slicing the data into 130 year replicates (as opposed to shorter replicates) reduces the likelihood of splitting extreme droughts across two replicates. Splitting extreme droughts could result in the over-estimation of yield in those droughts.
3. Whilst a 10,000 year daily time step stochastic dataset can be modelled as a single replicate in the Source modelling software, it requires a higher level of computer memory and takes much longer to run than shorter (130 year) replicates of the same total 10,000 year length. This is because running shorter replicates can take advantage of parallel computing (using multiple CPU cores) to shorten total run time, and because less output data needs to be stored in memory at any given time over the model run(s). Monthly time step modelling can overcome this shortcoming, where this longer time step does not

compromise modelling outcomes (e.g. for supply system with multiple years of storage capacity relative to demand).

4. The spread of yield results was sensitive to the replicate length, with the distribution of yield compressed when using 500 year replicates relative to 130 year replicates. This was due to the setting of restriction triggers unique for each replicate based on storage drawdown frequency and duration over 130 year periods relative to 500 year periods.
5. Application of the stochastic data is dependent upon having a robust rainfall-runoff model of each inflow to the supply system. This is because the Department's stochastic datasets prepared for the regional water strategies are available for rainfall, but not for streamflows. The accuracy of any calibrated rainfall-runoff model, particularly any biases in the model calibration (or in the data over the model calibration period), becomes an important factor when considering the uncertainty in yield estimates that rely upon those rainfall-runoff models. Utilising a rainfall-runoff model is also essential for most climate change impact assessments for surface water supply systems.
6. Optimising restriction triggers for each stochastic replicate, which assumes perfect knowledge of future climate conditions, resulted in a higher yield than when adopting a fixed restriction trigger across all replicates. The lower yield distribution resulting from adopting the same restriction trigger across all climate replicates is considered by HARC to better reflect the yield which a local water utility could expect in practice in the absence of perfect knowledge of what climate conditions (wet or dry) will unfold over the coming years. Setting restriction triggers should ideally be informed not only by yield analysis considerations, but also by the likely time available for customers to respond to different restriction levels, and the lead time required to implement contingency supply measures and/or the next supply system augmentation.
7. The stochastic data was readily adjusted to estimate yield under projected climate change. One NARCliM1.0 climate change projection (averaged across three regional climate model outputs) for the period 2060-2079 was used to test the ability to estimate yield under climate change as part of the case study for this project, with average monthly adjustments made to input climate datasets. Whilst not tested, the same approach could readily be applied to estimate future "secure yield" with the stochastic data for the x/y/z approach.
8. The stochastic data could readily be applied to alternative supply system configurations associated with supply system augmentations or changes in operating rules. Whilst not specifically tested in the case study, in principle, yield analysis will follow an identical process with alternative supply system configurations. The only technical issue to resolve in this case is the potential adjustment of restriction triggers and/or storage buffers, where those triggers and buffers have been designed to provide for a given duration of supply, as part of lead time considerations for implementing contingency or augmentation supply measures.
9. Utilising stochastic data requires additional skills and processing time. This includes a requirement to use scripts to automate the yield analysis for the stochastic replicates. At the current time, the feature in eWater's Source modelling platform to run stochastic replicates without external scripts cannot reliably be used. The additional model run time for a simple model run (with two inflows, one storage, one demand) on a daily time step was in the order of 0.5 to 2 days on a standalone desktop computer, but could increase for more complex supply systems. For more complex supply systems, monthly time step modelling could be

required, as is currently done when utilising stochastic data for yield analysis of many major urban water supply systems (e.g., Sydney, Newcastle).

10. There is a trade-off between the level of effort to use the stochastic data and the benefit derived from its use. This benefit is likely to be greatest in supply systems at risk of breaching performance criteria under historic (instrumental record) climate conditions, and where the consequences of breaching those performance criteria are high. This will particularly be the case for larger towns with limited or no access to contingency supply measures, and uncertain lead times for future supply system augmentation. There may be little benefit in undertaking yield analysis using stochastic data for very secure supply systems with available contingency supply measures and low consequences associated with breaching performance criteria.
11. The representation of storage buffers was the main source of difference in yield estimates when comparing yields using the x/y/z approach relative to the “alternative”) approach. Buffers represent water set aside in storage for unforeseen events, including droughts worse than modelled, and to allow sufficient time to implement contingency supply measures or augmentations. In the x/y/z approach, the storage buffer is implicit in the method (i.e., it is an outcome of applying the method), whereas in the alternative approach it is explicitly defined as an input to the method.
12. Other differences in demand and restriction policy assumptions between the x/y/z approach and the alternative approach resulted in differences in yield that were much smaller than the representation of buffer storages. The case study demonstrated that the x/y/z approach, with an assumed 10% demand reduction under restrictions, can over- or under-estimate yield where anticipated demand reductions differ from 10%, such as at different stages of restriction (mild vs severe). A flat 10% demand reduction will likely over-estimate demand reduction under mild restrictions (and under-estimate storage drawdown) and likely under-estimate demand reduction under severe restrictions. Reductions in total demand will also vary across supply systems for regional towns, depending on the extent to which they have non-restrictable major industrial water users.

These findings are informed by a single hypothetical case study with a relatively simple supply system configuration. Whilst the findings are considered by HARC to be applicable to a wide range of supply systems, further applications would be required to definitively confirm this.

A.8 Additional Millennium Drought datasets

Two additional datasets were available or created over the Millennium Drought to provide additional information about inflows to Yass dam for the purposes of verifying Yass Source model behaviour over the Millennium Drought. These were:

- The sum of gauged flows in Murrumbateman Creek and the Yass River at Buckmaster Bridge (sites YSC001 and YSC002 respectively) from 2006 to 2008
- Back-calculated monthly inflows to Yass Dam, using the spot monthly water level readings, the demand model estimates of historical water consumption (monthly historical water use at that time was not available), an assumed 1 ML/day passing flow when the dam was drawn down below its full supply level, and net evaporation on the storage.

For the back-calculated monthly inflows to Yass Dam, spills and releases are not recorded, and therefore were set to an assumed 1 ML/day when the historical volume in storage was less than the full supply volume, and set equal to the recorded flow at gauge 410026, located 2 km downstream of the dam, when Yass Dam was historically at its full supply volume. This estimate of spills and releases ignores any stormwater inflows or rural diversions between the dam and the gauge 2 km further downstream.

The volume in storage has been recorded as monthly or quarterly spot readings. The back-calculated inflows were therefore limited to being generated on a monthly or quarterly time step, and cannot be reliably estimated on a daily time step. After examining the results, the back-calculated inflows were constrained to the period where monthly spot readings were available, because the value of quarterly inflows for model calibration purposes is limited.

Recorded historical water use from Yass Dam is also not available in the pre-dam upgrade period, so the historical demands in this period were estimated using HARC's demand model and historical population, as described previously. Assumed demand reductions for Yass (previously estimated in Section 2.5) under historical restriction periods were applied to the modelled unrestricted demands, noting that demand reductions may have been different historically to what is currently assumed.

The back-calculated inflows could not be adequately verified against the observed data in Yass River and Murrumbateman Creek (sites YSC001 and YSC002 respectively) because the monthly spot readings used to back-calculate the inflows ceased in July 2006, and the gauged data at these two sites only commenced in mid-June 2006. Where there was one single month of overlapping data, in July 2006, the gauged inflows (460 ML/month) were more similar to the back-calculated inflows (440 ML/month) than the modelled inflows (750 ML/month), again suggesting that the modelled inflows are over-estimated, albeit with limited data to definitively confirm this.