ARMIDALE WATER SUPPLY

Yield Studies (2020-2025)
Final Report

Prepared for NSW Public Works on behalf of Armidale Regional Council

Report No. 24007
December 2025
NSW Urban Water Services Pty Ltd

Summary

This report provides a summary of the Yield Modelling undertaken by NSW Urban Water Services (NUWS) from 2020 to 2025. The Yield modelling was undertaken progressively as the results provided input into the process of developing a strategy to provide appropriate water supply security for Armidale to meet their future water supply demand. The iterative process of assessing different options was such that the Yield modelling was reported in a series of comprehensive Progress Reports. This report consolidates all the Progress Reports together into a single document.

The Yield modelling essentially provided *Secure Yield* estimates of Armidale's water supply headworks and proposed augmentation options. The *Secure Yield* estimates were estimated in accordance with DPIE Water/NSW Office of Water's[1] draft guidelines *"Assuring future urban water security, Assessment and Adaption guidelines for NSW local water utilities"* ("*2013 Guidelines*") (Ref 1).

It is noted '*secure yield'* is a defined term (see section 1.7) based on accepted methodology.

Subsequent to completion of much of the *Secure Yield* modelling, the Department of Planning and Environment's (DPE)[1] under their Regulatory and Assurance Framework (RAF) for Local Water Utilities released their December 2022 "*Guidance on strategic planning outcome - Understanding water security" (the "Water Security Guidance")* (Ref 2).

It is noted the secure yield methodology used meets the *Water Security Guidance* albeit with using NARCLiM data for assessing the impacts of climate change on the *Secure Yield*. However to satisfy the *Water Security Guidance* the historic climate secure yield estimates are recommended to be adjusted for climate change informed by the NARCLiM climate change data rather than the previously recommended SEACI climate change data (*which allowed for 1^0C climate warming from 1990*). The *Water Security Guidance* also suggests the 10,000 years of daily stochastic hydroclimate data that were used by DPE for their Regional Water Strategies could be used.

Using the NARCLiM1.5 data and the 10,000 years of hydroclimate data were tested on nominated options however for these cases they gave similar or higher Secure Yield estimates than using the *2013 Guidelines.* Thus it was considered the results obtained using the *2013 Guidelines* should still be used for assessing the options. *It appeared that the historic observed behaviour resulted in a more severe drought for 2017/2020 than from using the 10,000 years of daily stochastic data.*

1. *NSW Office of Water (NOW) roles migrated to NSW Department of Planning and Environment (DPE) and its predecessors during the period 2017-2021.Subsequently the DPE was absorbed into the new Department of Climate Change, Energy, the Environment and Water (DCCEEW)*

Numerous options as requested were modelled including:

- Raising of Malpas Dam.
- Additional sources from different catchments independent of the Gara River including the Styx River, Aberfoyle River, St Helena Creek and Chandler River.
- Oaky Dam (*on Oaky River, independent of the Gara River*) as a standalone system.
- Oaky Dam operating conjunctively with Malpas Dam.

The main Secure Yield findngs taken by NSWPW from this yield study in terms of assessing preferred options are summarised in Table S1. Table S2 provides the findings for Oaky Dam as a standalone scheme.

It is noted the secure yield estimates are dependent on the operating rules, data and assumptions as discussed in detail in this Report.

Table S1: Findings Summary

CLIMATE	YIELD RULE	EXISTING plus RAISE MALPAS DAM by 6.5m		EXISTING plus OAKY DAM STORAGE 2.78GL (No reverse transfer)		EXISTING plus RAISE MALPAS DAM by 6.5m plus OAKY DAM STORAGE 2.73 GL with 37.8 ML/d transfer+reverse transfer	
		SECURE YIELD* ML/a	Reference Progress Report & Run No	SECURE YIELD* ML/a	Reference Progress Report & Run No	SECURE YIELD* ML/a	Reference Progress Report & Run No
Historic	5/10/10	**4,868**	PR 16 (*20/01/2025*) Run 392	**7,521**	PR 14 (*26/03/2024*) Run 300	**10,893**	PR 12 (9/06/2023) Run 267
2013 Guidelines *Climate Change*	5/10/10	**3,650**	PR 16 (*20/01/2025*) Run 392CC	**6,248**	PR 14 (*26/03/2024*) Run 300CC	**9,077**	PR 12 (9/06/2023) Run 267CC
NARCLiM1.5 RCP8.5	5/10/10					**8,837**	PR 16 (*20/01/2025*) Case 2,Table 10.
10,0000 Years Daily Stochastic	5/10/10					**13,268**	PR 16 (*20/01/2025*) Run 388
10,000 Years Daily Stochastic perturbed for Climate Change	5/10/10					**11,240**	PR 16 (*20/01/2025*) Run 391

***** *Secure Yield includes supplying 755 ML/a to Guyra from Guyra Dams with any shortfall supplied from Malpas Dam.*

Table S2: Oaky Dam Standalone System Findings Summary

CLIMATE	YIELD RULE	OAKY DAM STORAGE 2.78 GL With 25 ML/d transfer	
		SECURE YIELD ML/a	Reference Progress Report & Run No
Historic	5/10/10	**3,425**	PR 11 (7/06/2023) Run 251r
2013 Guidelines *Climate Change*	5/10/10	**3,217**	PR 11 (7/06/2023) Run 251r
10,0000 Years Daily Stochastic	5/10/10	**3,613**	PR 11 (7/06/2023) Run 258
10,000 Years Daily Stochastic perturbed for Climate Change	5/10/10	**3,394**	PR 11 (7/06/2023) Run 258CC

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1. Introduction

1.1 Background

Armidale Regional Council (ARC) were undertaking strategy studies to develop options to meet their future water supply needs. As part of these studies *Secure Yield* assessments were required for their existing water supply headworks and proposed options.

Armidale's existing water supply headworks consists of three storages:

- Malpas Dam: Located on the Gara River, a tributary of Macleay River. This is the main water supply source and has a storage of about 12000 ML.
- Puddledock Dam: Located on Puddledock Creek and has a storage of about 700 ML.
- Guyra Dam: Located on the Gara River upstream of Malpas Dam, and consists of two connected dams, No.1 (immediately downstream of No 2) and No.2 (immediately upstream of No.1). Their combined storage is about 460 ML. The storage primarily provides water supply for the township Guyra.

Armidale has two other headworks storages that are not currently used for town water supply:

- Gara Dam: Located on the Gara River, downstream of Malpas Dam .and has a storage of about 200 ML.
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- Dumaresq Dam: Located on Dumaresq Creek and has a storage of about 400 ML.

Both Puddledock Dam and Dumaresq Dam are not part of the Gara River catchment that drains into Malpas Dam.

1.2 Scope of Work

Armidale Regional Council engaged NSW Public Works (NSWPW) to undertake the strategy studies and NSW Public Works engaged NSW Urban Water Services (NUWS) to essentially:

- Establish the Secure Yield of the existing water supply headworks system.
- Estimate the Secure Yield of nominated options towards meeting future water supply needs.

It is noted the details of the scope of work evolved as the results informed the strategy development which then led to further options and scenarios to be considered towards developing preferred augmentation options.

At the time of the proposed studies and study commencement the Secure Yield estimation were required to follow DPE-Water/NSW Office of Water[2] (NOW) guidelines *"Assuring future urban water security - Assessment and adaption guidelines for NSW local water utilities"* (Ref 1)(*"2013 Guidelines"*).

2. *NSW Office of Water (NOW) roles migrated to NSW Department of Planning and Environment (DPE) and its predecessors during the period 2017-2021.Subsequently the DPE was absorbed into the new Department of Climate Change, Energy, the Environment and Water (DCCEEW).*

Part way through the study, DCCEEW released their December 2022 ñ*Guidance on Strategic planning outcome - Understanding water security"*. (Ref 2) (ñ*Water Security Guidance")*.

It is noted the *Water Security Guidance* document provides suggested but not mandatory alternative approaches for assessing yield. One suggested approach essentially includes the previous recommended approach in the *2013 Guidelines* however with an implicit intention that climate change be addressed using the now available updated climate change data.

It is noted *Secure Yield* is a defined term as provided by *Best-Practice Management of Water Supply and Sewerage Guidelines* (Ref 3) and the *NSW Water Supply Investigation Manual* (Ref 4) and more recently by the NOW Draft ñ*Assuring future urban water security, Assessment and Adaption guidelines for NSW local water utilities*ò (Ref 1).

Use of Secure Yield provides a practical consistent basis for assessing the yield of a system on a security of supply basis. Details of the basis of Secure Yield are provided in Section 1.7.

1.3 Objectives

This report contains a summary of the modelling undertaken from 2020 to 2025 by NUWS to provide secure yield estimates for specified operating and streamflow conditions for Armidaleøs Water Supply Headworks system and for nominated augmentation options.

The outcomes from this modelling were required to assist NSW Public Works to develop options to meet Armidaleøs future water supply demand.

1.4 Methodology

Estimating the yield of a headworks system involves two important stages:

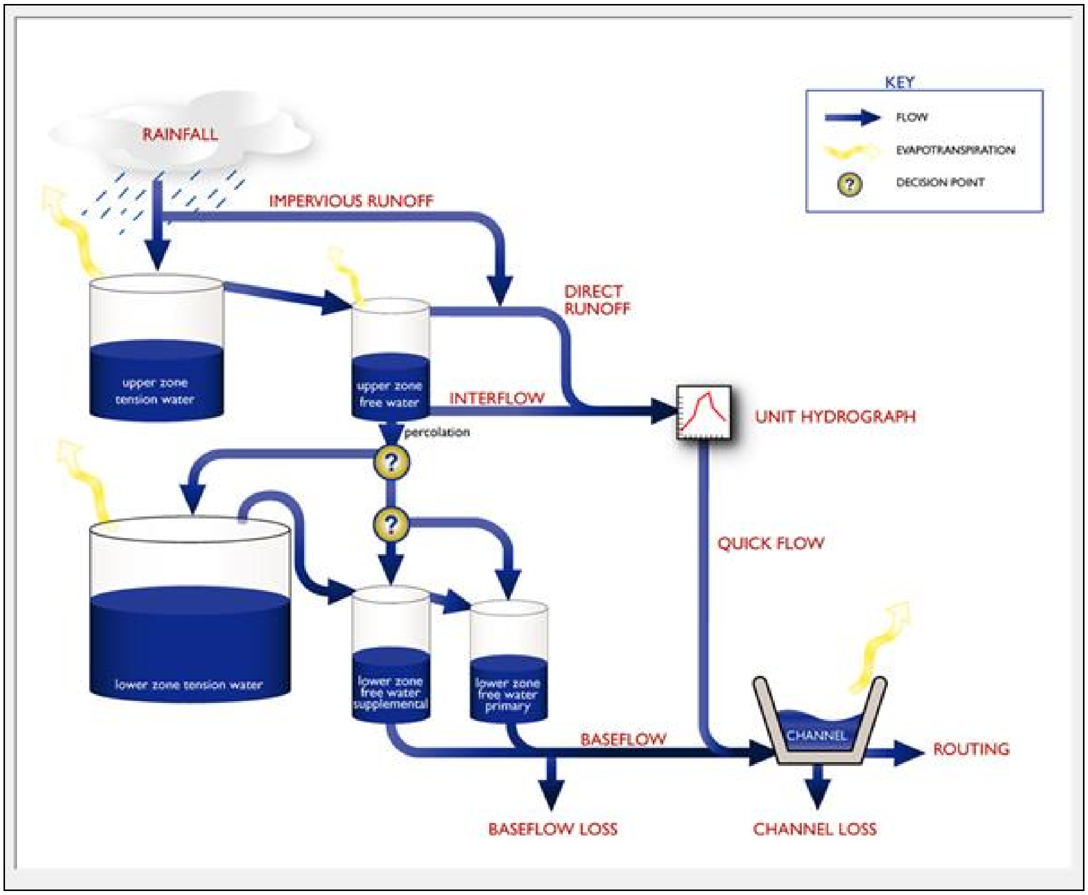
- Streamflow estimation:

  Developing an appropriate sequence of streamflows

- System Behaviour Modelling:

  Modelling the behaviour of the headworks system subject to operating constraints using the streamflows to assess what demand subject to reliability or security criteria can be satisfied.

For this study, the required streamflows were obtained using the Sacramento rainfall runoff model (Ref 5). Figure 1 provides a schematic of the rainfall runoff model.



Source Reference 6

Figure 1: Sacramento Model Schematic

Details of the rainfall runoff model calibration for the different catchments modelled are provided in the Progress Reports (See Appendix B)

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For the behaviour modelling the purposely developed system behaviour model to determine yield in terms of ósecure yieldô for the headworks systems was used. The underlying methodology used in the model arises from the definition of *Secure Yield* and has been successfully used on many other water supply headworks systems. The model logic has been developed and tested through many uses over the years. A schematic of the model is provided in Figure 2.

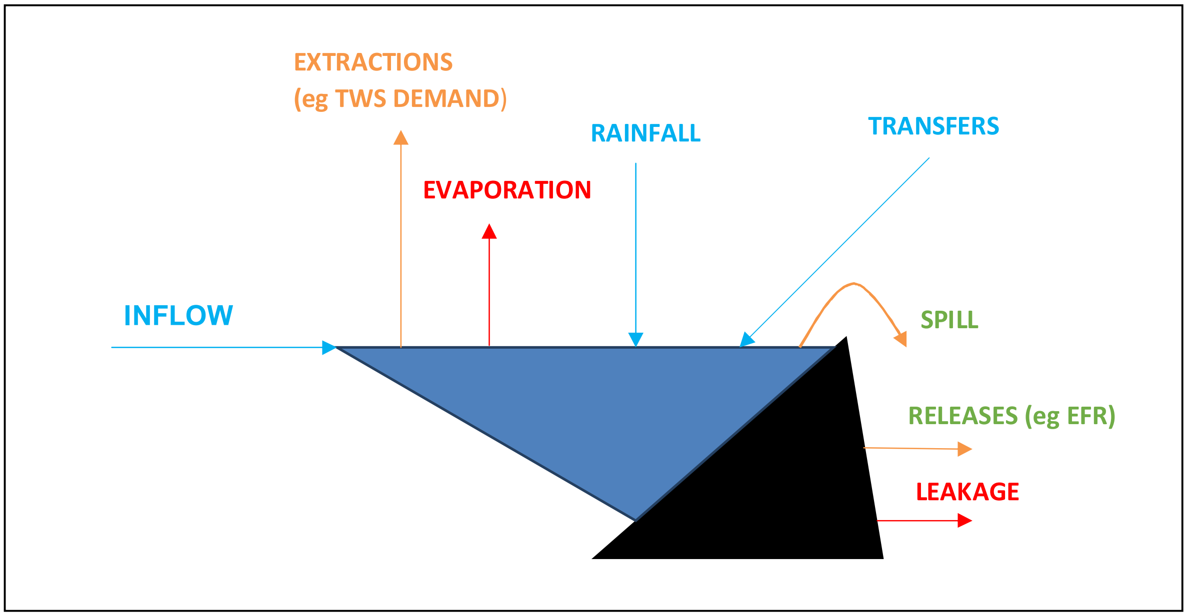


Figure 2: Storage Behaviour Model Schematic

1.5 Climate Change

While secure yield allows for meeting demand with restrictions through a much worse drought than has occurred since about 1890, consideration needs to be given to possible changes from Climate Change.

For most of the modelling the approach in the *2013 Guidelines* to allow for Climate Change was used. Use of NARCLiM data as recommended by the Water Security Guidance was also tested. The proposed approach adopted so as to make use of the latest available NARCLiM data is shown in Figure 3. The figure also compares it with the approach provided in the previous NSW Office of Waterȇs (NOW) Guidelines (Ref 1).

During the study the latest available NARCLiM data for the required variables was NARCLiM1.5 which was a later development to the NARCLiM1.0 data used for the NSW Regional Water Strategy Studies. Climate Change data are continually evolving. While some NARCLiM2.0 data were available towards the end of the study, the specific daily evapotranspiration data required for the rainfall runoff modelling were not available.

The six NARCLiM1.5 climate models for which daily rainfall and evapotranspiration were available and thus used were:

1. **ACCESS1.0_R1**
2. **ACCESS 1.0 _R2**
3. **ACCESS 1.3_R1**
4. **ACCESS1.3_R2**
5. **CanESM2_R1**
6. **CaseESM2_ R2**

The six NARCLiM1.5 data series used to obtain the required flow series were provided by NSW Public Works. The data was based on RCP8.5 emissions scenario. It is noted some argue RCP4.5 may be too optimistic while others argue RCP8.5 may be too pessimistic. Thus for future planning purposes at the time it was assumed appropriate to use RCP8.5.

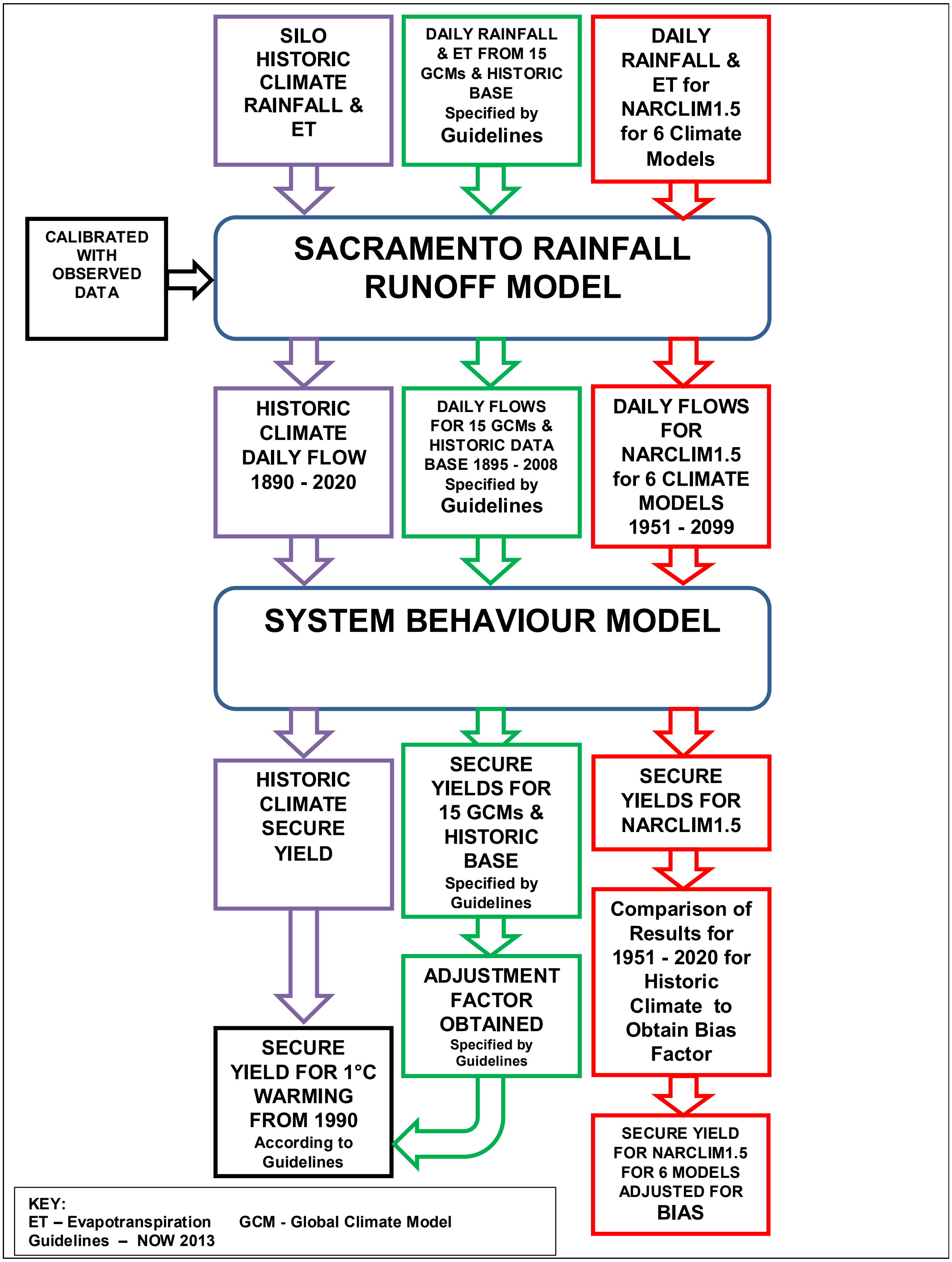
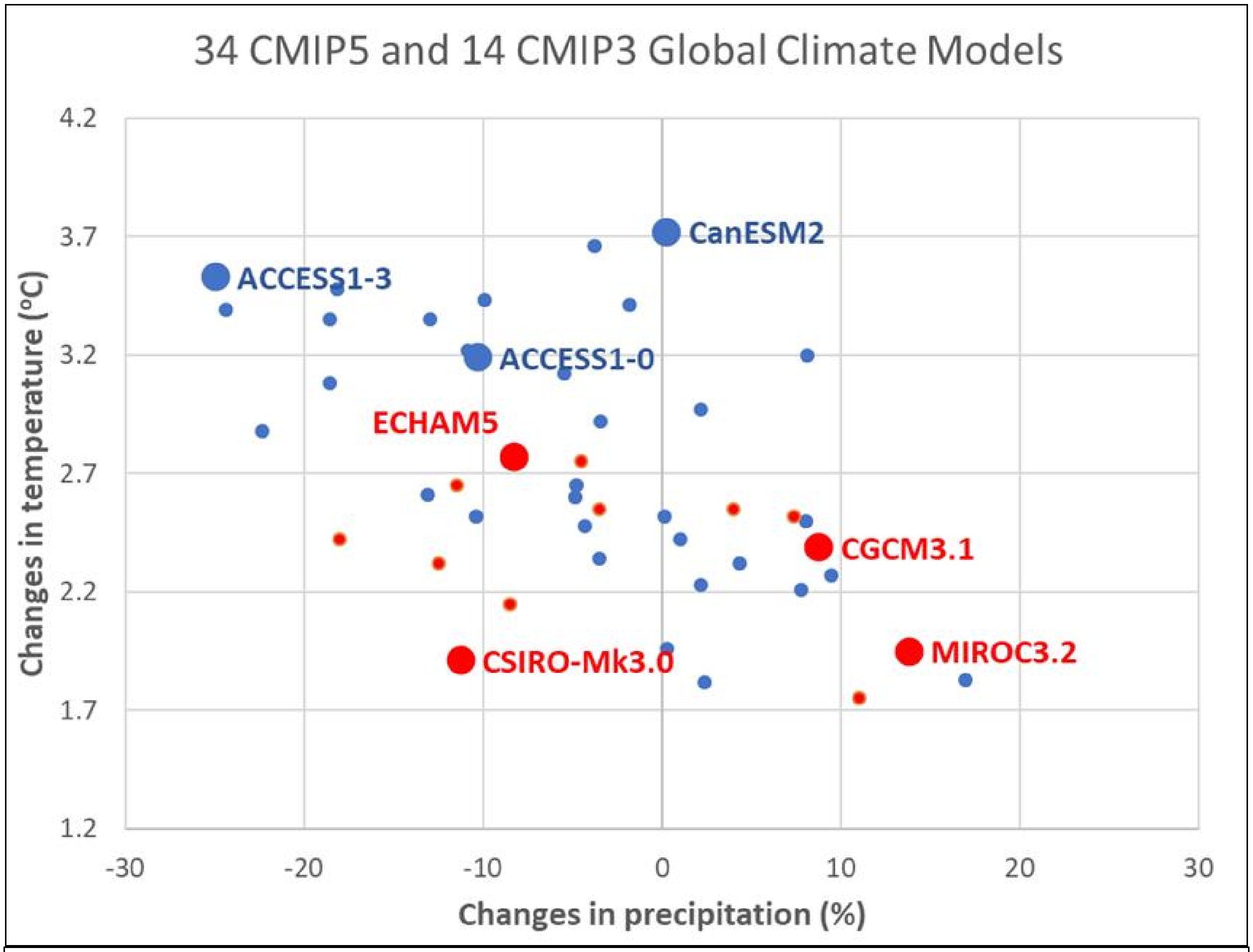


Figure 3: Modelling Process Flow Chart

The following provides a comparison of findings from using NARCLiM1.0 and NARCLiM1.5 with numerous climate models. It can be seen the nominated NARCLiM1.5 models tend to be the models that give the higher increase in temperature change (*and thus higher evapotranspiration*) and the larger reduction in rainfall and thus would provide meaningful sensitivity analysis.



Scatter plot of future change (differences between 2060ï 2079 and 1990ï 2009) in rainfall and temperature over the land part of the NARCliM domain (*ie South East Australia*) for 34 Coupled Model Inter-comparison Project Phase 5 (CMIP5) (blue) and 14 CMIP3 (red) Global climate models (GCMs) that passed the performance test. Larger dots represent the three GCMs selected for N1.5 (blue) and the four GCMs selected for N1.0 (red).

Source:

Nishant, N., Evans J.P., Di Virgilio G, Downes S. M., Ji F., Cheung K.K.W, Tam E., Miller J., Beyer K & Riley M.L. (2021, ñIntroducing NARCliM1.5: evaluating the performance of regional climate projections for southeast Australia for 1950-2100ò, Earths Future. 9, e2020EF001833. https://doi.org/10.1029/2020EF001833

1.6 Qualifications

The work contained in this Report (*and the included Progress Reports*) was undertaken in accordance with instructions and the scope of work as agreed with NSW Public Works and Council.

Caution should be exercised if aspects of this report, including data and estimates, are abstracted out of context or are to be used for some other purpose. Hydrology is not an exact science and necessarily involves uncertainty and the results should be regarded as estimates within the limitations of the study and available data to be used as indications in a much larger decision making process.

The yield of a headworks system is dependent on the modelled streamflows and system operating constraints. For this study key hydroclimate data and the operating constraints were provided by others.

NSW Urban Water Services Pty Ltd (NUWS) does not warrant or accept any liability in relation to the quality or accuracy of the yield estimates which are reliant on provided information and in particular provided modelled data and no responsibility is accepted by NSW Urban Water Services Pty Ltd for the accuracy, currency, reliability and correctness of any information in this publication provided by the client or third parties.

It is noted that the approach used to develop the required hydrometeorological data series was designed to be commensurate with determining *Secure Yield* (which is a defined term) for feasibility purposes for this Study and thus may not necessarily be appropriate for other models or purposes.

1.7 Yield Model

Secure Yield

For about the past 40 years most urban water supply headworks in country NSW have been sized on a robust Security of Supply basis. This security of supply basis was developed to cost-effectively provide sufficient dam storage capacity to allow the water utility to effectively manage its water supply in future droughts of greater severity than experienced over the past 100 or more years. ó*Secure Yield*ô is the water demand that can be expected to be supplied with only moderate restrictions during a significantly more severe drought than has been experienced since about 1895 (from when generally reliable rainfall records are available). The required water restrictions must not be too severe, not too frequent, nor of excessive duration. It has been argued that the definition of *Secure Yield* in effect allows meeting demand with moderate restrictions through a severe water supply drought akin to a ó1 in 1000 yearô drought[3].

3. *It is noted that ‘1 in 1000 year drought’ does not mean it only occurs once every thousand years but means it has a 0.1% probability of occurring any year.*

Under the NSW Security of Supply basis (previously commonly referred to as the '5/10/20 rule'), water supply headworks system were normally sized so that:

a) Duration of restrictions does not exceed 5% of the time; and

b) Frequency of restrictions does not exceed 10% of years (ie 1 year in 10 on average)

c) Severity of restrictions does not exceed 20%. Systems must be able to meet 80% of the unrestricted water demand (ie 20% average reduction in consumption due to water restrictions) through a repetition of the worst recorded drought, commencing with the storage drawn down to the level at which restrictions need to be imposed to satisfy a) and b) above.

It is noted the importance of this draw down condition has often been overlooked or misunderstood. The drawdown allows demand to be met in worse droughts than have occurred in the last 130 years or so.

'Secure Yield' was defined as the highest annual water demand that can be supplied from a water supply headworks system while meeting the above '5/10/20' rule.

Over the last 30 years there has been a significant reduction in residential water consumption per property and thus it was considered it would be difficult to achieve a 20% reduction in consumption as implied by the earlier '5/10/20' rule . Consequently NSW Office of Water (NOW) recommended that future planning should be based on a 10% reduction in consumption through a repetition of the worst drought commencing with the storage already drawn down to satisfy the 5% duration and 10% frequency criteria. Thus the '5/10/20' rule became a '5/10/10' rule.

It is also noted that more recently the 10% frequency rule was slightly refined by NOW from frequency of restrictions occurring 1 in 10 years on average to only being applied in 10% of years. For a sample of test cases this was of little consequence, and was desired to fit in with NOWs requirements for Performance Reporting of restrictions and thus was also based on the financial year.

The procedures to determine secure yield are illustrated in Appendix A.

Climate Change

While secure yield allows for meeting demand with restrictions through a much worse drought than has occurred since about 1890, consideration was also given to possible changes from Climate Change. Details of how such consideration was employed was previously provided in NSW Office of Water's (NOW) Draft Guidelines (Ref 1). It involved using climate change data from 15 global climate models (GCMs) projected for ~2030 and were obtained by Vaze et al (Ref 7) by scaling the historical 1894-2008 daily rainfall and evapotranspiration data using the methods detailed in Chiew et al, 2008 (Ref 8). Of note it allowed for 1^{o}C warming from 1990.

The new *Water Security Guidance* suggests using NARCLiM projections but provides little guidance on how to use the data. Figure 3 details the approach developed and proposed by NUWS for using the NARCLiM climate change data. The approach was designed to be comparable to the previous approach.

Model

Essentially the model is a computer program that balances continuity equations between all the water sources and demands while incorporating the procedures (as illustrated in Figures 1 and 2 of Appendix A) to determine secure yield. The model simulates the behaviour of the system by accounting for and balancing the available water. The hydrological cycle is modelled external to the model and the required hydrometeorological data is provided as input to the system behaviour model. In essence the system model is driven by operating conditions such as the need to meet a particular demand while satisfying constraints and available flow.

2. Hydrometeorological Data

2.1 Introduction

In general estimates of daily rainfalls, streamflows and daily evaporation and evapotranspiration for as long a historical period as possible is desirable.

Satisfying the ó5,10,10ô rule for determining secure yield requires more than 100 years of daily streamflows to be a sufficiently long data sample for testing the rules and so as to include the significant Federation drought (1895-1902) and other known significant droughts.

In addition to daily streamflows, accompanying daily rainfalls and evaporation are required for input to the system behaviour model for determining the net loss or gain from or to storageõs water surface area due to evaporation or rainfall.

The daily rainfalls are also required as input to the Sacramento rainfall runoff model as well as daily evapotranspiration to obtain streamflows when no observed streamflows are available.

Details of the Sacramento rainfall runoff model are provided in Ref 5 and illustrated in Figure 1.

2.2 Meteorological Data

The daily rainfall and daily evapotranspiration data were obtained from the SILO Data Drill for the grid points covering the different catchments. The SILO Data Drill is a service provided by the Science Delivery Division of Queenland Department of Science, Information Technology, Innovation and the Arts (DSITIA). The Data Drill accesses grids of data derived from interpolation of point Bureau of Meteorology station records. Interpolations are calculated by Splinning and Kriging techniques. Further details of the processes are given in Ref 9. The SILO grid points were selected to areally represent the rainfall over the modelled catchments and for which the NARCLiM1.5 data were available.

Daily lake evaporation data were only also obtained from the SILO Data Drill for use in estimating losses from storage water surface area.

2.3 Streamflow Data

The key input for determining *secure yield* is a historic daily inflow sequence going back to about 1890 to cover all observed significant droughts particularly the Federation drought. Thus historic daily inflow sequences had to be developed from rainfall runoff modelling for the different sources considered.

For the Malpas system yield modelling the inflow series developed for the 2016 study were extended by using the post 2016 study observed gauging station and operational data adjusted for differences in catchment area . (See Progress Reports 1 &,2 Appendix B)

To obtain the required historic inflow series for the new catchments under consideration Sacramento rainfall runoff models were set up for the catchments under consideration. The models were calibrated using the SILO data and observed flows at various gauging stations. Details of the calibrations are provided in Progress Reports 5,10 &11 (See Appendix B).

Towards the end of the modelling it was requested that the 10,000 years of daily stochastic hydroclimate data and the NARCLiM1.5 data should be trialled for the Malpas system. In order to do this Sacramento rainfall runoff models were be set up and calibrated for the Malpas Dam catchment. The subarea rainfall runoff models were linked using the SOURCE model (Ref 10).

3. System Behaviour Modelling

3.1 Introduction

Modelling of the behaviour of the water supply headworks system is required to determine the *secure yield* of that system. The aim of the modelling is to determine the maximum annual demand that satisfies the ó5/10/10ô rules. This is done using a computer system storage behaviour model using an iterative process to satisfy all the requirements implied by the rules and available water from the various sources.

The model is essentially driven by operating conditions such as the need to meet a specified demand whilst satisfying constraints such as available water from streamflows.

In addition to the hydrometeorological data that has to be input into the computer simulation model, other data had to be incorporated into the model. These additional data are detailed in the respective Progress Reports and are briefly described in the following sections.

3.2 Headworks System

Represntation of the headworks system in terms of storages and how their water is sourced and how transfers can occur.

3.3 Demand Pattern

Secure yield provides the system annual demand that can be met, the annual demand needs to be broken down into monthly patterns to reflect seasonality and if the storage is relatively small relative to the annual demand, the pattern may be then broken down into a daily pattern.

It is NUWS experience that generally the secure yield is not that sensitive to the monthly demand pattern as long as seasonality is shown by the differentials. It generally only becomes an issue when the available storage is relatively small compared to demand.

3.4 Storages

Storage data are required. Storage area volume data are input to the system model so it can model the evaporation losses (or rainfall gain). Gross storage as well as dead storage is input to the model as well dam leakage.

3.5 Operating Rules

Operating rules of the system are input into the model including transfer rules and release rules.

4. Modelling Results

4.1 Introduction

The secure yield estimates determined from the behaviour modelling for the requested specified cases are presented in the Progress Report.

Secure Yield determination is based on a defined methodology (see Section 1.7) and uses historic climate data and allows for supply to be met through a much more severe drought than has occurred in the last 130 years or so. Results presented are based on historic climate but also adjustments were made to these results to allow for projected climate change scenarios using the approach outlined in Section 1.5 and described in the respective Progress Reports (see Appendix B).

Some cases were also modelled using 10,000 years daily flow series developed from the 10,000 years of daily stochastic hydroclimate data with and without perturbation for climate change.

While secure yield is reliant on the available streamflows, it is also dependent on transfer capacities, environmental flow conditions, annual demands and their monthly distribution, level of security expected and the schemes operating rules. The conditions considered have been described in Chapter 3 and are detailed in the respective Progress Reports (See Appendix B).

The expected level of security arises from the 5/10/10 rules which provides for 10% restrictions occurring in 10% of the years for 5% of the time.

4.2 Chronology

The yield modelling results for the numerous (*over 300*) cases modelled are provided in the sixteen Progress Reports given in Appendix B.

It is noted the secure yield estimates are dependent on the operating rules, data and assumptions as discussed in the Progress Reports.

Table 4.1 provides a *Chronology* summarising the modelling undertaken as well as relevant events and key results that influenced NSWPW what modelling was to be undertaken towards developing preferred options.

Table 4.1: Modelling and Related Events Chronology

DATE	AGENT	DOCUMENT OR EVENT	AIM/CONTENTS	KEY RESULTS USED TO INFORM NEXT STAGE
June 2016	*WREMA*	Estimation of Secure Yield of Armidale Dumaresq Water Supply Dams Final Report (Ref 11)	Update secure yield estimates and assess the potential impact of building a pipeline from Malpas Dam to Guyra to provide supplementary water during droughts	Scenario 3.5 - Armidale supply from Malpas, Puddledock and Gara Dams. Puddledock and Gara only utilised during restrictions. Environmental flow release in accordance with Water Sharing Plan. Guyra takes water from Guyra dams only. Historical Climate Secure Yield 5,980 ML/year Climate change Secure Yield 2,951 ML/year
July 2016	*WREMA*	Estimation of Secure Yield of Armidale Dumaresq Water Supply Dams Supplementary Report (Ref 12)	Alternative yield estimate, utilising a different approach that incorporates stochastic hydrology	
July 2019	*NSWPW*	Armidale Regional Council Integrated Water Cycle Management Strategy Issues Paper (final draft)	2018 and forecast dry year extraction for Armidale and Guyra Assessment of adequacy of secure yield	Armidale 2018 extraction 3,400 ML/year 2048 extraction 5,066 ML/year Guyra 2018 extraction 589 ML/year 2043 extraction 712 ML/year Combined 2018 extraction 3,989 ML/year 2048 extraction 5,778 ML/year Climate change secure yield severely deficient for current demands
Early 2020	*Council/NSWPW*	IWCM Gap Analysis proposal accepted	Assess work undertaken for completeness and compliance with IWCM and other guidelines in-place at the time.	
30/3/2020	**NUWS**	Armidale Yield Study: Progress Report (1)	Initial review of the WREMA modelling approach Initial modelling using the 2013 guidelines	Secure yield without climate change from Guyra and Malpas Dams estimated at 3,277 ML/year without climate change

DATE	AGENT	DOCUMENT OR EVENT	AIM/CONTENTS	KEY RESULTS USED TO INFORM NEXT STAGE
26/5/2020	**NUWS**	Armidale Yield Study: Progress Report (2)	Undertake lake water balancing and extend flow series to May 2020	Secure yield without climate change using Guyra Dams, Malpas Dam, Puddledock Dam and Gara Weir estimated at 4,495 ML/year without climate change
15/5/2020	*NSWPW*	Malpas Dam Raising Options Assessment Interim Report		Dam originally designed with an option for a 6.5 m raising though the installation of gates Gates not recommended due to maintenance required and risk of mechanical failure Current storage volume 12,500 ML Options developed for raising Malpas Dam full supply level by either 3 m (19,000 ML storage) or 6.49 m (33,000 ML storage)
August 2020	*NSWPW*	Identification of additional water sources and dam sites commences		
18/9/2020	**NUWS**	Armidale Yield Study: Progress Report (3)	Assess impact of Climate Change on secure yield using SEACI data Assess impact of changing the environmental flow release rules Assess impact of raising Malpas Dam 3 m on system secure yield	Secure yield for Guyra+Malpas+Puddledock with environmental flow releases when water level above 55% (6,746 ML) without climate change 3,604 ML/year Secure yield for Guyra+Malpas+Puddledock with environmental flow releases when water level above 55% (6,746 ML) and climate change 2,427.5 ML/year (insufficient for current needs) If Malpas Dam is raised by 3m and the environmental flow release is required when storage is above 6,746 ML and there is climate change, then the yield increases to 3,052.5 ML (insufficient for current needs)

DATE	AGENT	DOCUMENT OR EVENT	AIM/CONTENTS	KEY RESULTS USED TO INFORM NEXT STAGE
19/10/2020	**NUWS**	Armidale Yield Study: Progress Report (4)	Corrections to Guyra Dams operating rules Assess impact of raising Malpas Dam 6.5 m on system secure yield	Malpas Dam is raised by 3m and the environmental flow release is required when storage is above 6,746 ML and there is climate change, then the revised yield is 2,983 ML (insufficient for current needs) Malpas Dam is raised by 6.5 m and the environmental flow release is required when storage is above 6,746 ML, with the historical climate then the yield is 4,493 ML (with climate change this was expected to be insufficient)
March 2021	*NSWPW*	Preliminary assessment of alternate water sources and storages completed and short-listed options provided to NUWS for yield modelling		Initial options identified: Pump from Styx River to Malpas Dam Pump from Aberfoyle River to Malpas Dam Pump from Styx River to off-river storage on St Helena Creek (6.15 GL) Chandler River onstream storage (67 GL)

DATE	AGENT	DOCUMENT OR EVENT	AIM/CONTENTS	KEY RESULTS USED TO INFORM NEXT STAGE
16/04/2021	**NUWS**	Armidale Yield Study: Progress Report (5)	Preliminary secure yield for alternate sources	Initial yield with climate change including existing sources: Pump up to 100 ML/day from Styx River to Malpas Dam, secure yield 9,638 ML/year with climate change for entire system Pump up to 50 ML/day from Styx River to Malpas Dam, secure yield 7,843 ML/year with climate change for entire system Pump up to 100 ML/day from Aberfoyle River to Malpas Dam, secure yield 6808 ML/year for entire system without climate change, no further analysis undertaken as improvement insufficient Pump up to 100 ML/day from Styx River to off-river storage on St Helena Creek (6.15 GL) additional yield 2,104 ML/year Chandler River onstream storage (67 GL) with pumped transfer of up to 100 ML/day from Styx River, secure yield 11,410 ML/year, no further analysis undertaken as yield excessive and storage very large and expensive Chandler River onstream storage (3.6 GL) with pumped transfer of up to 50 ML/day from Styx River, secure yield 3,101 ML/year with climate change
22/04/2021	**NUWS**	Armidale Yield Study: Progress Report (6)	Additional Aberfoyle River run with raised Malpas Dam	Pump up to 50 ML/day from Aberfoyle River to Malpas Dam with 6.5m raising, secure yield 4,828 ML/year for entire system with climate change
22/04/2021		NSWUWS Armidale Yield Study: Progress Report (7)	Additional Aberfoyle River run with raised Malpas Dam and Nowlands Backwater	Pump up to 50 ML/day from Aberfoyle River and 50 ML/day from Nowlands Backwater to Malpas Dam with 6.5m raising, secure yield 6,720 ML/year for entire system with climate change

DATE	AGENT	DOCUMENT OR EVENT	AIM/CONTENTS	KEY RESULTS USED TO INFORM NEXT STAGE
08/06/2021	**NUWS**	Armidale Yield Study: Progress Report (8)	Additional runs for the additional sources with raised Malpas Dam, additional daily transfer rates and alternate storage sizes for Chandler River onstream storage	All sources able to meet target secure yield Pumping from Styx River to Existing Malpas Dam at 20 ML/day resulted in a secure yield of 5,821 ML/year without climate change
July 2021		Essential Energy and Clarence Valley Council in negotiations for the sale of Nymboida Wier, potential for ARC to purchase Oaky Dam identified by NSW PW and communicated with ARC		
6/09/2021		Council applied for WAL for Guyra Bores		DPIE Water hydrogeologists recommend maximum extraction of 200 ML/year from Guyra Bores
7/09/2021	**NUWS**	Armidale Yield Study: Progress Report (9)	Pumping from Styx River to Existing Malpas Dam using a 10/15/25 secure yield rule	Pumping from Styx River to Existing Malpas Dam at 15 ML/day resulted in a 10/15/25 secure yield of 5,632 ML/year without climate change
February 2022		ARC Strategic Planning and Jobs Growth Summit	Determine Councilős vision for the Armidale region and inform the necessary next steps required to realise that vision	Revised population and water demands projections for Armidale and Guyra 2051 base case unrestricted annual extraction 5,989 ML/year 2051 aspirational case extraction 6,500 ML/year
September 2022		Essential Energy placed Oaky Dam up for sale through a two-stage EOI process		
November 2022		Council engaged specialists to assist in undertaking a valuation of Oaky Dam and assist in the preparation of the stage 1 EOI, NSWUWS issued variation to undertake preliminary yield analysis of Oaky Dam		

DATE	AGENT	DOCUMENT OR EVENT	AIM/CONTENTS	KEY RESULTS USED TO INFORM NEXT STAGE
15/11/2022	**NUWS**	Armidale Yield Study: Progress Report (10)	Preliminary yield analysis of Oaky Dam to feed into Oaky Dam valuation for EOI	Pumping from Oaky Dam to Malpas Dam to Malpas Dam with 6.5m raising resulted in a 5/10/10 secure yield with climate change of 6964 ML/year (constrained by the daily transfer capacity from Malpas Dam back to Armidale) Secure Yield of Oaky Dam standalone system 3,425 ML/year without climate change and 3,217 ML/year with climate change
14/12/2022		Armidale Regional Council purchased Oaky River Dam		
7/6/2023	**NUWS**	Armidale Yield Study: Progress Report (11)	Oaky Dam yield analysis using 10,000 years of DPE Water stochastic climate data	Secure Yield of Oaky Dam standalone system 3,613 ML/year using stochastic climate data without climate change (5% increase)

DATE	AGENT	DOCUMENT OR EVENT	AIM/CONTENTS	KEY RESULTS USED TO INFORM NEXT STAGE
9/6/2023	**NUWS**	Armidale Yield Study: Progress Report (12)	Oaky Dam transfer optimisation considering: Malpas Dam capacity Oaky Dam to Armidale WTP transfer capacity Malpas Dam to Armidale WTP transfer capacity Armidale WTP to Malpas Dam reverse transfer capacity Oaky Dam 2.78 GL for all options	Without rising Malpas Dam, combined system yield was contained by the Malpas Dam to Armidale WTP pipeline transfer capacity of 22 ML/day regardless of the Malpas Dam capacity or the Armidale WTP to Malpas Dam transfer capacity Once the Malpas Dam to Armidale WTP pipeline transfer capacity was increased to 100 ML/day, system yield increased though results were counterintuitive Oaky to WTP 17.8 ML/day, Armidale WTP to Malpas Dam 7.17 ML/day, existing Malpas Dam capacity gave secure yield of 6,828 ML/year without climate change Oaky to WTP 24.26 ML/day, Armidale WTP to Malpas Dam 17.3 ML/day, existing Malpas Dam capacity gave secure yield of 6,557 ML/year without climate change Oaky to WTP 17.8 ML/day, Armidale WTP to Malpas Dam 6.81 ML/day, Malpas Dam raised 6.5m gave secure yield of 9,736 ML/year without climate change and 8,083 ML/year with climate change Oaky to WTP 37.51 ML/day, Armidale WTP to Malpas Dam17.3 ML/day, Malpas Dam raised 6.5m gave secure yield of 10,138 ML/year without climate change and 8,322 ML/year with climate change

DATE	AGENT	DOCUMENT OR EVENT	AIM/CONTENTS	KEY RESULTS USED TO INFORM NEXT STAGE
19/6/2023	**NUWS**	Armidale Yield Study: Progress Report (13)	Climate change results for assessments skipped in last report Assess impact of smaller (0.75 GL) Oaky Dam	Oaky Dam 2.78 GL, Oaky to WTP 24.26 ML/day, Armidale WTP to Malpas Dam 17.3 ML/day, existing Malpas Dam capacity gave secure yield of 6,557 ML/year without climate change and 5,176 ML/year with climate change Oaky Dam 0.75 GL, Oaky to WTP 22.57 ML/day, Armidale WTP to Malpas Dam 17.3 ML/day, existing Malpas Dam capacity gave secure yield of 6,100 ML/year without climate change and 4,946 ML/year with climate change (4.3% drop in yield due to smaller storage) Oaky Dam 0.75 GL, Oaky to WTP 35.67 ML/day, Armidale WTP to Malpas Dam 17.3 ML/day, Malpas Dam raised 6.5m gave secure yield of 9,640 ML/year without climate change and 7,788 ML/year with climate change (6.4% drop in yield due to smaller storage)
26/3/2024	**NUWS**	Armidale Yield Study: Progress Report (14)	Assess impact of either: not operating the reverse transfer from Armidale WTP to Malpas Dam only operating the reverse transfer from Armidale WTP to Malpas Dam when Malpas Dam below 70%	Oaky Dam 2.78 GL, Oaky to WTP 25.03 ML/day, Armidale WTP to Malpas Dam 0 ML/day, existing Malpas Dam capacity gave secure yield of 6,766 ML/year without climate change and 5,496 ML/year with climate change ï result counter intuitive, yield 5.8% higher than with transfer Oaky Dam 2.78 GL, Oaky to WTP 25.03 ML/day, Armidale WTP to Malpas Dam 17.3 ML/day when Malpas <70% full, existing Malpas Dam capacity gave secure yield of 6,766 ML/year without climate change ï result counter intuitive, no yield improvement when compared to the zero transfer option

DATE	AGENT	DOCUMENT OR EVENT	AIM/CONTENTS	KEY RESULTS USED TO INFORM NEXT STAGE
27/8/2024	**NUWS**	Armidale Yield Study: Progress Report (14) (*miss-numbered in report, treated as Report 15 for subsequent numbering*)	Assess impact of reducing secure yield standard from 5/10/10 to 10/20/25	Guyra Dams climate change secure yield increases from 96 ML/year under 5/10/10 to 102 under 10/20/20 or 118 under15/25/35 Climate change secure yield for the existing system with Malpas Dam raised by 6.5m increases from 3,956 ML/year under 5/10/10 to 4,107 ML/year under 10/20/20 and 4,538 ML/year under 15/25/35
November 2024	*NSWPW*	Armidale IWCM Scenario Analysis presentation to Councillors	Final Water demand projection	Armidale 2054 unrestricted dry year extraction 5,634 ML/ year under base case, and 7,592 ML/year under aspirational case Guyra 2054 unrestricted dry year extraction 779 ML/ year under base case, and 791 ML/year under aspirational case Combined 2054 unrestricted dry year extraction 6,413 ML/ year under base case, and 8,384 ML/year under aspirational case
20/01/2025	**NUWS**	Armidale Yield Study: Progress Report (16)	Assess impact of using NARCliM1.5 and DCCEEW stochastic datasets with and without climate change to assess impact of climate change using more modern datasets Runs based on run 267 from Progress report 12 ï climate change secure yield 8,322	Including Guyra yield of 755 ML/year Stochastic flows without climate change resulted in yield of 13,268 ML/year Stochastic flows with climate change resulted in 11,240 ML/year Un-bias corrected NARCLiM1.5 results had extraordinarily high yields of >23,000 ML/year NARCLiM1.5 minimum yield 8,837 ML/year (including 755 ML/year for Guyra) Stochastic data resulted in higher yields NARCLiM1.5 median yield 9785 ML year

5. Recommendations

The results presented in this report should be used keeping in mind the assumptions on which the estimates are based.

To reduce in the uncertainty in future yield assessments appropriate data for the systems should be recorded. This data should include continuous (or at least daily) recording of all the storages levels, all the extractions from the storages, and the amount of water added to the storages (eg from carting).

6. References

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Appendix A: Secure Yield Determination

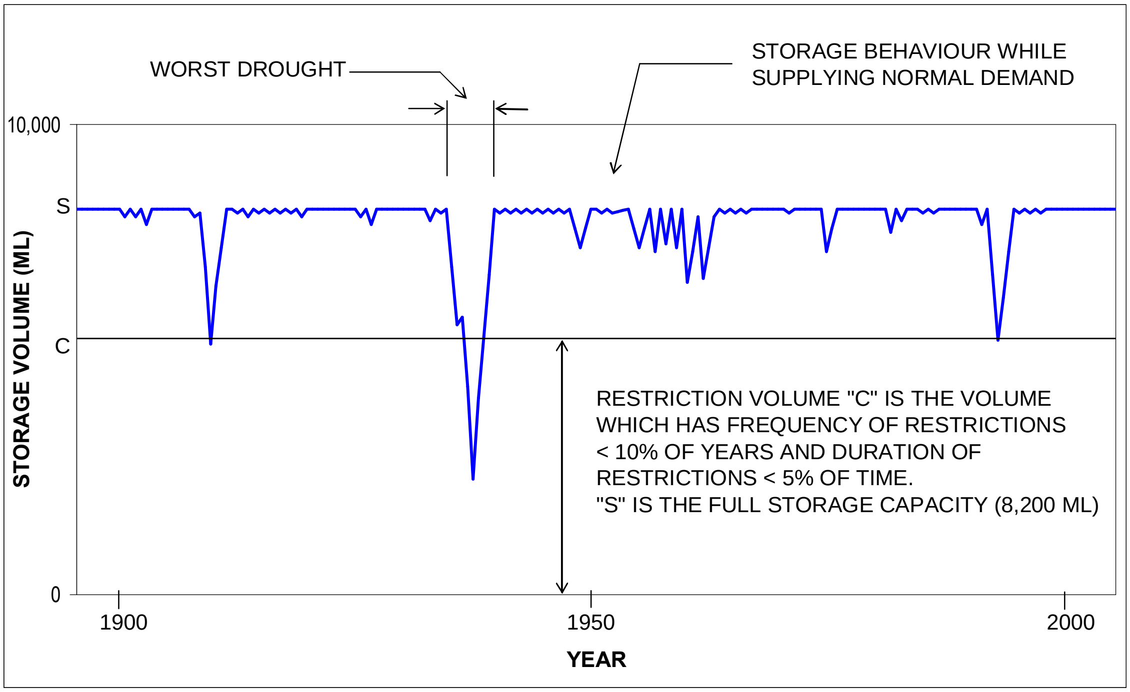

Figure 1: Duration and Frequency of Restrictions

Figure 1 shows the results of simulating an example utilityȇs storage behavior for 120 years of daily streamflow, rainfall and evaporation data and shows that:

- Unrestricted water demand can be supplied for over 95% of the time and over 90% of years (ie. whenever the storage volume is above the **restriction volume C**). In order to satisfy the 5/10/10 rule, restrictions must be imposed whenever the volume of water in storage falls below the **restriction volume C**.
- A 10% reduction in demand is applied when the storage falls below **restriction volume C**
- The worst drought shown in Figure 1 is for approximately the 5-year period January 1939 to December 1943
- The minimum simulated storage volume is approximately 30% of the full storage capacity.

It is noted Figures 1 and 2 as provided by NOW are not drawn to scale and are pictorial representations. For example the limiting condition in Figure 1 is supposed to be the 5% duration of restrictions however if scaled from the figure it is less than 5%.

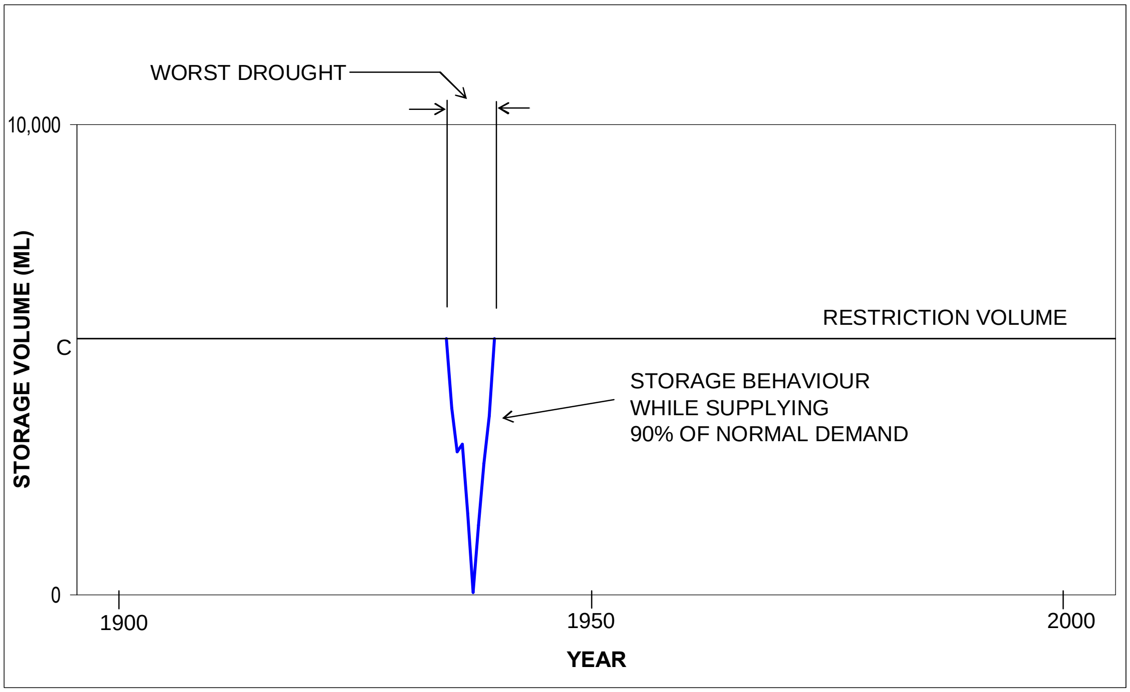

Figure 2: Severity of Restrictions

Figure 2 shows the results of simulating storage behaviour for the worst drought identified in Figure 1 (5-year drought from January 1939 to December 1943) on the following basis:

- A 10% reduction in demand for the full 5-year drought as the storage volume is below the Restriction volume C
- The commencing storage volume for this simulation is the **restriction volume C** and the resulting minimum simulated storage volume is approximately 2% of the full storage capacity.

Comment

Imposition of the requirements of the 5/10/10 rule approximates the severity of a ó1 in 1000 yearô drought and is necessary in order to enable a utility to manage its system in a drought more severe than the worst drought in the 120 year historical record, with only moderate drought water restrictions.

As the first year of the worst drought for this example utility is simulated in **both Figure 1 and Figure 2**, the water supply system must be able to cope with effectively a 6-year drought, rather than the 5-year worst drought in Figure 1 as it takes about 1-year to drawdown to **restriction volume C.**

It is important to note that the analytical process for the 5/10/10 rule is iterative and that a solution is identified only when all 3 requirements have been met.

A refinement that the NUWS model undertakes and as practiced by NSW Public Works Hydrology Group is to test all droughts for criticality when testing the critical drought with the storage already drawdown at the start of the drought. This is done as it was occasionally found in previous studies that the drought that is critical for the full storage was not necessarily the drought that was critical for in effect a smaller (ie drawdown) storage. This is achieved by modelling the full flow series with the reduced storage size and the restricted demand. This also arises from the "1 in 1000 year" security concept.

Appendix B: Progress Reports 1 to 16

working together to ensure water supply security

NUWS

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MEMORANDUM

TO	Glenn Fernandes Principal Engineer- Planning (Water Utilities) NSW Public Works Advisory
CC	
FROM	Peter Cloke, Principal Hydrologist
DATE	30 March 2020
SUBJECT	Armidale Yield Study: Progress Report (1)

The yield study has been progressing well and useful findings have been obtained and the study has now reached the stage where operating conditions and scenarios to be modelled need to be specified or agreed.

Summary

Towards meeting the study objectives the following has been undertaken:

1. **Overview Review of 2016 Study**: Informed by the material (*and/or lack of*) in the Report and trial simulations undertaken for the current study, it is judged the previous modelling did not fully employ the *5/10/10* methodology (*as practised by NUWS in accordance with the 2013 Draft Guidelines)* for determining *Secure Yield.*

   The rainfall runoff modelling undertaken generally appeared appropriate to obtain the required dam inflows. Appropriate model calibration for the purposes appears to have been achieved based on the reported comparisons of modelled and observed flows and storage levels. However there was a secondary issue regarding the type of evaporation data used as discussed later.

2. The NUWS system behaviour model has been set up for the headworks system.

3. The required data files have been set up for the system behaviour model.

4. The *preferred* evaporation data for allowing for losses from the storages was obtained and added to the data files.

5. The hydrometeorological data were extended to March 2020.

6. The previous study modelled flow data were merged with observed flow data.

7. Model testing has been undertaken which has been informative.

Test Results

Table 1 provides the modelling results based on conditions generally taken from the 2016 Yield Study. The modelling was done step by step to assess the sensitivity of the secure yield to aspects of interest:

- Use of *preferred* evaporation for loss from storage water surface area
- Use of merged observed flow data
- Extending flow data from 15/7/2015 to 22/3/2020
- Comparison with the 2016 Study modelling.

The *Guyra Dams Only* Cases assessed the secure yield of the Guyra Dams as a standalone system essentially supplying Guyra. Being a simple system it was better defined for comparison with the 2016 Yield Study. Furthermore the secure yield for the Guyra dams was then used as the demand on the Guyra dams when modelling the secure yield of the downstream dams as this would influence the available spill from the Guyra dams.

The *All Dams (Guyra, Malpas, Puddledock, Gara)* Cases were done to explore maximising the secure yield.

The *Guyra and Malpas Dams* Cases was understood to be essentially the preferred existing main system and simplified the All Dams case for comparison with the 2016 Yield Study.

It is noted the secure yield estimates are dependent on the operating rules, data and assumptions as discussed herein.

Table 1: Preliminary Secure Yield Estimates (Historic Climate)

Run No	Case	Flows	Secure Yield (5/10/10) ML/a	Restrictions			Critical Drought	
				Applied at storage (% full)	Duration (%)	% of Years	From	To
Guyra Dams Only:								
110	2016 Study	2016 Study	**352**	55	1.46	7.03	1/09/1918	12/06/1920
120	2016 Study & *preferred* Evaporation	2016 Study	**342**	55	1.57	7.87	1/09/1918	12/06/1920
121		2016 Study *merged* with *observed* flows	**342**	55	1.57	7.87	1/9/1918	12/06/1920
140		2016 Study *merged* with *observed* flows and extended to 3/2020	**245**	65	1.87	8.40	15/01/2018	15/01/2020

All Dams (Guyra, Malpas, Puddledock, Gara)								
115	2016 Study & NO EFR Use Malpas First, then Gara, then Puddledock	2016 Study	**4393**[1]	55	1.90	9.38	2/02/1918	12/06/1920
116	2016 Study & NO EFR Use Gara First, then Malpas, then Puddledock	2016 Study	**5240**[1]	60	3.18	9.38	2/02/1918	12/06/2020
117	2016 Study & NO EFR Use Puddledock First, then Gara, then Malpas	2016 Study	**5472**[1]	55	2.65	7.81	28/11/1917	12/06/1920
141	2016 Study & NO EFR Use Puddledock First, then Gara, then Malpas	2016 Study and extended to 3/2020	**4217**[2]	65	2.95	7.63	21/07/2017	25/01/2020
151	2016 Study & NO EFR Use Puddledock First, then Gara, then Malpas	2016 Study *merged* with *observed* flows	**5316**[1]	55	3.42	9.45	28/11/1917	12/06/1920
Guyra and Malpas Dams Only:								
112	2016 Study 0.2ML/d constant EFR Malpas	2016 Study	**4236**[1]	55	2.12	8.59	2/02/1918	12/06/1920
113	2016 Study Variable WSP EFR Malpas	2016 Study	**3688**[1]	55	2.39	9.38	2/02/1918	12/06/1920
122	2016 Study & *preferred* Evaporation 0.2ML/d constant EFR Malpas	2016 Study	**4144**[1]	50	1.32	4.72	2/02/1918	12/06/1920
123	2016 Study & *preferred* Evaporation Variable WSP EFR Malpas	2016 Study	**3573**[1]	55	2.49	9.45	2/02/1918	12/06/1920

142	2016 Study & *preferred* Evaporation 0.2ML/d constant EFR Malpas	2016 Study and extended to 3/2020	**3648**[2]	70	4.44	9.92	14/01/2018	6/02/2020
143	2016 Study & *preferred* Evaporation Variable WSP EFR Malpas	2016 Study and extended to 3/2020	**3032**[2]	65	3.00	7.63	14/01/2018	6/02/2020
152	2016 Study & *preferred* Evaporation 0.2ML/d constant EFR Malpas	2016 Study and *merged* with *observed* flows	**4144**[1]	50	1.41	5.51	2/02/1918	12/06/1920
153	2016 Study & *preferred* Evaporation Variable WSP EFR Malpas	2016 Study and *merged* with *observed* flows	**3555**[1]	55	2.51	9.45	2/02/1918	12/06/1920
[1,2] *Excludes Guyra Dams. The demand on the Guyra Dams was fixed at 342 (1) or 245 (2) ML/a being the secure yield for the Guyra dams only for that case.*								

Findings

Findings from the model testing include:

1. Use of the preferred evaporation data *(ie Morton Evaporation Over Shallow Lakes (mLake)))* compared to the evaporation data type used for the 2016 Yield study reduced the secure yield by about 2-3% (*compare run 120 with 110; run 122 with 112; run 123 with 113*).

2. Use of observed flow data in preference to modelled data (*ie merging*) did not change the secure yield (*compare run 120 with 121; run 122 with 152; run 123 with 153*). This relates to the critical drought being 1918/1920 when there was no observed flow data. Although it was noticed recent storage drawdowns were lower (see example Figures 1 and 2) with use of the merged data. This relates to the observed data being impacted by upstream dam operations.

3. Extending the flow data from 7/2015 to 3/2020 to include the recent severe drought has reduced the secure yield from about 28% to 12% depending on the case (*the smaller changes were when there is an EFR as relatively not so sensitive to low flows as if flows below EFR they cannot be utilised*) (*compare run 121 with 140; run 117 with 141; run 122 with 142; run 123 with 143*).

   Figure 3 provides an example storage behaviour diagram for Run 142 showing the 2018/2020 drought is worse than the 1918/1920 previous critical drought.

4. Use of Puddledock and Gara Dams with Malpas Dam depending how they are operated increases the secure yield by up to about 1000 ML/a (*compare runs 101, 102, 103 & 112)*.

5. Applying the 5/10/10 secure yield methodology correctly for this study seems to have resulted in lower secure yield estimates than for the 2016 study using the same flow data. However it is difficult to make a definitive comparison due to the reporting of the results in the 2016 Yield Study report :

   - The comparable secure yield for the Guyra dams only, run 120 of 342 ML/a, for the 2016 Yield Study is inferred to be 1150 ML/a (See Table 5.2, Scenario 1.4, row *Supply Guyra (ML/yr). However it is noted in a 2017 Yield Study for Guyra augmentation options prepared by the consultants who did the 2016 Yield study using the same data and methodology gave a safe yield of the existing system of 277 ML/a.*

   - The comparable secure yield for Malpas Dam with 0.2 ML/d EFR , run 112 of 4236 ML/a is inferred to be 4520 ML/a (See Table 5.2, Scenario 1.4, row *Supply Malpas (ML/yr) or perhaps 5770 ML/a* (See Table 5.2, Scenario 1.4, row *System Yield (ML/yr) less Guyra but is this 277 or 1150 as above).*

   - The comparable secure yield for Malpas Dam with WSP variable EFR , run 113 of 3688 ML/a is inferred to be 4320 ML/a (See Table 5.2, Scenario 1.4, row *Supply Malpas (ML/yr) or perhaps 5430 ML/a* (See Table 5.2, Scenario 1.4, row *System Yield (ML/yr) less Guyra but is this 277 or 1090 as above).*

Assumptions

The system behaviour modelling used the system data available from the 2016 Yield Study and the key items that need to be confirmed before proceeding with Final Scenario Runs include:

Storage Details:

Stage Storage Area Curves for the dams were taken from Tables 2.7 to 2.11. Only FSL were given for Guyra South and Guyra North Dams. Thus FSL for Malpas Dam, Puddledock Dam and Gara Dam were taken from Figure 42 of storage traces to be 11600 ML, 700 ML and 220 ML respectively. Dead storage for all the dams were 0 ML and leakage was negligible.

It is noted different sources give different values for some of this information.

Environmental Flow Release:

Two cases of EFR were applied *(to Malpas Dam only):*

1. A constant discharge of 0.2 ML/d (current)
2. Proposed rules from the WSP:
   - Any inflows less than 1 ML/d must be released + 1 ML/d;
   - If the flows are between 1 and 6 ML/d then 2 ML/d must be released;
   - If the flows are larger than 6 ML/d then 3 ML/d must be released;
   - No environmental releases if the Malpas Dam storage is at or below 55%.

Demand Pattern:

No demand pattern as such was available from the 2016 Yield Study report. This was because the daily demand was modelled based on climate variables for the 2016 Yield Study, so potentially it would appear that each day the demand could be different. It is understood this is quite different to the intentions of the 5/10/10 methodology whereby a fixed demand pattern is used to reflect the future dry year unrestricted demand so that the secure yield reflects for planning purposes the demand that can be met in all years (subject to the 5/10/10 rules). Also it intentionally allows for more drawdown in a wet year (which may have a lower demand) that may preceed a drought to further allow for a worse drought occurring than in the past.

Arising from how the demand was climate driven for the 2016 Yield Study, the question arises what is the reported secure yield annual value? Is it the average that was achieved in the 120 years or so of simulation, was it the maximum, or was it the minimum or was it what was achieved during the critical drought or was it something else.

For the test modelling the following demand pattern taken from the 2014 Guyra Yield Study was used:

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
% of Annual Demand	**10.1**	**8.6**	**7.1**	**8.4**	**8.6**	**6.7**	**6.2**	**6.4**	**8.3**	**10.1**	**9.2**	**10.3**

Climate Change

Table 2 provides for four selected cases secure yields (*based on flows extended to 3/2020*) adjusted for 1 °C Climate warming in accordance with DPIE Water's *"Assuring future urban water security, Assessment and Adaption guidelines for NSW local water utilities".* The individual results for the 15 GCMs and corresponding historic data base are provided in Attachment A.

Table 2: Preliminary Secure Yield Estimates Adjusted for Climate Change

Run	Case	Historic Secure Yield ML/a	Adjustment Factor for Climate Change	Secure Yield with 1 °C Climate Warming ML/a
Run 140	*Guyra Dams only*	245	0.6406	**157**
Run 141	*NO EFR* *Use Puddledock First, then Gara, then Malpas*	4217	0.7329	**3090***
Run 142	*Malpas Dam* *0.2 ML/d EFR*	3648	0.7176	**2617***
Run 143	*Malpas Dam* *WSP Variable EFR*	3032	0.6776	**2054***
*** *Excludes Guyra Dams.The demand on the Guyra Dams was fixed at 157 ML/a being the secure yield for the Guyra dams only with 1°C Climate Warming.*				

It is noted the climate change data covers the period 1/1/1894 to 31/12/2008 which means the climate adjustment factors can be applied to the same base case (ie the historic climate runs) independent of flow series (ie modelled, merged or extended).

From the provided material it was apparent the FAO evapotransipration data were used to calibrate the rainfall runoff models for the 2016 Yield Study. There are different types of evapotranspiration data. To a certain extent the differences in their values are allowed for implicitly in the rainfall runoff model calibration. Thus its use is ok if only required for developing the historic secure estimates on their own. However the climate change data provided by DPIE Water based on how it was developed gives *Morton's wet environment areal evapotranspiration* type data.

To be consistent it would have been better if the rainfall runoff models had been calibrated using the same type of evapotranspiration data. However it is judged due to the way the climate adjustment factor is obtained as a factor of relativity that the evapotranspiration inconsistency would only have a minor effect on the adopted results and thus it is not warranteed recalibrating all the rainfall runoff models.

It would also seem for the 2016 Yield Study the climate change evapotransipration data were used directly to model the evaporation losses from the storages water surfaces. This is not considered appropriate. For the above cases as practiced by NUWS, since the DPIE Water Climate Change data sets do not provide evaporation data , the evapotransipration data were adjusted by a series of factors developed from comparing the SILO *Morton Evaporation Over Shallow Lakes* data with the SILO *Morton's wet environment areal evapotranspiration* data.

Tasks Remaining

Tasks remaining to be done include:

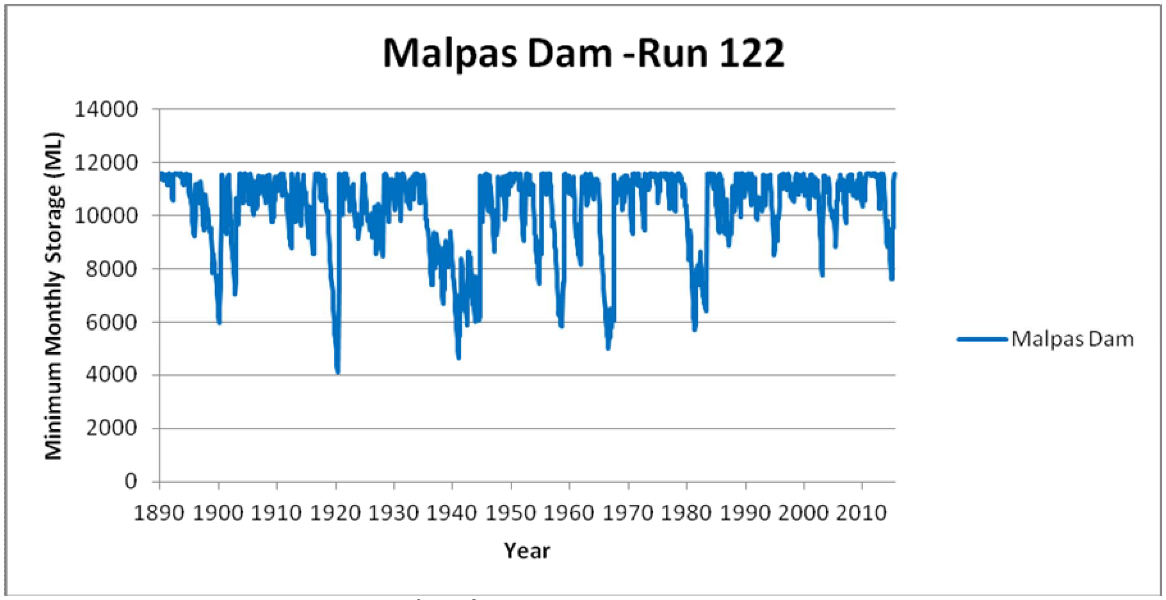
1. Using operational records to refine and verify flows extended to 3/2020.
2. Confirmation and refining of assumptions.
3. Finalise secure yield estimates based on updated assumptions and flow data for specified Scenarios.
4. Drafting Report.

Information Required

For completion of the tasks the following information needs to be provided or agreed:

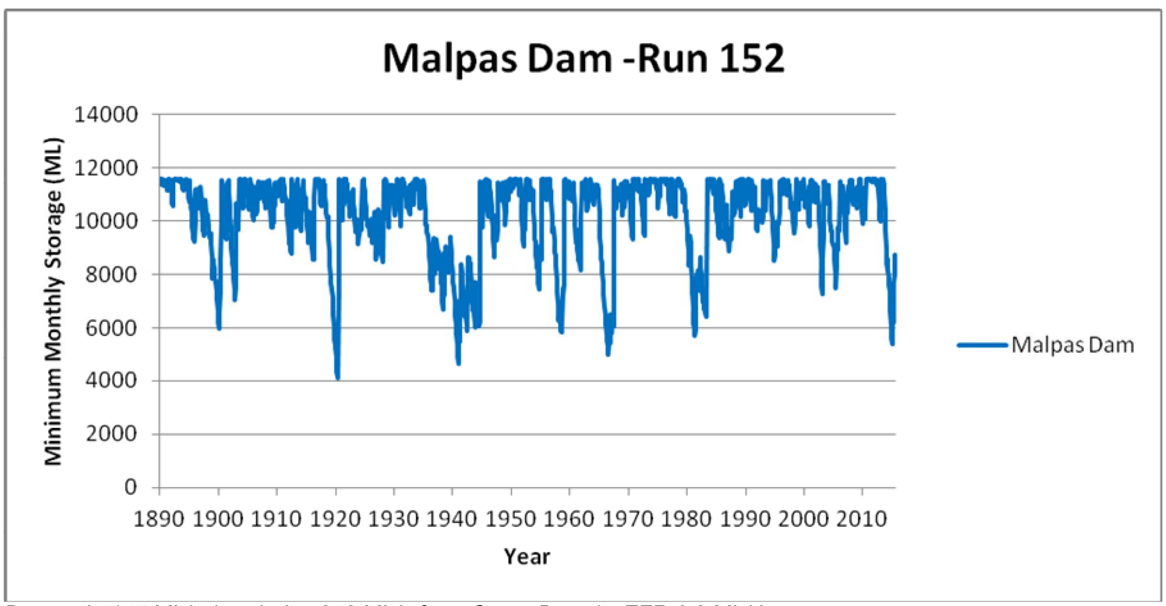
1. Confirmation of storage details.
2. Demand pattern to be used.
3. Confirmation of EFR.
4. Daily operational records of Dams in excel spreadsheet providing storage level, spill, releases, and extractions from July 2015 to March 2020.
5. Details and conditions for Scenarios to be modelled.

Figures



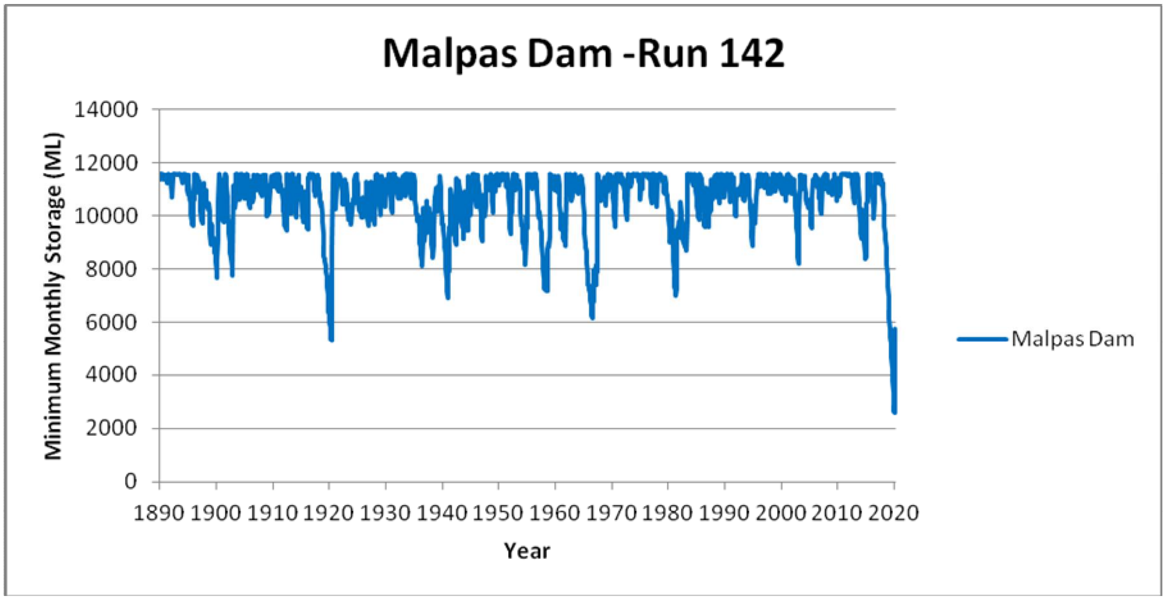
Demand 4144 ML/a (excludes 342 ML/a from Guyra Dams); EFR 0.2 ML/d

Figure 1 : Storage Behaviour - Modelled Flows



Demand 4144 ML/a (excludes 342 ML/a from Guyra Dams); EFR 0.2 ML/d

Figure 2 : Storage Behaviour - Modelled Flows merged with Observed Flows



Demand 3648 ML/a (excludes 245 ML/a from Guyra Dams); 0.2 ML/d EFR

Figure 3 : Storage Behaviour - Modelled Flows with Flows Extended to 3/2020

ATTACHMENT A
Model Results for 15 GCMs and corresponding Historic Base

Note that in each case shown on the following pages the data is based on modelled flow information (from a data base of daily rainfall and daily evapotranspiration) and not observed flow data. The adopted historical secure yields uses a longer period and are those in Table 1. The following data is used to adjust the yields in Table 2 in accordance with the DPIE Water Guidelines

Guyra Dams Only

Armidale, Run 140/121CC F:\Results\Armidale\Mar2020\Data\ClimateChange\Armidale_

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	Run	Storage Capacity	Secure Yield	% Restricted at	Restricted: % of duration	Restricted: % of years	Critical Drought: Start	Critical Drought: End
HISTORICAL	1	463.46	345	60	2.63	9.48	01/09/1918	12/06/1920
	2	463.46	330	55	1.78	9.48	30/11/1964	30/11/1965
	3	463.46	317	55	1.94	8.62	11/12/1964	30/11/1965
	4	463.46	249	60	2.92	9.48	31/08/1918	12/06/1920
LOWEST	5	463.46	182	60	2.49	9.48	23/08/1918	12/06/1920
	6	463.46	324	55	2.07	8.62	31/08/1918	12/06/1920
	7	463.46	225	60	2.01	7.76	01/09/1918	12/06/1920
	8	463.46	276	60	2.40	8.62	01/09/1918	12/06/1920
	9	463.46	209	55	1.42	5.17	31/08/1918	12/06/1920
MEDIAN	10	463.46	304	60	1.71	9.48	30/11/1964	30/11/1965
	11	463.46	376	55	1.26	8.62	19/04/1957	30/01/1958
	12	463.46	366	55	1.77	8.62	19/04/1957	30/01/1958
	13	463.46	255	60	2.35	9.48	31/08/1918	12/06/1920
	14	463.46	249	60	2.35	9.48	31/08/1918	12/06/1920
	15	463.46	309	60	2.78	9.48	01/09/1918	12/06/1920
	16	463.46	311	60	2.74	9.48	01/09/1918	12/06/1920
10/15/25	5	463.46	221	60	3.28	11.21	23/08/1918	12/06/1920

Use Puddledock First, then Gara, then Puddledock Dam, NO EFR

Armidale, Run 141/151CC F:\Results\Armidale\Mar2020\Data\ClimateChange\Armidale_

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					Restricted		Critical Drought	
	Run	Storage Capacity	Secure Yield	% Restricted at	% of duration	% of years	Start	End
HISTORICAL	1	12520	5125	55	2.44	9.48	06/02/1933	30/12/1940
	2	12520	4813	50	2.67	6.90	03/02/1933	30/12/1940
	3	12520	4751	50	3.43	9.48	03/02/1933	30/12/1940
	4	12520	3722	45	1.92	8.62	31/01/1933	30/12/1940
LOWEST	5	12520	3235	45	3.42	9.48	25/02/1928	30/12/1940
	6	12520	4696	50	3.24	9.48	15/02/1894	14/02/1900
	7	12520	4067	50	3.82	9.48	01/01/1894	14/02/1900
	8	12520	4402	45	1.65	7.76	28/02/1928	30/12/1940
	9	12520	3699	45	2.89	8.62	26/02/1928	30/12/1940
	10	12520	4956	55	4.30	9.48	08/02/1933	29/12/1940
	11	12520	5827	55	2.79	9.48	05/12/1917	12/06/1920
	12	12520	5215	55	2.74	9.48	08/02/1933	30/12/1940
	13	12520	4132	50	3.79	9.48	15/02/1894	14/02/1900
	14	12520	4066	50	3.80	9.48	15/02/1894	14/02/1900
MEDIAN	15	12520	4595	50	2.86	9.48	02/02/1933	30/12/1940
	16	12520	4659	50	2.90	9.48	02/02/1933	30/12/1940
10/15/25	5	12520	3756	40	7.51	14.66	25/02/1928	30/12/1940

Malpas Dam 0.2 ML/d EFR

Armidale, Run 142/152CC F:\Results\Armidale\Mar2020\Data\ClimateChange\Armidale_

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	Run	Storage Capacity	Secure Yield	% Restricted at	Restricted % of duration	Restricted % of years	Critical Drought Start	Critical Drought End
HISTORICAL	1	11600	4125	50	1.59	6.03	26/01/1935	30/12/1940
	2	11600	3809	50	3.69	9.48	26/01/1935	30/12/1940
	3	11600	3713	50	3.95	9.48	21/01/1935	30/12/1940
	4	11600	2976	45	4.75	9.48	21/01/1935	30/12/1940
LOWEST	5	11600	2560	40	4.34	8.62	20/01/1935	30/12/1940
	6	11600	3686	50	3.54	9.48	14/02/1895	14/02/1900
	7	11600	3180	50	4.00	9.48	20/02/1894	14/02/1900
	8	11600	3571	45	4.19	9.48	21/01/1935	30/12/1940
	9	11600	2932	45	4.90	9.48	20/01/1935	30/12/1940
	10	11600	4038	55	4.60	9.48	26/01/1935	30/12/1940
	11	11600	4658	55	2.78	9.48	05/02/1918	12/06/1920
	12	11600	4255	50	2.33	7.76	26/01/1935	30/12/1940
	13	11600	3204	50	4.24	9.48	14/02/1895	14/02/1900
	14	11600	3142	50	4.22	9.48	14/02/1895	14/02/1900
MEDIAN	15	11600	3682	50	4.83	9.48	21/01/1935	30/12/1940
	16	11600	3731	50	4.77	9.48	21/01/1935	30/12/1940
10/15/25	5	11600	2960	35	7.43	12.93	20/01/1935	30/12/1940

Armidale, Run 143/153CC F:\Results\Armidale\Mar2020\Data\ClimateChange\Armidale_

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					Restricted		Critical Drought	
		Storage	Secure	% Restricted	% of	% of		
	Run	Capacity	Yield	at	duration	years	Start	End
HISTORICAL	1	11600	3567	55	2.79	9.48	26/01/1935	30/12/1940
	2	11600	3339	50	4.11	9.48	26/01/1935	30/12/1940
	3	11600	3184	45	1.74	6.03	21/01/1935	30/12/1940
	4	11600	2515	45	4.84	9.48	21/01/1935	30/12/1940
LOWEST	5	11600	2081	40	3.68	7.76	20/01/1935	30/12/1940
MEDIAN	6	11600	3121	50	2.98	9.48	14/02/1895	14/02/1900
	7	11600	2702	50	4.08	9.48	20/02/1894	14/02/1900
	8	11600	3076	45	4.08	8.62	21/01/1935	30/12/1940
	9	11600	2449	45	4.45	9.48	20/01/1935	30/12/1940
	10	11600	3522	50	3.74	5.17	26/01/1935	30/12/1940
	11	11600	4138	55	3.21	9.48	05/02/1918	12/06/1920
	12	11600	3676	50	2.14	7.76	26/01/1935	30/12/1940
	13	11600	2706	50	3.91	9.48	14/02/1895	14/02/1900
	14	11600	2650	45	2.12	5.17	14/02/1895	14/02/1900
	15	11600	3143	50	4.17	9.48	21/01/1935	30/12/1940
	16	11600	3200	50	4.19	9.48	21/01/1935	30/12/1940
10/15/25	5	11600	2417	40	8.41	14.66	20/01/1935	30/12/1940

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MEMORANDUM

TO	Glenn Fernandes Principal Engineer- Planning (Water Utilities) NSW Public Works Advisory
CC	
FROM	Peter Cloke, Principal Hydrologist
DATE	26 May 2020
SUBJECT	Armidale Yield Study: Progress Report (2)

This Progress Report follows on from the Progress Report (1) report of 30 March 2020.

Following receipt of the operational data, lake water balancing has been undertaken to compare resulting inflows with the previously estimated dam inflows that were used to extend the previous flow series from 2015.

Summary

Good agreement was achieved for the Malpas Dam and reasonable agreement was achieved for the Guyra and Puddledock Dams. Lake Water balancing was not undertaken for Gara Dam as it was not used for town water supply and there was only intermittent observed data recorded for the Dam.

The inflows determined from the water balance modeling were used to estimate the secure yield for three previous modelled cases to assess the sensitivity of the secure yield to the water balance inflows. Use of the water balance inflows increased the secure yields by about 100 to 400 ML/a.

To progress the study details of the cases and conditions to be modelled as discussed in the teleconference meeting on the 1 May are now required.

Flow Comparison

Figure 1 compares the observed storage behaviour of Malpas Dam with that modelled using the previous estimated extended flows (*based on factoring observed flows*) as used in Progress Report 1. It shows good agreement thus implying the estimated inflows were appropriate. This is considered particularly assuring as Malpas Dam is the main component of the water supply headworks system.

Figure 1: Maplas Dam Storage Behaviour

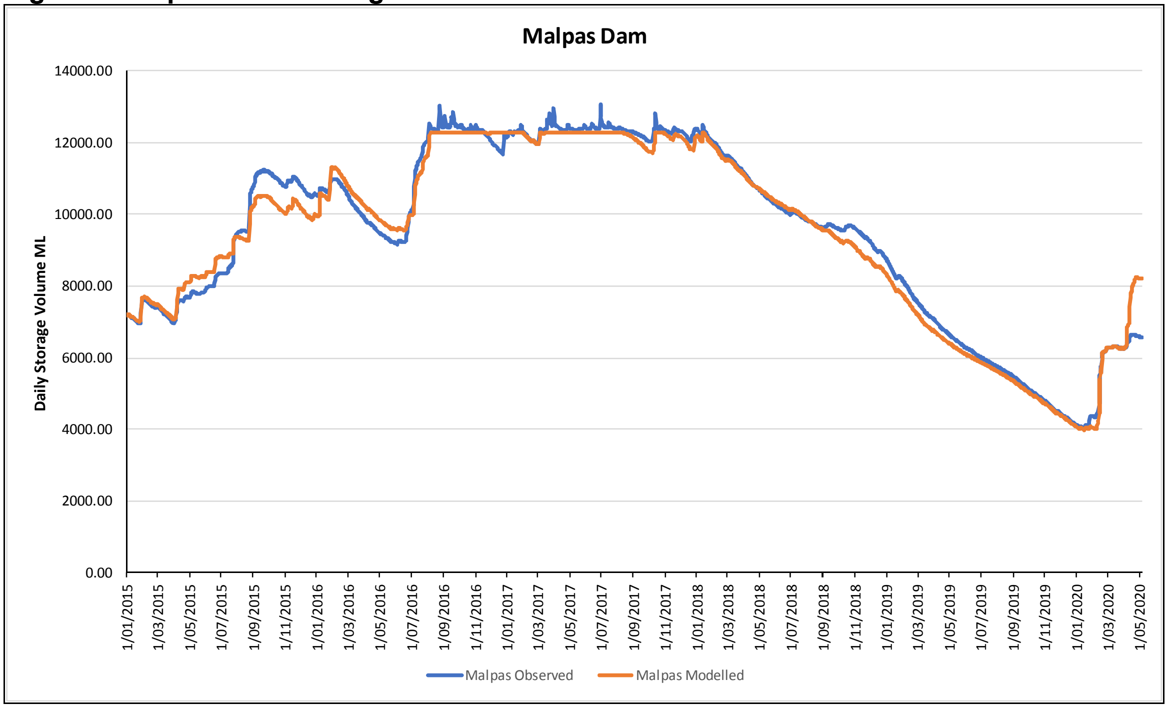
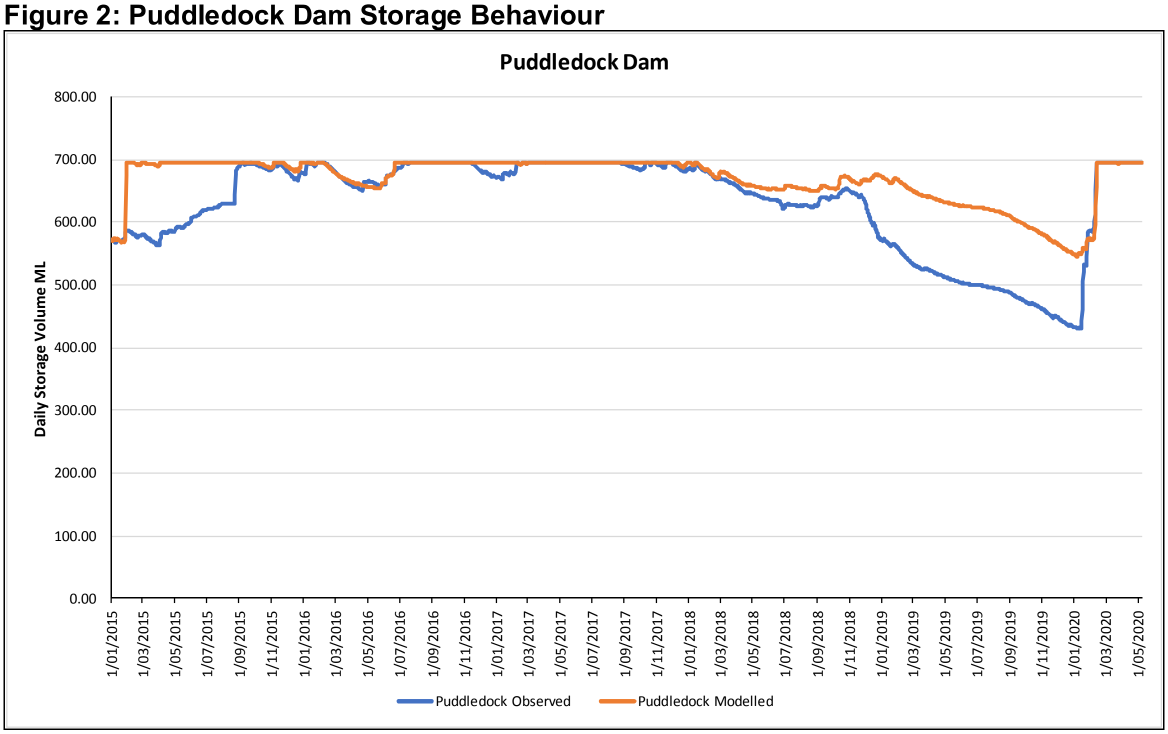


Figure 2 compares the observed storage behaviour of Puddledock Dam with that modelled using the previous estimated extended flows (*based on factoring observed flows*) as used in Progress Report 1. It shows reasonable agreement except that the observed storage volume gets about 100 ML lower thus implying the estimated inflows may be slightly overestimated. This may relate to the estimated flows being based on observed Gara River flows as there were no observed flow data for Puddledock Creek and the two river catchments having slightly different characteristics.

Figure 2: Puddledock Dam Storage Behaviour



Figures 3 and 4 compares the observed storage behaviour of the Guyra Dams with that modelled using the previous estimated extended flows (*based on factoring observed flows*) as used in Progress Report 1. For the Guyra Dams the general pattern was followed and there was good agreement with the North Dam for most of the time but for the South Dam the modelled minimum storage was about 40 ML lower than observed minimum implying the previously estimated inflows may be underestimated. It would seem actual inflows from about June to December 2018 were not *captured* and this is considered to relate to the observed flows being downstream of the Guyra dams and thus affected by the Guyra Dams.

Figure 3: North Guyra Dam Storage Behaviour

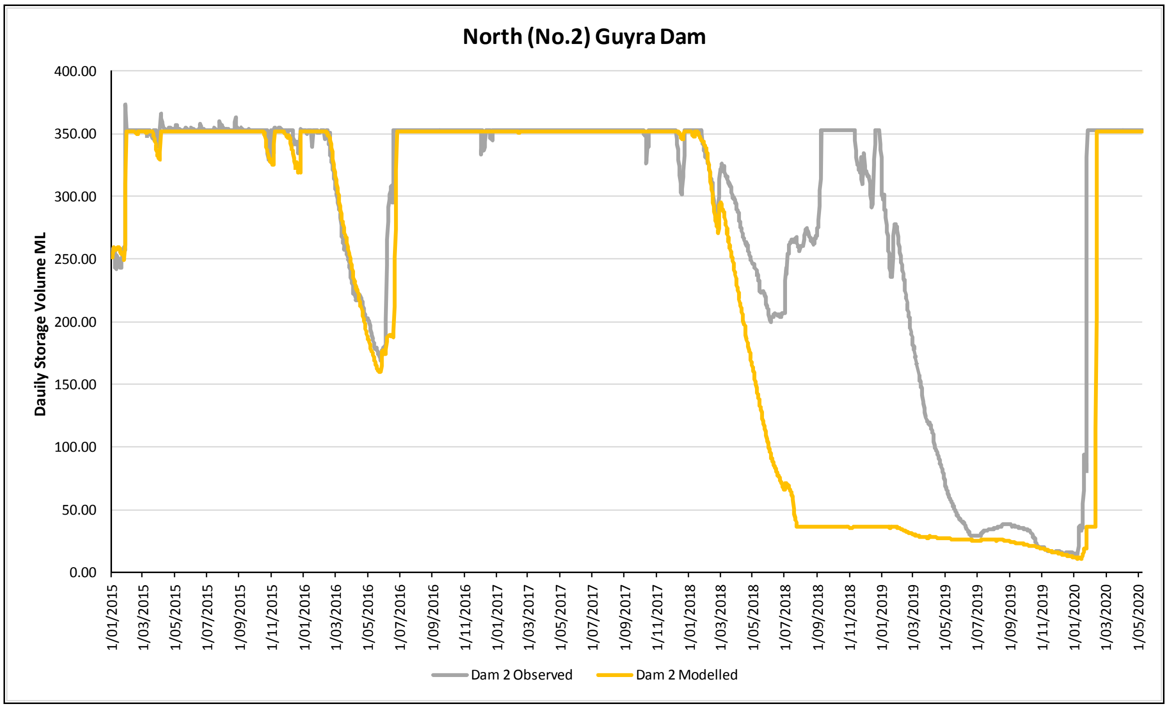
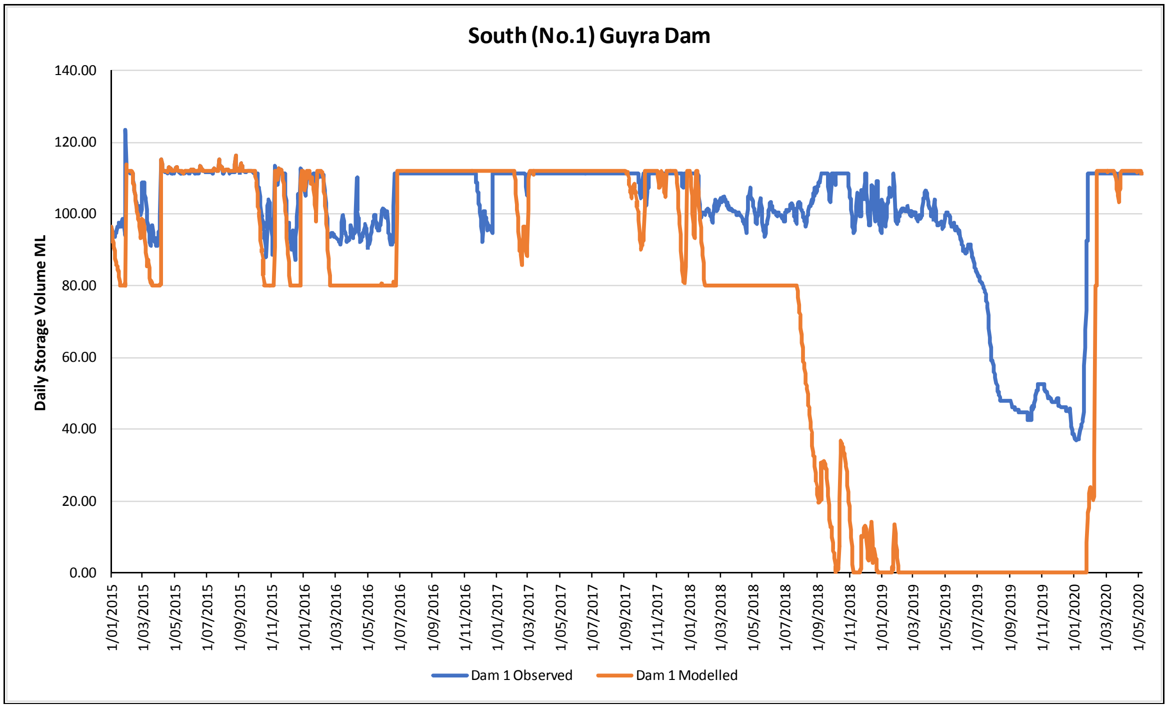


Figure 4: South Guyra Dam Storage Behaviour



Secure Yield Comparison

Table 1 provides compares the modelling results for three cases selected to show the changes in Secure Yield for a range of cases from using the lake water balance inflows compared to using the previous estimated flows (*based on factoring observed flows*) as used in Progress Report 1.

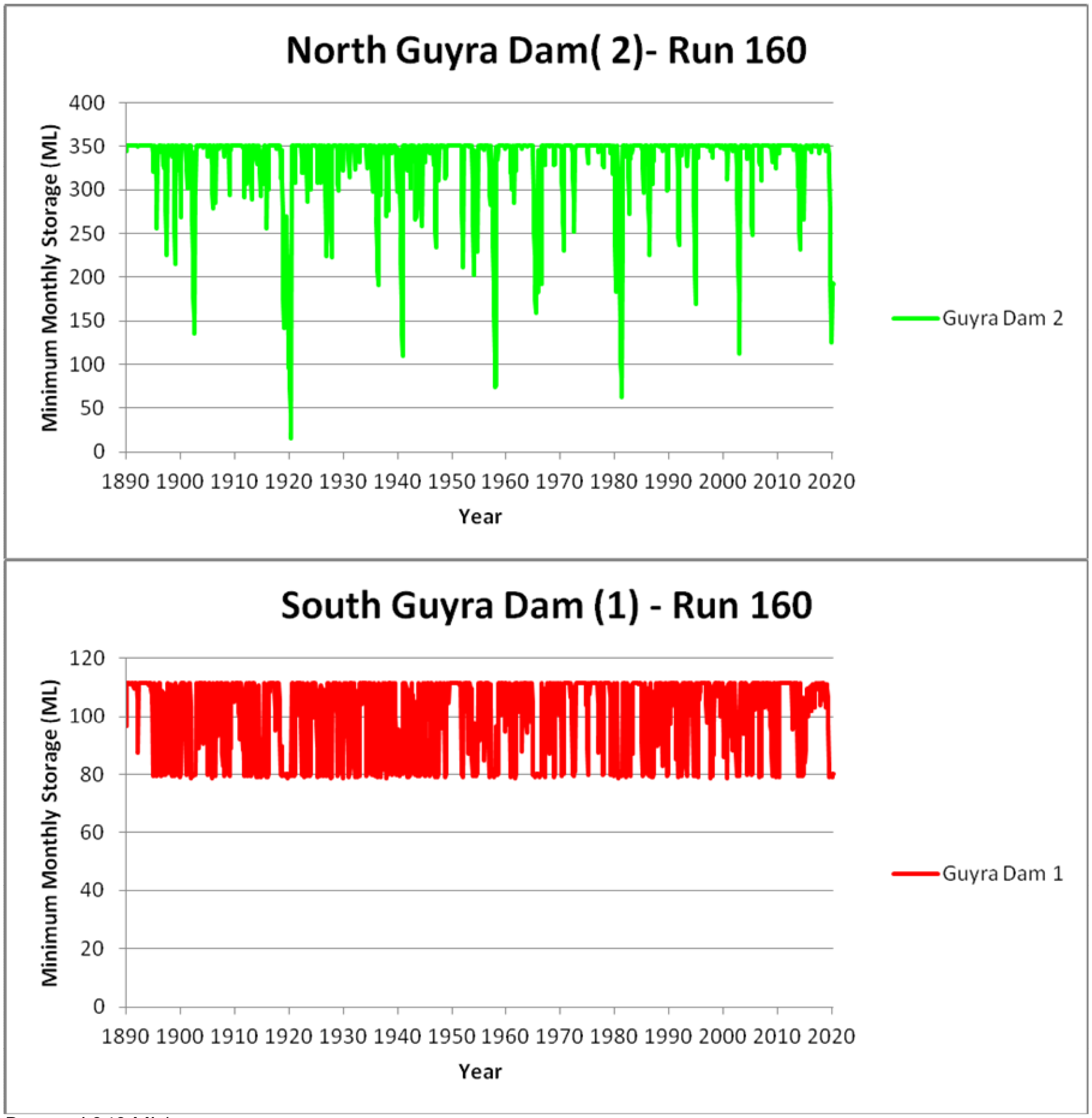
Table 1: Preliminary Secure Yield Estimates (Historic Climate)

Run No	Case	Flows	Secure Yield (5/10/10) ML/a	Restrictions			Critical Drought	
				Applied at storage (% full)	Duration (%)	% of Years	From	To
Guyra Dams Only:								
140	2016 Study & *preferred* Evaporation	2016 Study *merged* with *observed* flows and extended to 3/2020	*245*	*65*	*1.87*	*8.40*	*15/01/2018*	*15/01/2020*
160		2016 Study *merged* with *observed* flows and extended to 5/2020 using water balance inflows	**342**	55	1.62	8.40	11/09/1918	12/06/1920
All Dams (Guyra, Malpas, Puddledock, Gara)								
141	2016 Study & NO EFR Use Puddledock First, then Gara, then Malpas	*2016 Study and extended to 3/2020*	*4217*[2]	*65*	*2.95*	*7.63*	*21/07/2017*	*25/01/2020*
161		2016 Study and extended to 5/2020 using water balance inflows	**4153**[1]	65	3.07	7.63	15/12/2011	15/01/2020
Guyra and Malpas Dams Only:								
143	2016 Study & *preferred* Evaporation Variable WSP EFR Malpas	2016 Study and extended to 3/2020	*3032*[2]	*65*	*3.00*	*7.63*	*14/01/2018*	*6/02/2020*
163		2016 Study and extended to 5/2020 using water balance inflows	**3430**[1]	60	3.68	9.92	30/06/20217	15/01/2020

[1,2] *Excludes Guyra Dams. The demand on the Guyra Dams was fixed at 342 (1) or 245 (2) ML/a being the secure yield for the Guyra dams only for that case.* *See Progress Report 1 for Assumptions and Conditions*

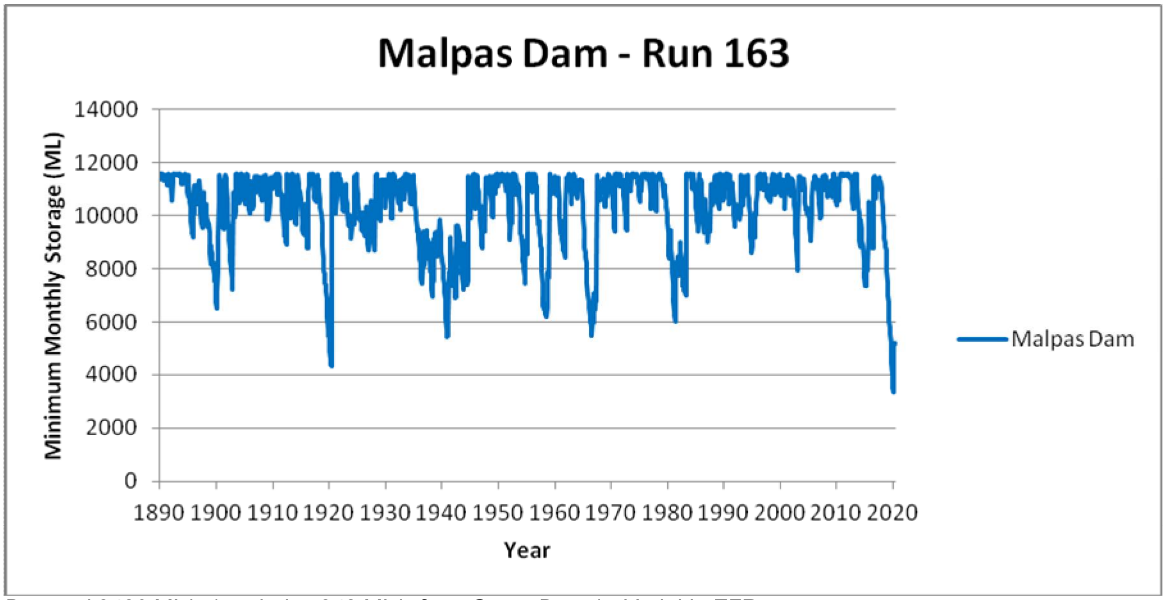
Figures 5 and 6 provide modelled storage behaviour diagrams for a repeat of the historic climate while meeting the secure yield demands for above two main cases (ie use of Guyra Dams and Malpas Dam without using Puddledock and Gara Dams).

Figure 5 : Storage Behaviour – Guyra Dams



Demand 342 ML/a

Figure 6 : Storage Behaviour – Malpas Dam



Demand 3430 ML/a (excludes 342 ML/a from Guyra Dams); Variable EFR

working together to ensure water supply security

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MEMORANDUM

TO	Glenn Fernandes Principal Engineer- Planning (Water Utilities) NSW Public Works Advisory
CC	
FROM	Peter Cloke, Principal Hydrologist
DATE	18 September 2020
SUBJECT	Armidale Yield Study: Progress Report (3)

The Phase 1 and Phase 2 Scenarios as requested in your email of 2/9/2020 have been modelled and the results are reported herein.

Summary

The requested results are provided in Table 1.

Table 2 provides the secure yield modelling results for the historic climate.

It is noted the secure yield estimates are dependent on the operating rules, data and assumptions as discussed herein and or in the previous two Progress Reports (30/3/2020 & 26/5/2020).

Table 1: Armidale Water supply – Requested Scenarios for Secure Yield Modelling

No	Scenario	Release from Malpas dam does not apply when	**Climate change secure yield* ML/a**	Cease to flow at Willow gauging station (206035)			Cease to flow at Gara River gauging station (206039)			Cease to flow metrics for Puddledock d/s of dam		
				Days	Average	Maximum	Days	Average	Maximum	Days	Average	Maximum
PHASE 1												
1	Guyra+Malpas (Base case)	Malpas dam less than 55%	**2256**	1966	4.45	84	205	12.82	84			
2	Guyra+Malpas	Malpas dam less than 70%	**2356**	1966	4.45	84	389	6.95	84			
3	Guyra+Malpas FSL increased by 3m	Malpas dam less than 55%	**2890**	1966	4.45	84	673	5.75	84			
4	Guyra+Malpas FSL increased by 3m	Malpas dam less than 6,746 ML	**2874**	1966	4.45	84	15	7.50	13			
5	Guyra+Malpas FSL increased by 3m	Malpas dam less than 70%	**2922**	1966	4.45	84	861	5.35	84			
PHASE 2												
6	Guyra+Malpas+Puddledock (Base case)	Malpas dam less than 55%	**2333**	1966	4.55	84	236	11.24	84	25925	15.24	881
7	Guyra+Malpas+Puddledock	Malpas dam less than 70%	**2465**	1966	4.55	84	576	5.76	84	25900	15.22	881
8	Guyra+Malpas FSL increased by 3m+Puddledock	Malpas dam less than 55%	**2949**	1966	4.55	84	875	5.61	84	26128	15.78	2137
9	Guyra+Malpas FSL increased by 3m+Puddledock	Malpas dam less than 6,746 ML	**2958**	1966	4.55	84	4	1.33	2	26101	15.74	2137
10	Guyra+Malpas FSL increased by 3m+Puddledock	Malpas dam less than 70%	**2974**	1966	4.55	84	1208	5.35	84	26068	15.68	1845

Total Storage for Malpas Dam 12266 ML. Thus 55% equates to 6746 ML
Total Storage for Malpas raised 3m 18475 ML. Thus 55% equates to 10161 ML and 70% 12932 ML
Cease to flow metrics based on historic climate secure yield (Modelling Period 1/1/1890 to 1/9/2020)
*Excludes Guyra dams secure yield. The demand on the Guyra dams was fixed at 94.5 ML/a being the determined climate change secure yield for the Guyra dams only.

Table 2 : Preliminary Secure Yield Estimates (Historic Climate)

No	Model Run No	Scenario	Release from Malpas dam does not apply when	Secure Yield ML/a	Restrictions			Critical Drought	
					Applied at storage (% full)	Duration (%)	% of Years)	From	To
	175	Guyra Dams Only		**176**	70	1.39	6.82	15/01/2018	15/01/2020
PHASE 1									
1	177	Guyra+Malpas (Base case)	Malpas dam less than 55%	**3235***	65	3.36	9.09	30/06/2017	6/02/2020
2	178	Guyra+Malpas	Malpas dam less than 70%	**3284***	65	3.17	8.33	30/06/2017	6/02/2020
3	179	Guyra+Malpas FSL increased by 3m	Malpas dam less than 55%	**4328***	55	4.94	9.85	4/08/2017	6/02/2020
4	180	Guyra+Malpas FSL increased by 3m	Malpas dam less than 6,746 ML	**4167***	55	4.31	9.09	4/08/2017	6/02/2020
5	181	Guyra+Malpas FSL increased by 3m	Malpas dam less than 70%	**4328***	55	3.07	7.58	4/08/2017	6/02/2020
PHASE 2									
6	187	Guyra+Malpas+Puddledock (Base case)	Malpas dam less than 55%	**3428***	65	3.68	8.33	30/06/2017	6/02/2020
7	188	Guyra+Malpas+Puddledock	Malpas dam less than 70%	**3475***	65	3.43	8.33	30/06/2017	6/02/2020
8	189	Guyra+Malpas FSL increased by 3m+Puddledock	Malpas dam less than 55%	**4442***	55	4.71	9.85	30/06/2017	6/02/2020
9	190	Guyra+Malpas FSL increased by 3m+Puddledock	Malpas dam less than 6,746 ML	**4308***	55	4.38	8.33	4/08/2017	6/02/2020
10	191	Guyra+Malpas FSL increased by 3m+Puddledock	Malpas dam less than 70%	**4490***	55	2.99	8.33	4/08/2017	6/02/2020

Total Storage for Malpas Dam 12266 ML. Thus 55% equates to 6746 ML
Total Storage for Malpas raised 3m 18475 ML. Thus 55% equates to 10161 ML and 70% 12932 ML
Modelling Period 1/1/1890 to 1/9/2020
*Excludes Guyra dams secure yield. The demand on the Guyra dams was fixed at 176 ML/a being the determined historic climate secure yield for the Guyra dams only.

Assumptions

The system behaviour modelling included the following updated assumptions:

Inflows

The dam inflows were based on those developed for Run 143 as detailed in Progress Report 2 and extended in a similar way to 1/9/2020.

Storage Details

Dam	Total Storage ML	Dead Storage ML
Malpas Dam (Existing)	12,266	613
Malpas (FSL raised by 3m)	18,475	613
South Guyra Dam (No.1)	112	33
North Guyra Dam (No.2)	352	36
Puddledock Dam	696	105

Release Rules

No release rules were applied to the Guyra Dams and Puddledock Dam.

For Malpas Dam two sets of conditional rules were applied:

1. When inflows to Malpas Dam, as measured at the Gara River at Willow Glen gauge (206035), were:
   (a) less than 1 ML/day, a release equal to or greater than the inflows plus 1 ML/day, as measured at the Gara River downstream Malpas Dam gauge (206039), was made from Malpas Dam, or
   (b) equal to or greater than 1 ML/day and less than or equal to 6 ML/day, a release of 2 ML/day or greater, as measured at the Gara River downstream Malpas Dam gauge (206039), was made from Malpas Dam, or
   (c) greater than 6 ML/day, a release of 3 ML/day or greater, as measured at the Gara River downstream Malpas Dam gauge (206039), was be made from Malpas Dam.

   The above did not apply when the Malpas Dam was less than or equal to the stated release condition in terms of the damõs storage capacity.

2. If the inflow to Malpas Dam was greater than 0.2 ML/d, then 0.2 ML/d was released. If the inflow was less than 0.2 ML/d then the inflow was released.

In applying the rules any spill from the dam was counted as contributing towards satisfying the releases. Furthermore if any releases were made from the first set of rules these were counted towards satisfying the release under the second of rule.

Operational Rule

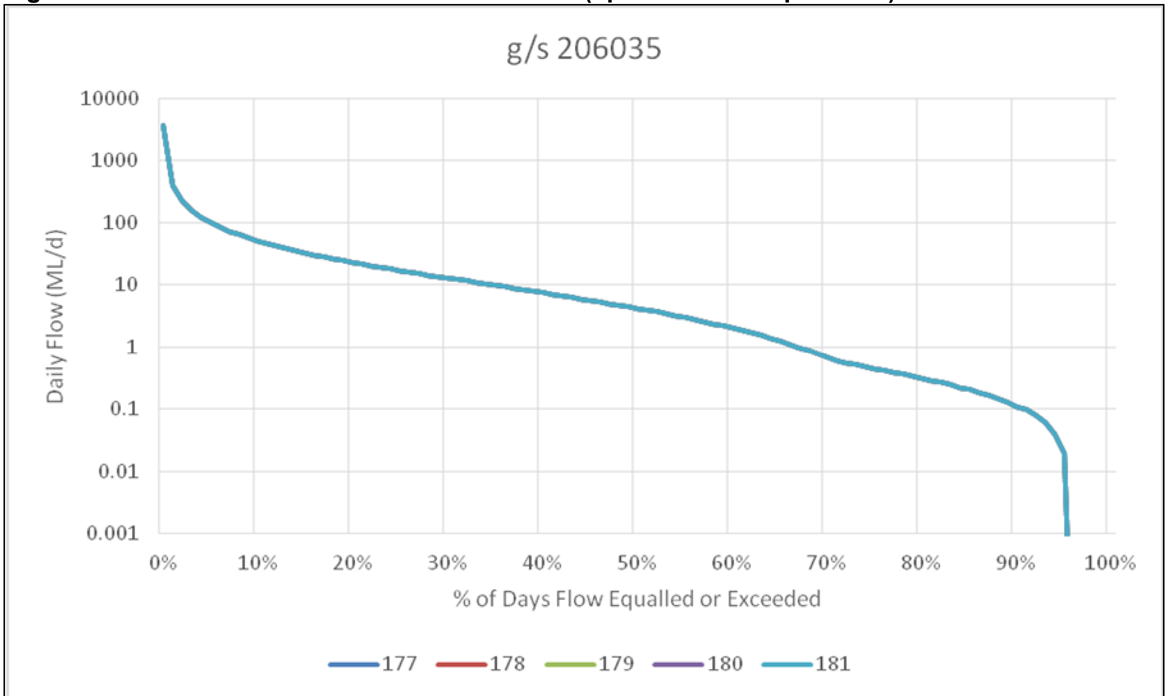
Demand equivalent to the secure yield of the Guyra Dams was taken from the Guyra Dams.

Malpas Dam was used to supply demand until it was drawdown to 50% then Puddledock Dam was used and then Malpas Dam was used to meet demand that could not be met by Puddledock Dam.

Discussion
Cease to flow metrics

Table 1 provides requested cease to flow metrics. Considering the additional work that would be involved and the little difference between the options compared to the existing base case and that the options do not meet the future target demand pursuing the metrics further downstream may not be warranted. Figures 1 to 3 provide a *snap shot* of the change in the full range of flows for the Phase 1 cases and Figures 4 to 7 provide duration curves for the Phase 2 cases.

Figure 1: Modelled Flow Duration at G/S 206035 (upstream of Malpas Dam) - Phase 1



All the lines coincide with each other as expected for the upstream gauging station

Figure 2: Modelled Flow Duration at G/S 206039 (Just Downstream of Malpas Dam) - Phase 1

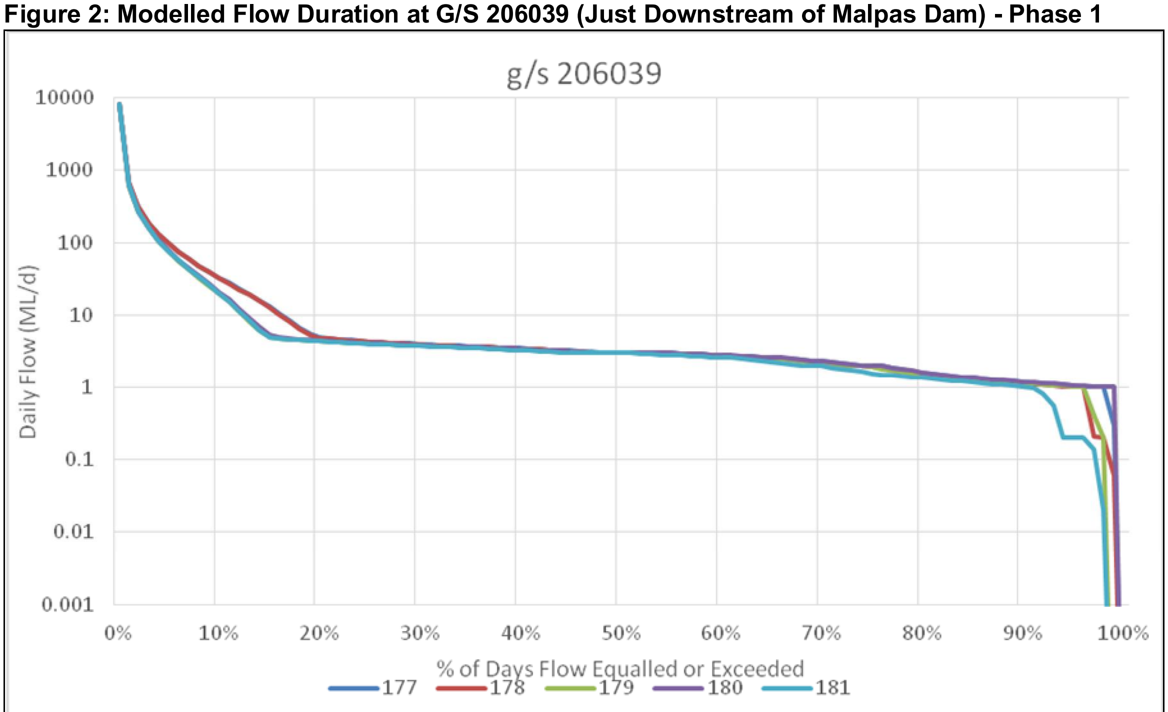


Figure 3: Modelled Flow Duration at G/S 206039 and at G/S 206035 - Phase 1

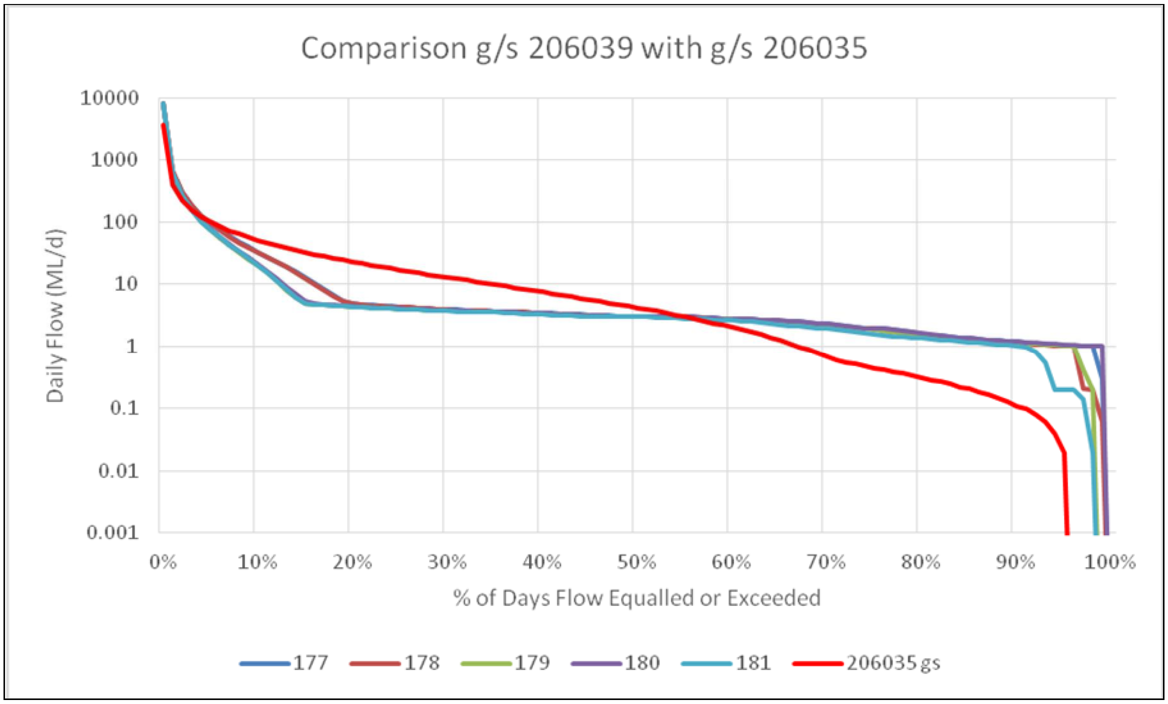
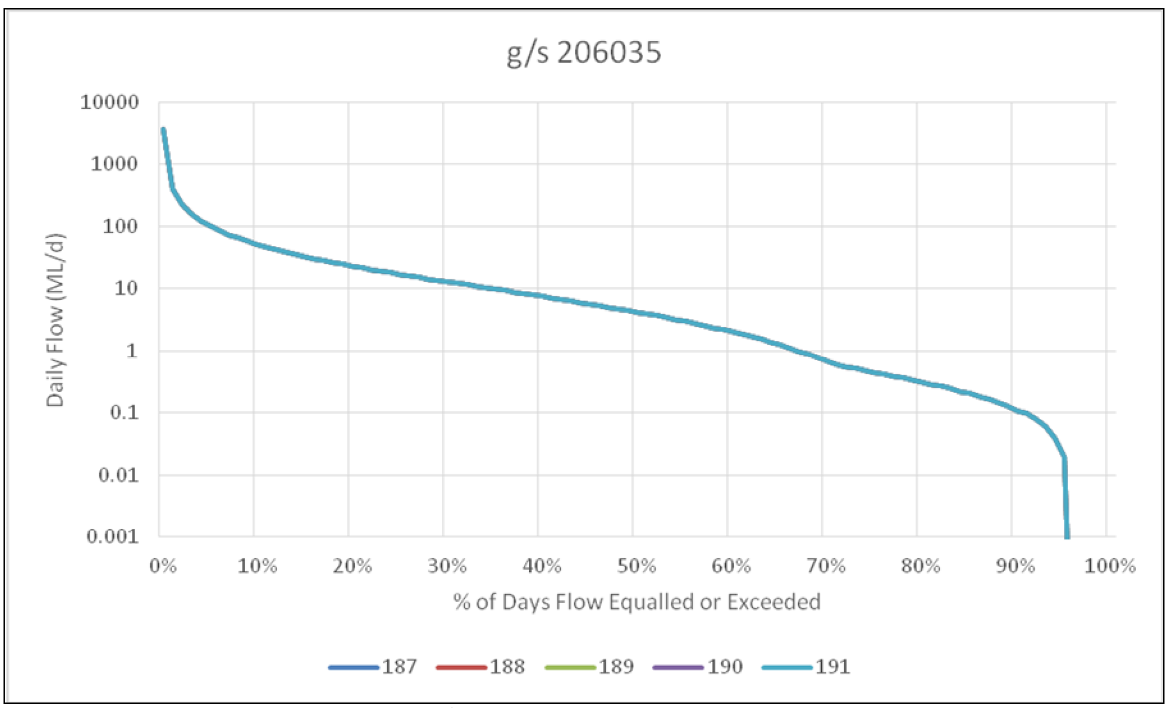


Figure 4: Modelled Flow Duration at G/S 206035 (upstream of Malpas Dam) - Phase 2



All the lines coincide with each other as expected for the upstream gauging station

Figure 5: Modelled Flow Duration at G/S 206039 (Just Downstream of Malpas Dam) - Phase 2

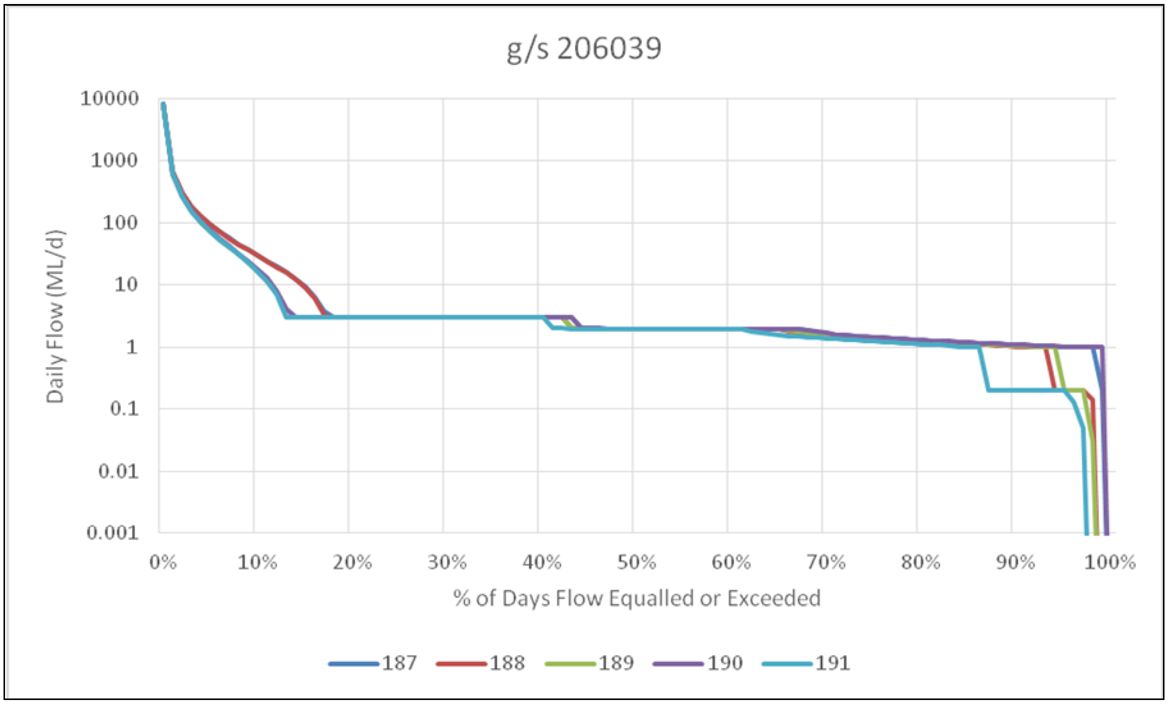


Figure 6: Modelled Flow Duration at G/S 206039 and at G/S 206035 - Phase 2

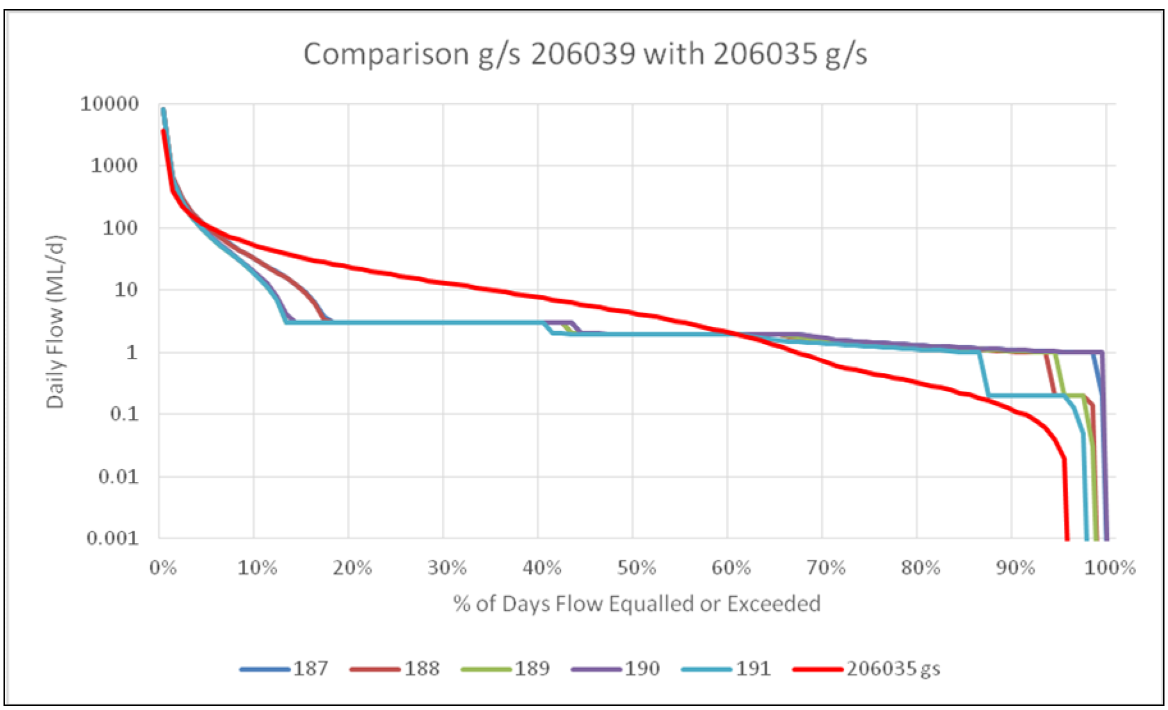
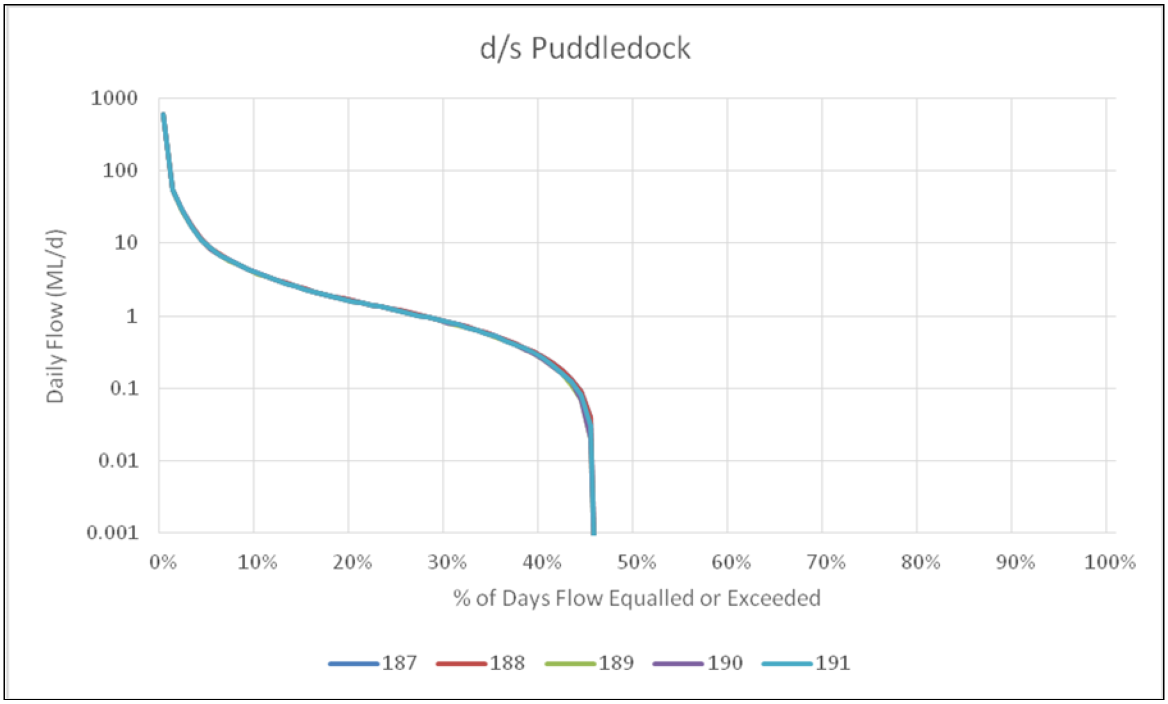


Figure 7: Modelled Flow Duration just downstream of Puddledock Dam - Phase 2

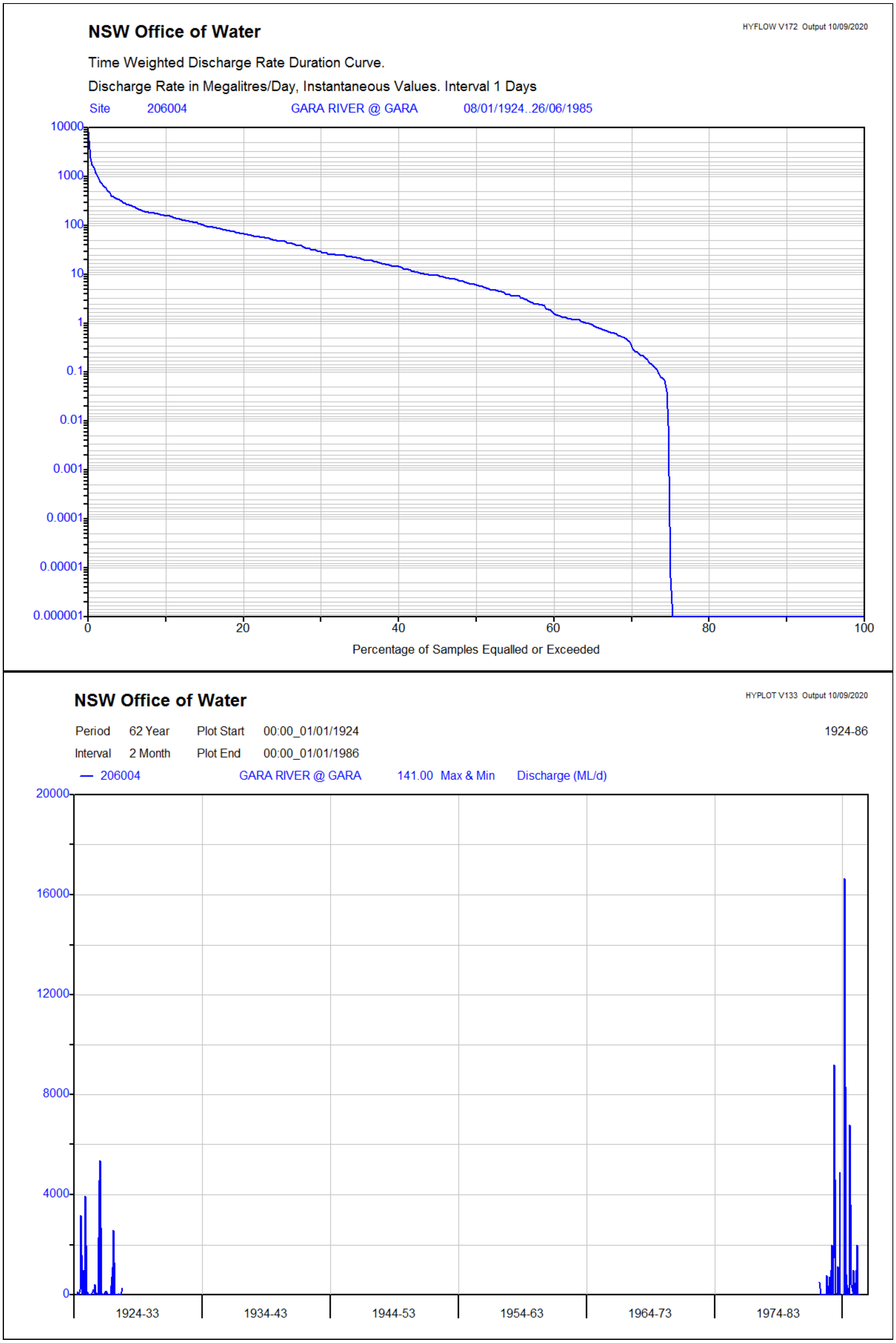


The flow duration curves suggest that the differences in the overall flow regimes between the different scenarios would not be that discernible and this would be further mitigated by the increasing contributing catchment area as one goes further downstream of the dams.

Figure 8 shows observed flows at the gauging station Gara River at Gara (206004). This gauging station had a catchment area of 407 km^2 compared to 197 km2 for the gauging station Gara River d/s Malpas Dam (206039). The gauging station was located just upstream of the junction with Commissioners Waters however it was closed in 1985. Malpas Dam was completed in 1968.

The cease to flow metrics (see Table 1) and the flow duration curves (Figures 1 to 7) suggest low flows are maintained and or even enhanced. The observed flows (see Figure 8) suggests a full range of flows including high flows still occur arising from the catchment area downstream of the dams.

Figure 8: Observed Flows Gara River at Gara (206004)



Note: It is likely the long period of apparent zero flows is missing record *Source: PINNENA Version 10.2*

Storage Behaviour

Figures 9 to 19 provide the modelled storage behaviour diagrams for a repeat of the historic climate supplying annual demands (with restrictions applied in accordance with 5/10/10 rules) that equate to the secure yields for that particular storage case.

The diagrams clearly show the influence of the recent severe 2019/2020 drought.

Climate Change

Attachment A provides the results of the required model runs for the 15 GCMs and comparable historic data base for assessing 1 ^{o}C climate warming.

The climate adjustment factor based on the lowest GCM with10/25/25 depending on case varied from 0.66 to 0.72, thus resulting in a reduction of about 30% in secure yield for 1 ^{o}C climate warming.

Figure 9: Storage Behaviour – Guyra Dams

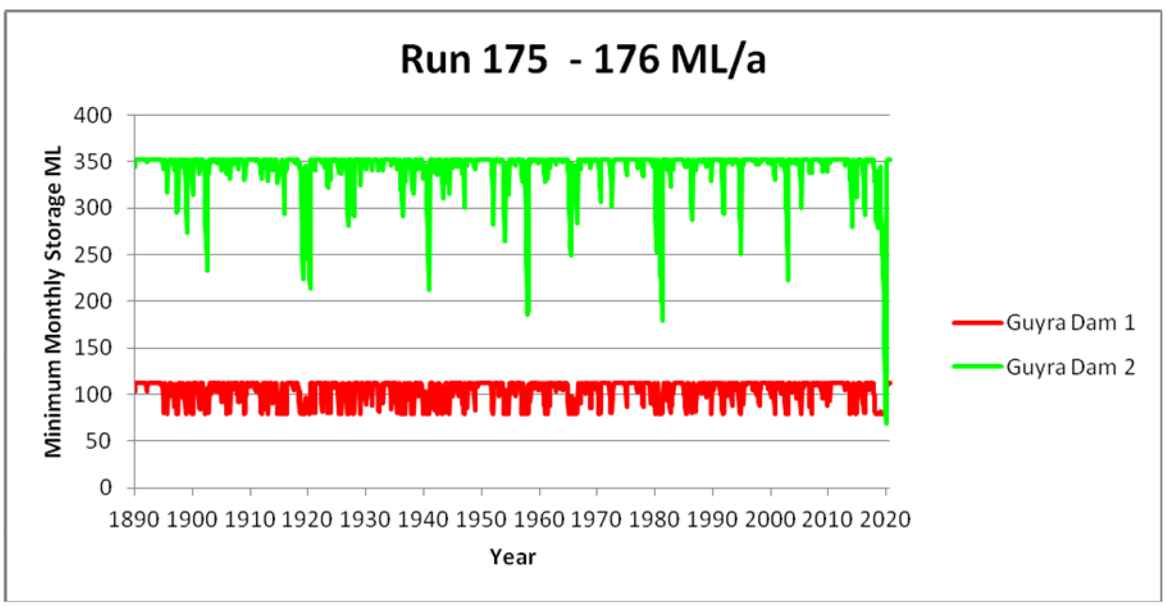


Figure 10: Storage Behaviour – Run 177

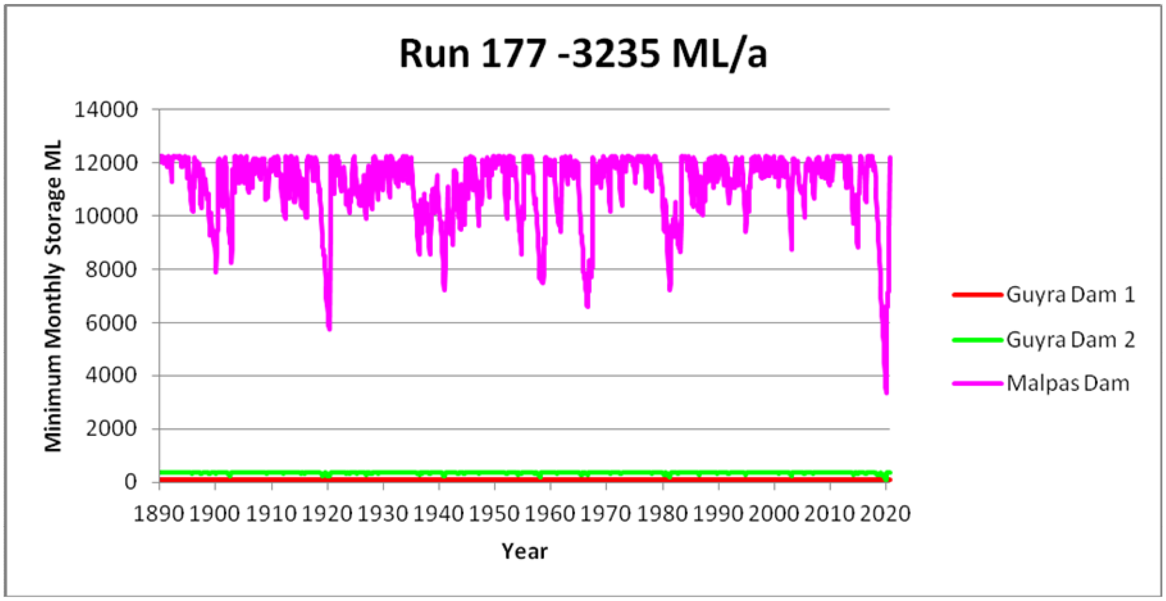


Figure11: Storage Behaviour – Run 178

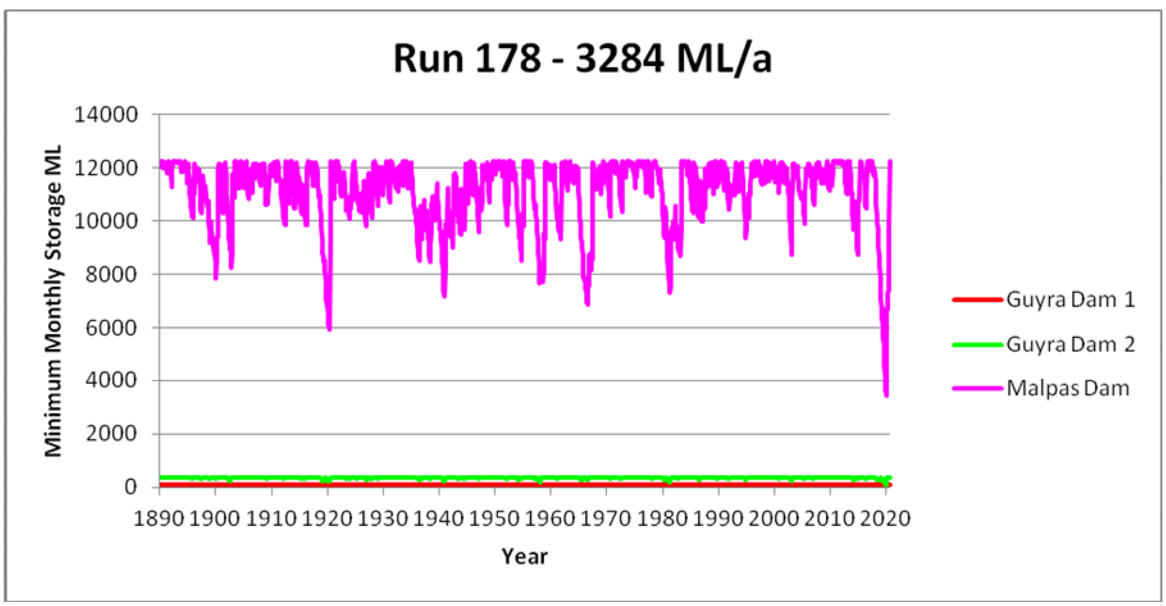


Figure 12: Storage Behaviour – Run 179

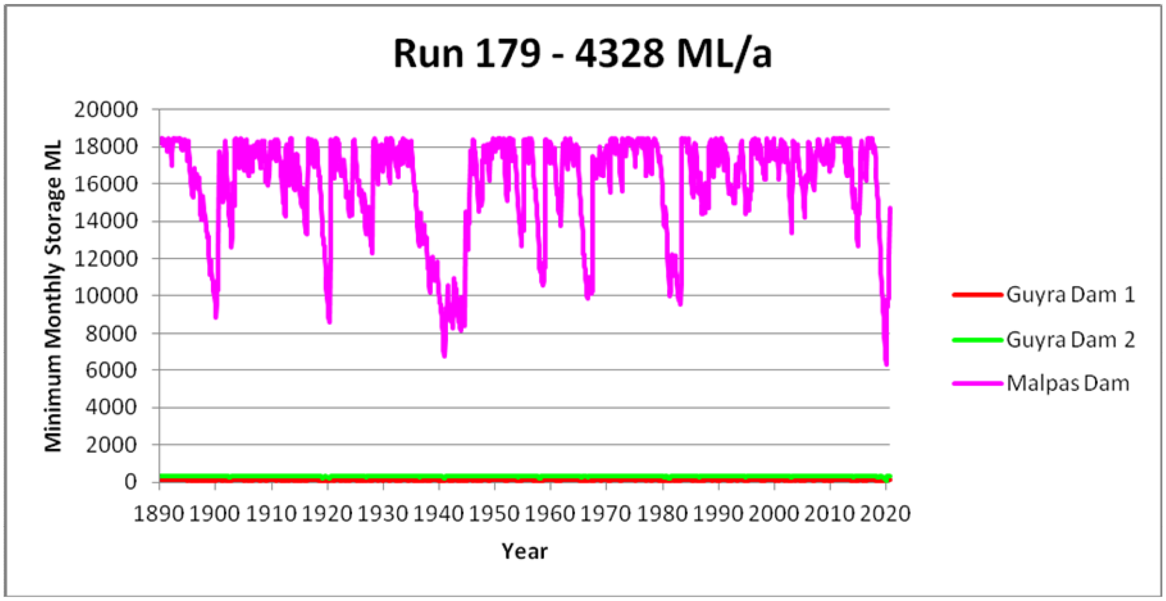


Figure 13: Storage Behaviour – Run 180

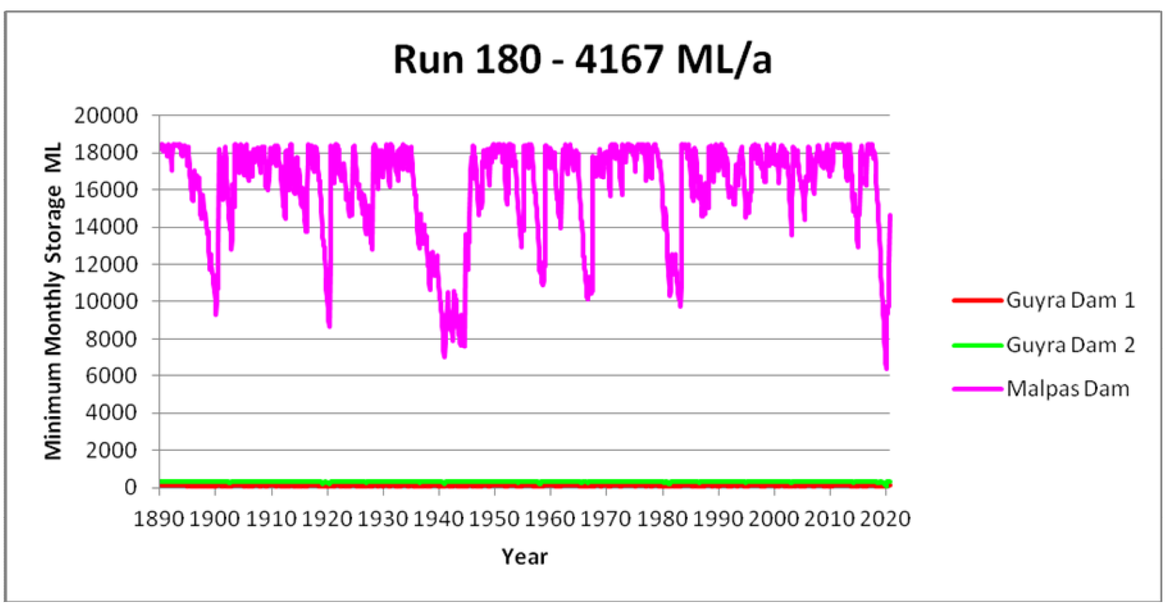


Figure 14: Storage Behaviour – Run 181

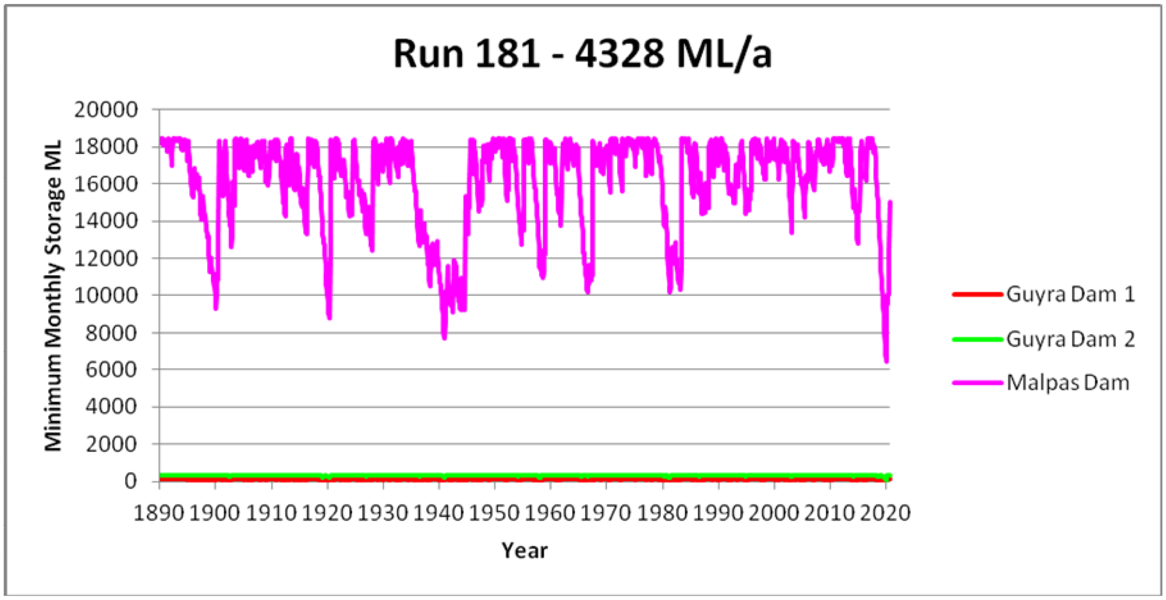
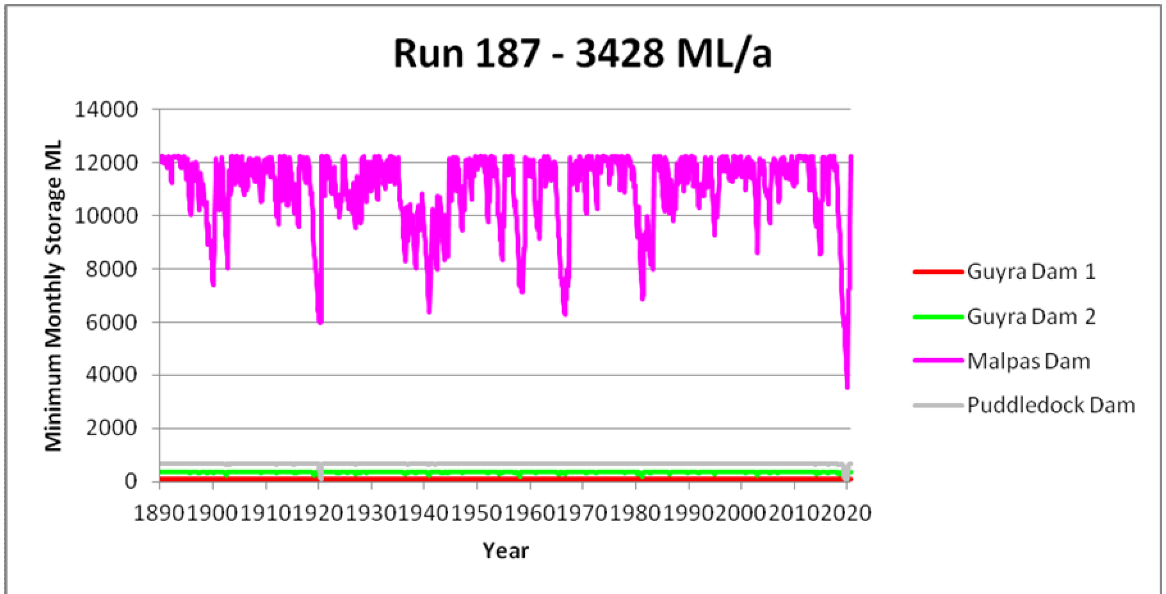


Figure 15: Storage Behaviour – Run 187



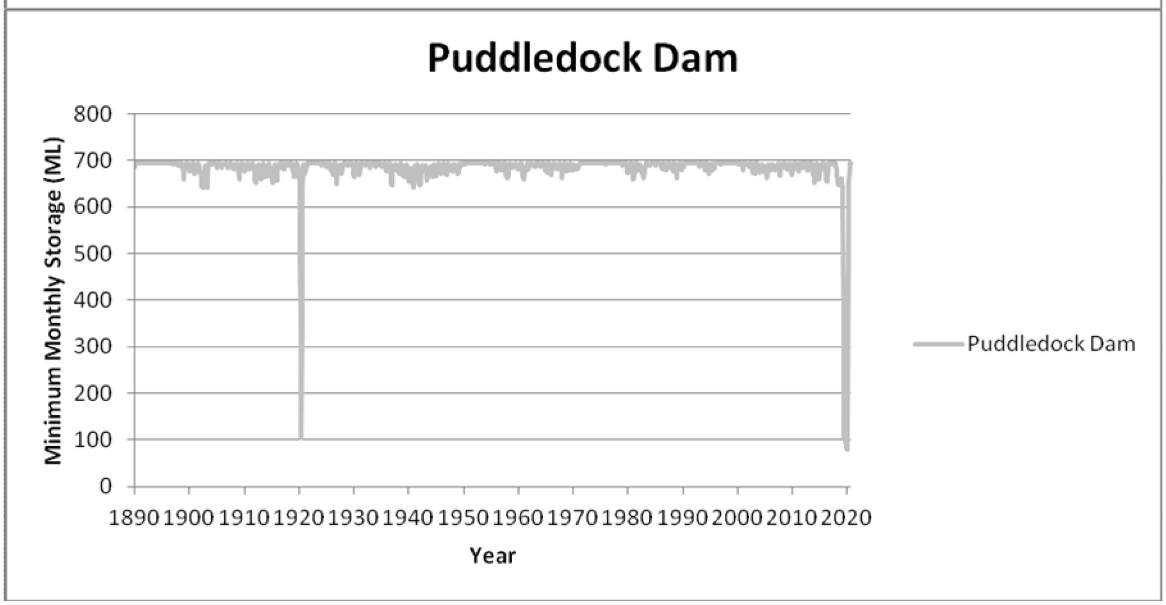
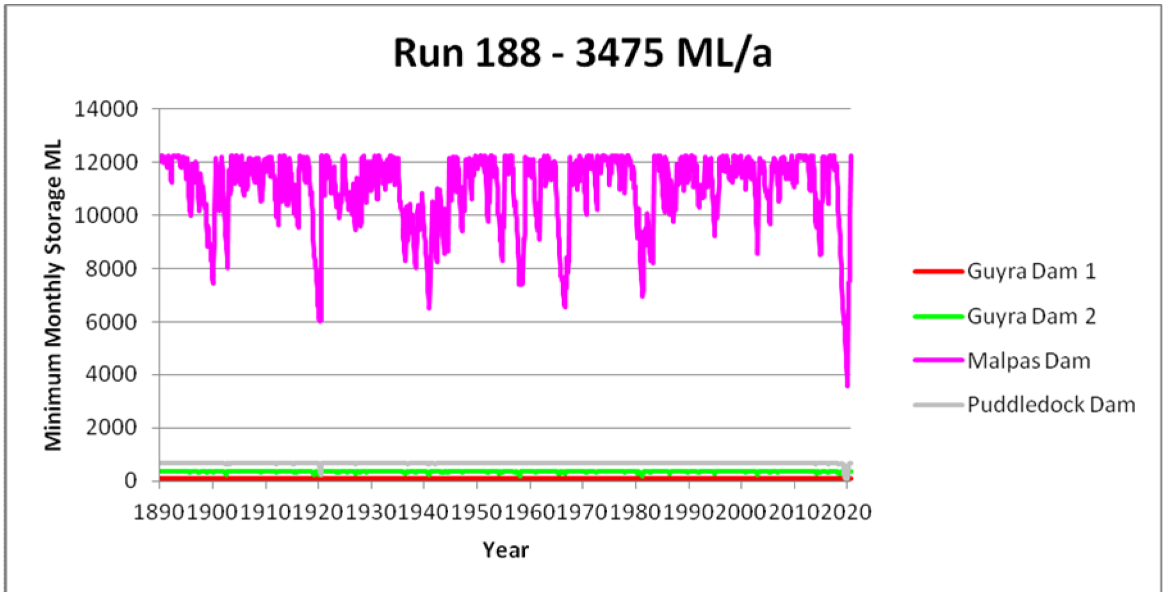


Figure 16: Storage Behaviour – Run 188



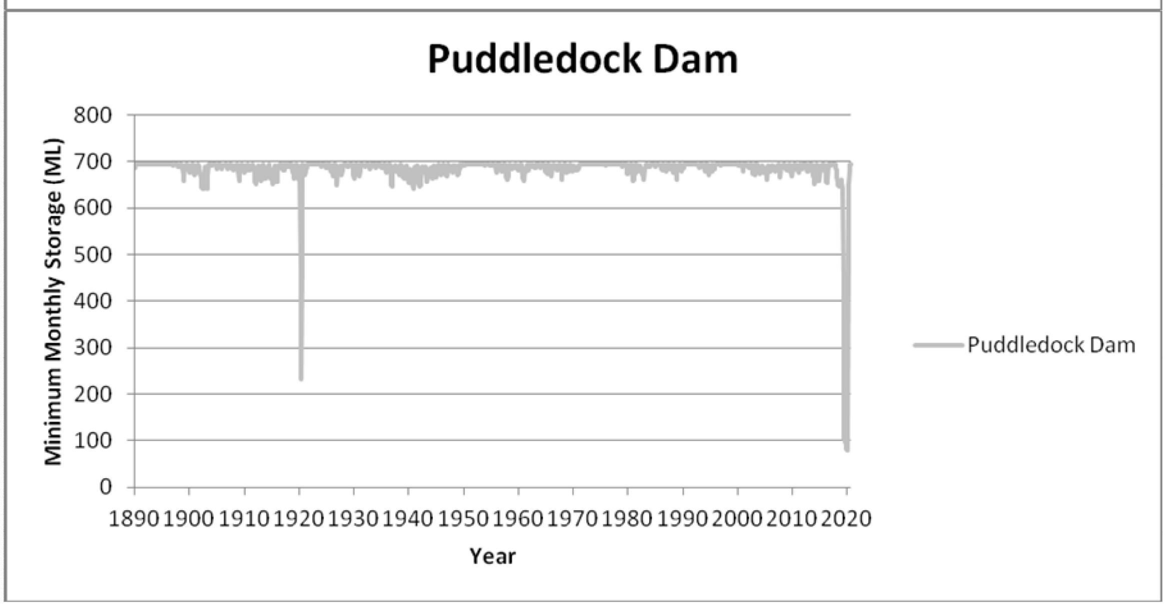
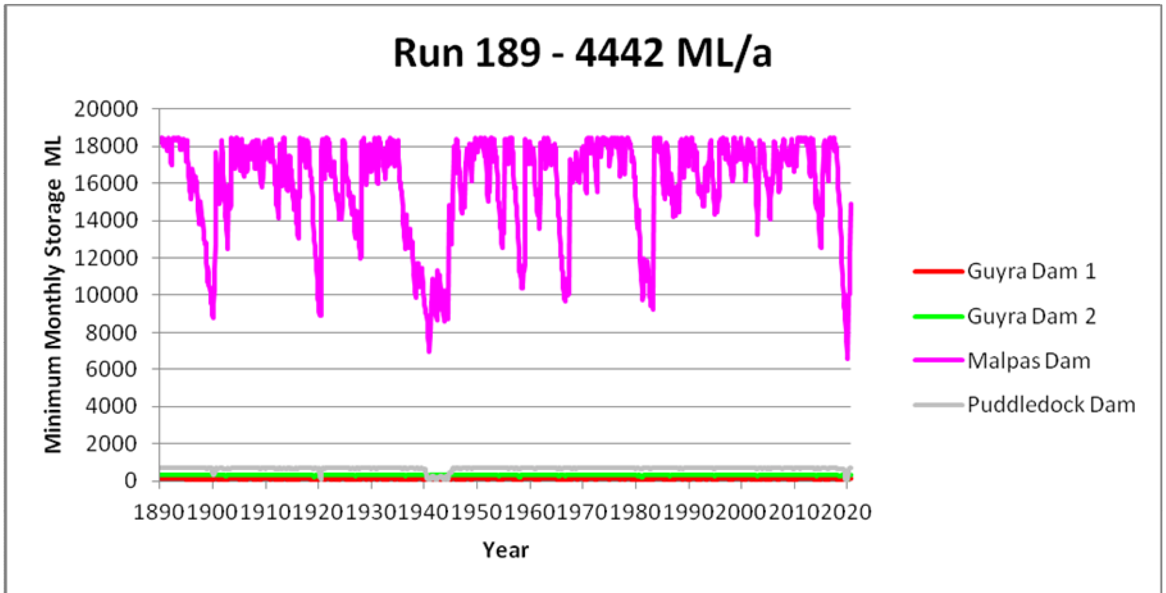


Figure 17: Storage Behaviour – Run 189



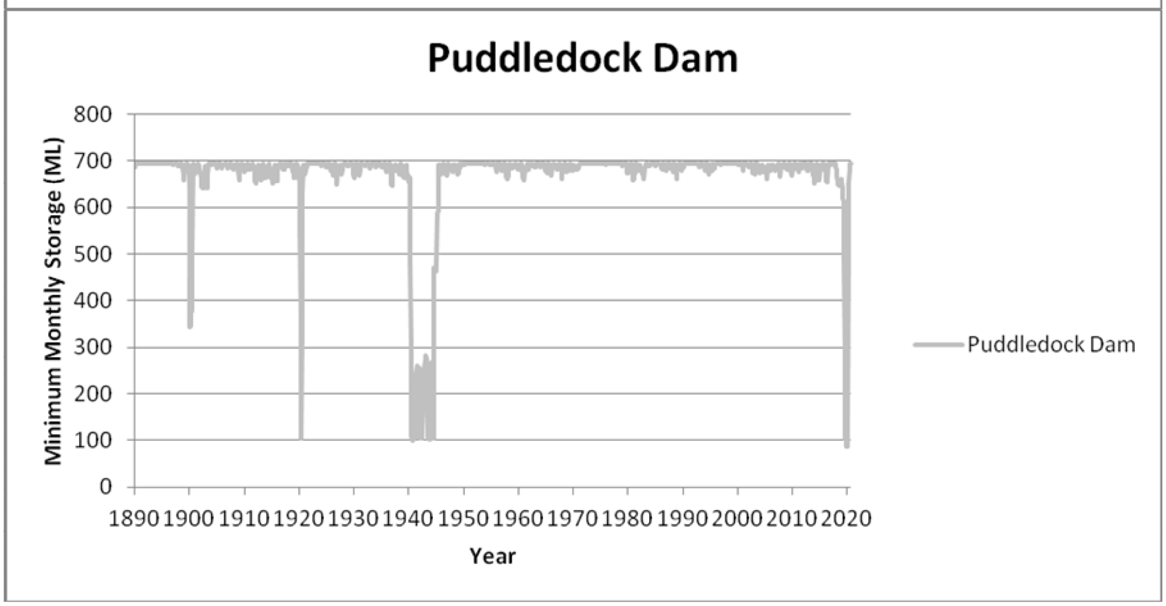
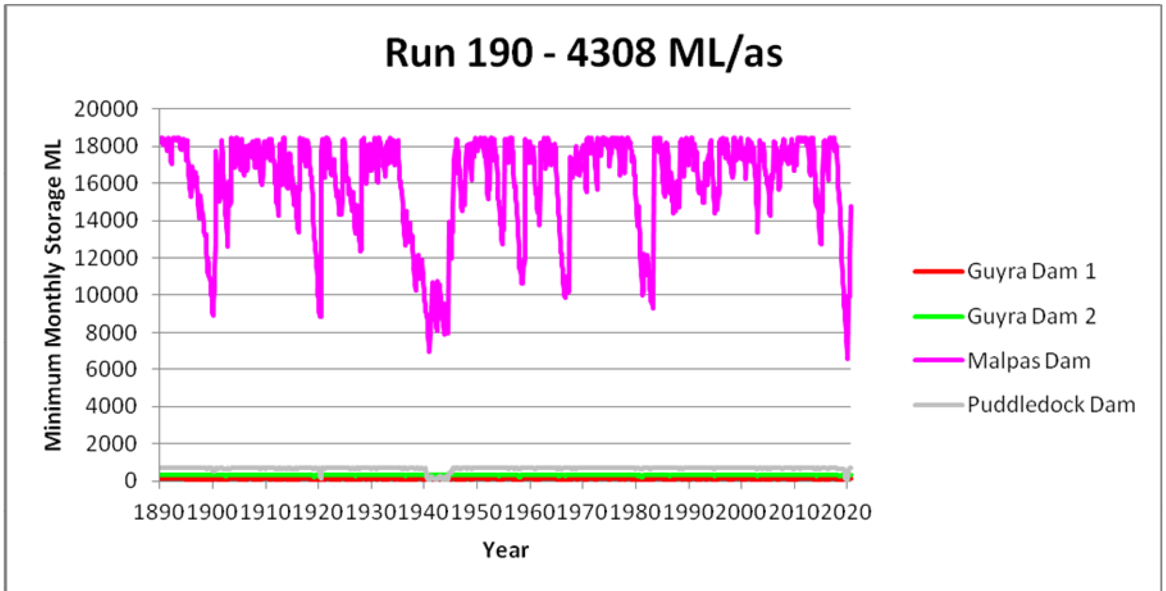


Figure 18: Storage Behaviour – Run 190



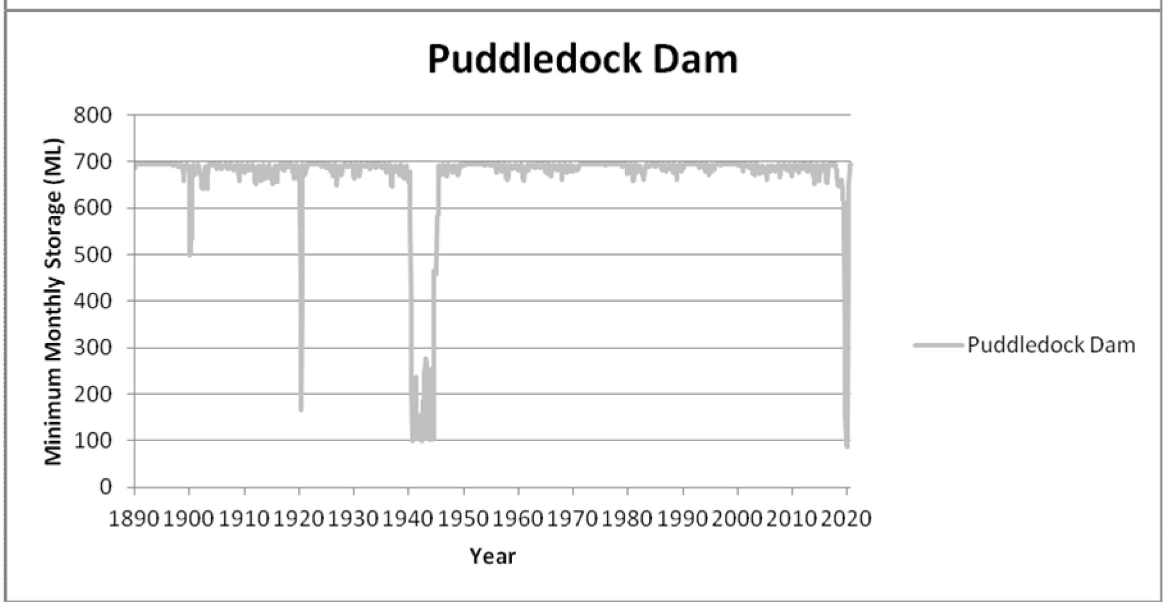
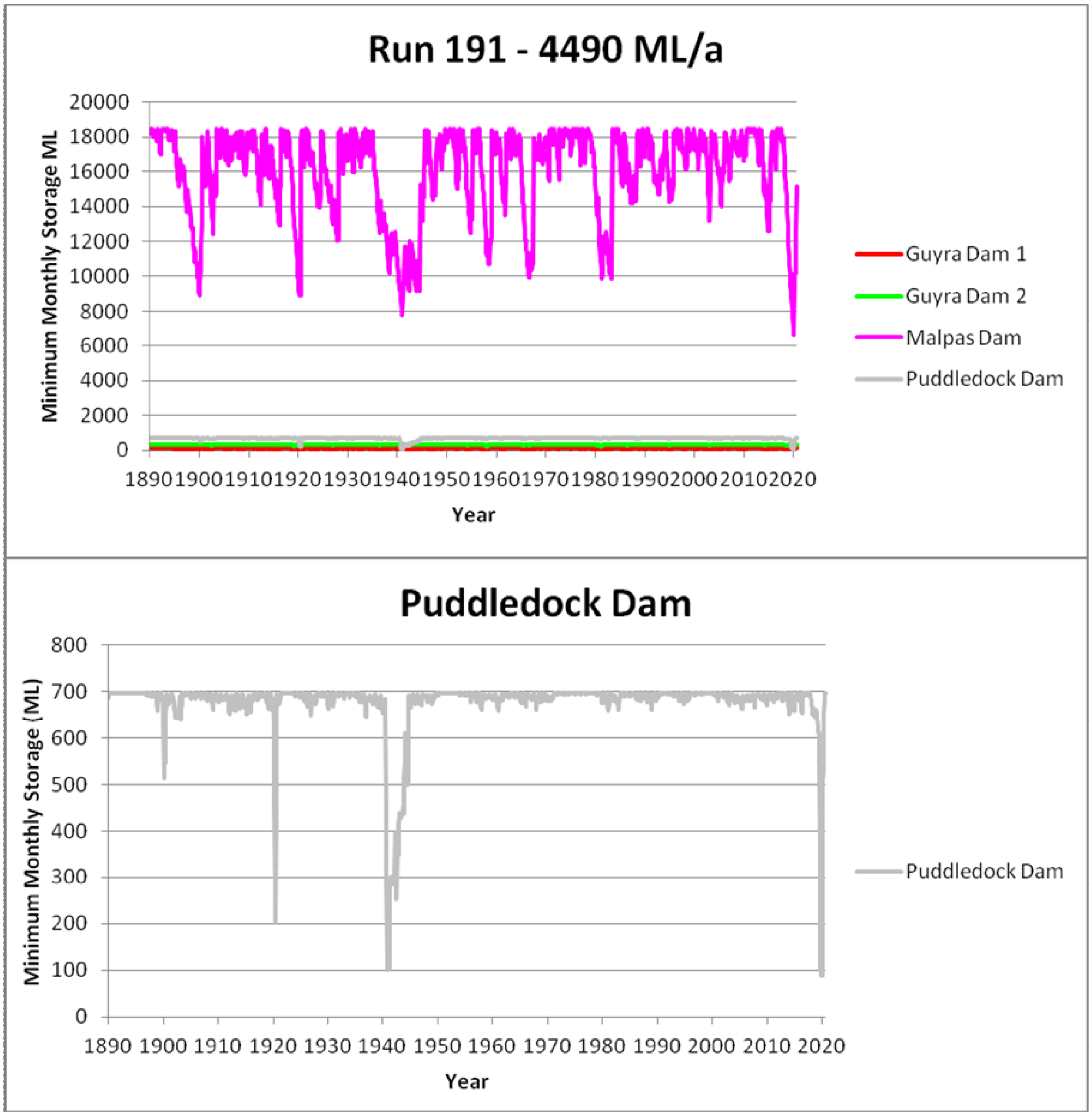


Figure 19: Storage Behaviour – Run 191



ATTACHMENT A
Model Results for 15 GCMs and corresponding Historic Base

Note that in each case shown on the following pages the data is based on modelled flow information (from a data base of daily rainfall and daily evapotranspiration) and not observed flow data. The adopted historical secure yields uses a longer period and are those in Table 2. The following data is used to adjust the yields in Table 2 in accordance with the DPIE Water Guidelines

Run 175 :Guyra Dams Only

Armidale, Run 175CC F:\Results\Armidale\Mar2020\Data\ClimateChange\Armidale_

Time: 09/09/2020 11:57:09 AM

					Restricted		Critical Drought	
		Storage	Secure	% Restricted	% of	% of		
	Run	Capacity	Yield	at	duration	years	Start	End
HISTORICAL	1	464	285	65	2.30	9.48	02/09/1918	12/06/1920
	2	464	253	60	1.00	7.76	30/11/1964	30/11/1965
	3	464	241	60	1.16	7.76	11/12/1964	30/11/1965
	4	464	181	65	2.43	7.76	31/08/1918	12/06/1920
LOWEST	5	464	124	70	2.76	9.48	23/08/1918	12/06/1920
	6	464	264	65	2.41	8.62	01/09/1918	12/06/1920
	7	464	173	70	2.42	9.48	01/09/1918	12/06/1920
	8	464	214	65	1.91	7.76	01/09/1918	12/06/1920
	9	464	154	65	1.72	7.76	31/08/1918	12/06/1920
MEDIAN	10	464	233	65	1.29	8.62	30/11/1964	30/11/1965
	11	464	308	65	1.57	9.48	20/04/1957	30/01/1958
	12	464	272	65	1.64	9.48	19/04/1957	30/01/1958
	13	464	193	65	1.99	8.62	31/08/1918	12/06/1920
	14	464	188	65	2.01	8.62	31/08/1918	12/06/1920
	15	464	247	65	2.48	9.48	01/09/1918	12/06/1920
	16	464	250	65	2.45	9.48	01/09/1918	12/06/1920
10/15/25	5	464	153	70	3.61	13.79	23/08/1918	12/06/1920

Run 177: Guyra + Malpas (Base Case)(55% Full Trigger)

Armidale, Run 177CC F:\Results\Armidale\Mar2020\Data\ClimateChange\Armidale_

Time: 09/09/2020 5:47:23 PM

					Restricted		Critical Drought	
	Run	Storage Capacity	Secure Yield	% Restricted at	% of duration	% of years	Start	End
HISTORICAL	1	12266	3944	50	3.12	9.48	01/09/1934	30/12/1940
	2	12266	3571	45	2.42	7.76	07/01/1935	30/12/1940
	3	12266	3520	45	2.82	9.48	07/01/1935	30/12/1940
	4	12266	2866	40	2.43	7.76	16/01/1935	30/12/1940
LOWEST	5	12266	2505	40	4.62	9.48	07/01/1935	30/12/1940
	6	12266	3461	45	2.70	8.62	01/09/1934	30/12/1940
	7	12266	2984	45	3.22	9.48	01/01/1894	14/02/1900
	8	12266	3345	45	3.64	9.48	01/09/1934	30/12/1940
	9	12266	2787	45	4.54	9.48	16/01/1935	30/12/1940
	10	12266	3831	50	4.16	9.48	16/01/1935	29/12/1940
	11	12266	4349	50	2.10	6.90	16/01/1935	30/12/1940
	12	12266	3969	50	3.28	9.48	07/01/1935	30/12/1940
	13	12266	3126	45	3.93	9.48	01/01/1894	14/02/1900
	14	12266	3068	45	3.90	9.48	01/01/1894	14/02/1900
MEDIAN	15	12266	3438	45	2.40	8.62	07/01/1935	30/12/1940
	16	12266	3462	45	2.14	7.76	16/01/1935	30/12/1940
10/15/25	5	12266	2751	35	4.82	8.62	07/01/1935	30/12/1940

Run 178: Guyra + Malpas (70% Full Trigger)

Armidale, Run 178CC F:\Results\Armidale\Mar2020\Data\ClimateChange\Armidale_

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	Run	Storage Capacity	Secure Yield	% Restricted at	Restricted % of duration	Restricted % of years	Critical Drought Start	Critical Drought End
HISTORICAL	1	12266	3961	55	3.06	9.48	01/09/1934	30/12/1940
	2	12266	3746	50	3.76	9.48	01/09/1934	30/12/1940
	3	12266	3620	50	3.32	9.48	07/01/1935	30/12/1940
	4	12266	2928	45	3.96	9.48	16/01/1935	30/12/1940
LOWEST	5	12266	2505	40	2.94	6.90	07/01/1935	30/12/1940
	6	12266	3580	50	3.10	9.48	01/01/1894	14/02/1900
	7	12266	3141	50	4.53	9.48	01/01/1894	14/02/1900
	8	12266	3415	45	2.28	6.90	01/09/1934	30/12/1940
	9	12266	2881	45	4.07	9.48	16/01/1935	30/12/1940
	10	12266	3886	55	4.67	9.48	16/01/1935	29/12/1940
	11	12266	4398	55	2.51	9.48	17/11/1917	12/06/1920
	12	12266	4098	50	2.14	6.03	01/09/1934	30/12/1940
	13	12266	3132	50	3.73	9.48	01/01/1894	13/02/1900
	14	12266	3087	45	2.22	5.17	01/01/1894	14/02/1900
MEDIAN	15	12266	3572	50	3.67	9.48	01/09/1934	30/12/1940
	16	12266	3629	50	3.68	9.48	16/01/1935	30/12/1940
10/15/25	5	12266	2843	40	6.96	14.66	07/01/1935	30/12/1940

Run 179: Guyra + Malpas FSL increased by 3m (55% Full Trigger)

Armidale, Run 179CC F:\Results\Armidale\Mar2020\Data\ClimateChange\Armidale_

Time: 10/09/2020 2:57:43 PM

					Restricted		Critical Drought	
	Run	Storage Capacity	Secure Yield	% Restricted at	% of duration	% of years	Start	End
HISTORICAL	1	18475	4816	45	4.99	9.48	01/09/1934	30/12/1940
	2	18475	4234	45	5.00	9.48	16/01/1935	30/12/1940
	3	18475	4160	40	3.33	6.03	16/01/1935	30/12/1940
	4	18475	3235	40	4.47	7.76	16/01/1935	30/12/1940
LOWEST	5	18475	2721	35	2.91	6.90	16/01/1935	22/08/1944
	6	18475	3997	40	2.97	6.90	16/01/1935	30/12/1940
	7	18475	3494	45	4.90	9.48	01/01/1894	14/02/1900
	8	18475	3805	40	3.24	6.90	16/01/1935	30/12/1940
	9	18475	3231	40	4.34	7.76	16/01/1935	02/07/1944
	10	18475	4453	45	3.62	9.48	18/01/1935	29/12/1940
	11	18475	5287	45	3.20	9.48	16/01/1935	30/12/1940
	12	18475	4843	45	4.99	9.48	07/01/1935	30/12/1940
	13	18475	3560	45	4.99	8.62	07/01/1935	30/12/1940
	14	18475	3487	45	4.99	9.48	07/01/1935	30/12/1940
MEDIAN	15	18475	3995	45	4.99	7.76	16/01/1935	30/12/1940
	16	18475	4063	45	4.99	7.76	16/01/1935	30/12/1940
10/15/25	5	18475	3216	35	7.54	12.93	06/11/1933	30/12/1940

Run 180: Guyra + Malpas FSL increased by 3m (6746 ML Trigger)

Armidale, Run 180CC F:\Results\Armidale\Mar2020\Data\ClimateChange\Armidale_

Time: 10/09/2020 8:32:16 PM

	Run	Storage Capacity	Secure Yield	% Restricted at	Restricted % of duration	Restricted % of years	Critical Drought Start	Critical Drought End
HISTORICAL	1	18475	4518	45	4.99	7.76	07/01/1935	30/12/1940
	2	18475	4176	40	5.00	6.90	16/01/1935	30/12/1940
	3	18475	4054	40	4.99	7.76	16/01/1935	30/12/1940
	4	18475	3102	35	3.68	6.03	16/01/1935	30/12/1940
LOWEST	5	18475	2650	35	5.00	8.62	16/01/1935	22/08/1944
	6	18475	3942	40	4.99	8.62	16/01/1935	30/12/1940
	7	18475	3416	40	4.29	8.62	01/01/1894	14/02/1900
	8	18475	3714	40	4.98	6.90	16/01/1935	30/12/1940
	9	18475	3063	35	3.20	6.90	16/01/1935	02/07/1944
	10	18475	4328	40	3.44	7.76	18/01/1935	30/12/1940
	11	18475	5115	45	3.68	8.62	16/01/1935	30/12/1940
	12	18475	4555	40	3.02	6.90	16/01/1935	30/12/1940
	13	18475	3443	40	4.09	7.76	16/01/1935	30/12/1940
	14	18475	3399	40	4.45	7.76	07/01/1935	30/12/1940
MEDIAN	15	18475	3938	40	5.00	8.62	16/01/1935	30/12/1940
	16	18475	4001	40	4.94	8.62	16/01/1935	30/12/1940
10/15/25	5	18475	3116	30	6.08	10.34	06/11/1933	30/12/1940

Run 181: Guyra + Malpas FSL increased by 3m (70% Trigger)

Armidale, Run 181CC F:\Results\Armidale\Mar2020\Data\ClimateChange\Armidale_

Time: 11/09/2020 3:23:10 PM

					Restricted		Critical Drought	
	Run	Storage Capacity	Secure Yield	% Restricted at	% of duration	% of years	Start	End
HISTORICAL	1	18475	4836	45	4.03	8.62	01/09/1934	30/12/1940
	2	18475	4368	45	4.90	8.62	16/01/1935	30/12/1940
	3	18475	4249	45	4.99	8.62	16/01/1935	30/12/1940
	4	18475	3235	40	3.34	6.03	16/01/1935	30/12/1940
LOWEST	5	18475	2787	40	5.00	8.62	19/02/1934	22/08/1944
	6	18475	4149	45	5.00	8.62	01/01/1894	14/02/1900
	7	18475	3603	45	4.10	9.48	01/01/1894	14/02/1900
	8	18475	3911	45	5.00	7.76	16/01/1935	30/12/1940
	9	18475	3231	40	3.35	6.03	16/01/1935	02/07/1944
	10	18475	4491	45	2.95	8.62	18/01/1935	29/12/1940
	11	18475	5417	50	4.44	9.48	16/01/1935	30/12/1940
	12	18475	4904	45	4.42	9.48	07/01/1935	30/12/1940
	13	18475	3632	45	4.30	7.76	01/01/1894	14/02/1900
	14	18475	3585	45	4.59	8.62	01/01/1894	14/02/1900
MEDIAN	15	18475	4112	45	4.83	7.76	16/01/1935	30/12/1940
	16	18475	4158	45	4.59	7.76	16/01/1935	30/12/1940
10/15/25	5	18475	3266	35	7.34	12.07	06/11/1933	22/08/1944

Run 187: Guyra + Malpas + Puddledock (base Case) (55% Trigger)

Armidale, Run 187CC F:\Results\Armidale\Mar2020\Data\ClimateChange\Armidale_

Time: 18/09/2020 12:29:37 AM

					Restricted		Critical Drought	
	Run	Storage Capacity	Secure Yield	% Restricted at	% of duration	% of years	Start	End
HISTORICAL	1	12962	4120	50	3.87	9.48	01/09/1934	30/12/1940
	2	12962	3610	45	1.98	7.76	07/01/1935	30/12/1940
	3	12962	3600	45	2.85	9.48	07/01/1935	30/12/1940
	4	12962	2908	40	2.20	7.76	16/01/1935	30/12/1940
LOWEST	5	12962	2519	40	3.95	8.62	07/01/1935	30/12/1940
	6	12962	3592	45	2.95	9.48	01/09/1934	30/12/1940
	7	12962	3046	40	1.70	3.45	01/01/1894	14/02/1900
	8	12962	3419	45	3.74	9.48	01/09/1934	30/12/1940
	9	12962	2833	45	4.64	9.48	16/01/1935	30/12/1940
	10	12962	3903	50	3.83	7.76	16/01/1935	29/12/1940
	11	12962	4574	50	2.73	8.62	01/09/1934	30/12/1940
	12	12962	4142	50	3.48	9.48	01/09/1934	30/12/1940
	13	12962	3199	45	4.10	9.48	01/01/1894	13/02/1900
	14	12962	3151	45	4.23	9.48	01/01/1894	14/02/1900
MEDIAN	15	12962	3578	45	3.04	9.48	01/09/1934	30/12/1940
	16	12962	3603	45	2.80	8.62	16/01/1935	30/12/1940
10/15/25	5	12962	2804	40	6.70	14.66	19/02/1934	30/12/1940

Run 188: Guyra + Malpas + Puddledock (70% Trigger)

Armidale, Run 188CC F:\Results\Armidale\Mar2020\Data\ClimateChange\Armidale_

Time: 17/09/2020 2:56:29 AM

	Run	Storage Capacity	Secure Yield	% Restricted at	Restricted % of duration	Restricted % of years	Critical Drought Start	Critical Drought End
HISTORICAL	1	12962	4170	50	2.17	6.03	01/09/1934	30/12/1940
	2	12962	3837	50	3.93	9.48	01/09/1934	30/12/1940
	3	12962	3711	50	3.46	9.48	01/09/1934	30/12/1940
	4	12962	2992	45	3.96	9.48	16/01/1935	30/12/1940
LOWEST	5	12962	2531	45	5.00	9.48	07/01/1935	30/12/1940
	6	12962	3690	50	3.43	9.48	01/01/1894	14/02/1900
	7	12962	3175	50	4.34	9.48	01/01/1894	14/02/1900
	8	12962	3567	45	3.34	9.48	01/09/1934	30/12/1940
	9	12962	2950	45	4.27	9.48	07/01/1935	30/12/1940
	10	12962	3963	55	4.74	9.48	16/01/1935	29/12/1940
	11	12962	4574	50	1.64	3.45	01/09/1934	30/12/1940
	12	12962	4269	50	2.69	6.90	01/09/1934	30/12/1940
	13	12962	3199	45	2.10	4.31	01/01/1894	13/02/1900
	14	12962	3157	45	2.20	5.17	01/01/1894	14/02/1900
MEDIAN	15	12962	3652	50	3.75	9.48	01/09/1934	30/12/1940
	16	12962	3711	50	3.78	9.48	07/01/1935	30/12/1940
10/15/25	5	12962	2958	40	7.89	14.66	06/11/1933	30/12/1940

Run 189: Guyra + Malpas FSL increased by 3m+ Puddledock (55% Trigger)

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					Restricted		Critical Drought	
	Run	Storage Capacity	Secure Yield	% Restricted at	% of duration	% of years	Start	End
HISTORICAL	1	19171	4930	45	4.94	9.48	01/09/1934	30/12/1940
	2	19171	4341	45	5.00	9.48	16/01/1935	30/12/1940
	3	19171	4232	40	3.09	6.03	16/01/1935	30/12/1940
	4	19171	3260	40	3.88	6.90	16/01/1935	30/12/1940
LOWEST	5	19171	2751	40	4.99	8.62	19/02/1934	22/08/1944
	6	19171	4102	40	2.93	6.90	07/01/1935	30/12/1940
	7	19171	3561	45	4.83	9.48	01/01/1894	14/02/1900
	8	19171	3856	45	5.00	8.62	16/01/1935	30/12/1940
	9	19171	3283	40	4.14	6.90	07/01/1935	02/07/1944
	10	19171	4518	45	3.14	9.48	16/01/1935	29/12/1940
	11	19171	5512	45	3.64	9.48	01/09/1934	30/12/1940
	12	19171	4915	45	4.42	9.48	07/01/1935	30/12/1940
	13	19171	3641	45	5.00	9.48	07/01/1935	30/12/1940
	14	19171	3566	45	5.00	9.48	07/01/1935	30/12/1940
MEDIAN	15	19171	4086	45	4.99	7.76	16/01/1935	30/12/1940
	16	19171	4158	45	5.00	7.76	16/01/1935	30/12/1940
10/15/25	5	19171	3273	35	7.53	12.07	06/11/1933	30/12/1940

Run 190: Guyra + Malpas FSL increased by 3m+ Puddledock (6746 ML Trigger)

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	Run	Storage Capacity	Secure Yield	% Restricted at	Restricted % of duration	Restricted % of years	Critical Drought Start	Critical Drought End
HISTORICAL	1	19171	4632	45	4.99	7.76	07/01/1935	30/12/1940
	2	19171	4286	40	5.00	6.90	16/01/1935	30/12/1940
	3	19171	4156	40	5.00	7.76	16/01/1935	30/12/1940
	4	19171	3126	35	3.43	6.03	16/01/1935	30/12/1940
LOWEST	5	19171	2691	35	5.00	8.62	19/02/1934	22/08/1944
	6	19171	4032	40	4.99	8.62	16/01/1935	30/12/1940
	7	19171	3477	40	4.30	8.62	01/01/1894	14/02/1900
	8	19171	3790	40	4.99	6.90	16/01/1935	30/12/1940
	9	19171	3108	35	3.17	6.90	16/01/1935	02/07/1944
	10	19171	4427	45	5.00	9.48	18/01/1935	29/12/1940
	11	19171	5332	45	4.27	9.48	16/01/1935	30/12/1940
	12	19171	4726	40	3.46	6.90	16/01/1935	30/12/1940
	13	19171	3515	40	4.17	7.76	07/01/1935	30/12/1940
	14	19171	3469	40	4.56	7.76	07/01/1935	30/12/1940
MEDIAN	15	19171	4012	40	4.91	7.76	16/01/1935	30/12/1940
	16	19171	4058	40	4.70	6.90	16/01/1935	30/12/1940
10/15/25	5	19171	3180	35	9.03	14.66	06/11/1933	30/12/1940

working together to ensure water supply security

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MEMORANDUM

TO	Glenn Fernandes Principal Engineer- Planning (Water Utilities) NSW Public Works Advisory
CC	
FROM	Peter Cloke, Principal Hydrologist
DATE	19 October 2020
SUBJECT	Armidale Yield Study: Progress Report (4) **REVISED**[1]

This Revised Progress Report (4) supersedes Progress Report 4 of 14 October 2020..

The Phase 3 Scenarios and additional cases as requested in the meeting with Council/DPIE Water PWA & NUWS on the 29/9/2020 and the DPIE Water email of 30/9/2020 have been modelled and the results are reported herein.

Summary

The requested results are provided in Table 1.

Table 2 provides the secure yield modelling results for the historic climate.

It is noted the secure yield estimates are dependent on the operating rules, data and assumptions as discussed herein and or in the previous 3 Progress Reports (30/3/2020, 26/5/2020 & 18/9/2020).

The provided future target demand was 5066 ML/a for Armidale and 589 ML/a for Guyra**.**

While the Malpas storage size could be found to meet the target demands on a secure yield basis for a repeat of the historic climate, the required storage sizes could not be found for the 1 ^{o}C climate warming scenario.

1. *Progress Report 4 was revised as the old rule (see Progress Report 1) for Gara Dam was used whereby Gara Dam was used in preference to Malpas Dam rather than the intended use. See operational rule p5.*

Table 1: Armidale Water supply – Requested Scenarios for Secure Yield Modelling

No	Scenario	Release from Malpas dam does not apply when	**Climate change secure yield* ML/a**	Cease to flow at Willow gauging station (206035)			Cease to flow at Gara River gauging station (206039)			Cease to flow metrics for Puddledock d/s of dam			Cease to flow metrics for Gara Dam d/s of dam		
				Days	Average	Maximum	Days	Average	Maximum	Days	Average	Maximum	Days	Average	Maximum
PHASE 3															
11	Guyra+Malpas FSL increased by 6.5 m	Malpas dam less than 6746 ML	**3469**	1969	4.56	84	42	3.5	11	-	-	-	-	-	-
12	Guyra+Malpas FSL increased by 6.5m +Puddledock	Malpas dam less than 6746 ML	**3595**	1969	4.56	84	0	0	0	26186	16.07	2423	-	-	-
13	Existing (Guyra+Malpas) dams	No release requirements	**2615**	1969	4.56	84	38112	56.96	1401	-	-	-	-	-	-
14	Guyra+Malpas FSL increased by 3m +Puddledock +Gara	Malpas dam less than 6746 ML	**2887**	1969	4.56	84	0	0	0	26104	15.75	2137	863	61.64	252
15	Guyra+Malpas FSL increased by 6.5 m +Puddledock+ Gara	Malpas dam less than 6746 ML	**3956**	1969	4.56	84	0	0	0	26352	16.31	2611	2182	43.64	306
16	Guyra+Malpas FSL increased to 28572 ML to provide required water security+Puddledock+Gara	Malpas dam less than 6746 ML	**3833**	1969	4.56	84	0	0	0	26128	15.90	2137	1642	44.38	306
16b	Guyra+Malpas FSL increased to 39039 ML to provide required water security+Puddledock+Gara	Malpas dam less than 6746 ML	**4139**	1969	4.56	84	0	0	0	26099	15.93	2423	1834	45.85	306
17b	Guyra+Malpas FSL increased to 39039 ML to provide required water security	Malpas dam less than 6746 ML	**3892**	1969	4.56	84	0	0	0	-	-	-	-	-	-
ADDITIONAL CASES													Cease to flow metrics for Dumaresq Dam d/s of dam		
	Guyra+Malpas FSL increased by 3m + Puddledock	No release requirements	**3028**	1966	4.55	84	40647	76.79	3830	25941	15.40	1188	-	-	-
	Dumaresq Dam on its own	n/a	**101**	-	-	-	-	-	-	-	-	-	32673	33.75	2505

Total Storage for existing Malpas Dam 12266 ML (55% is 6746 ML). Total Storage for Malpas raised 3m is 18475 ML. Total Storage for Malpas Dam raised 6.5 M is 27630 ML .
Cease to flow metrics based on historic climate secure yield (Modelling Period 1/1/1890 to 1/9/2020)
*Excludes Guyra dams secure yield. The demand on the Guyra dams was fixed at 96 ML/a being the determined climate change secure yield for the Guyra dams only.

Table 2: Preliminary Secure Yield Estimates (Historic Climate)

No	Model Run No	Scenario	Release from Malpas dam does not apply when	Secure Yield ML/a	Restrictions			Critical Drought	
					Applied at storage (% full)	Duration (%)	% of Years)	From	To
	200	Guyra Dams Only	n/a	**175**	70	1.38	7.58	15/01/2018	15/01/2020
PHASE 3									
11	201	Guyra+Malpas FSL increased by 6.5 m	Malpas dam less than 6746 ML	**5176***	45	4.08	6.06	16/01/1935	2/07/1944
12	202	Guyra+Malpas FSL increased by 6.5m +Puddledock	Malpas dam less than 6746 ML	**5279***	50	5.00	7.58	16/01/1935	2/07/1944
13	203	Existing (Guyra+Malpas) dams	No release requirements	**3631***	70	3.93	9.09	14/01/2018	6/02/2020
14	206	Guyra+Malpas FSL increased by 3m +Puddledock +Gara	Malpas dam less than 6746 ML	**4318***	55	3.77	8.33	14/01/2018	25/01/2020
15	207	Guyra+Malpas FSL increased by 6.5 m +Puddledock+ Gara	Malpas dam less than 6746 ML	**5593***	50	5.00	7.58	20/01/1935	30/12/1940
16	208	Guyra+Malpas FSL increased to 28572 ML to provide required water security+Puddledock+Gara	Malpas dam less than 6746 ML	**5479***	50	4.58	6.82	16/01/1935	30/12/1940
16b	209	Guyra+Malpas FSL increased to 39039 ML to provide required water security+Puddledock+Gara	Malpas dam less than 6746 ML	**6201***	50	4.71	6.82	16/01/1935	02/07/1944
17	204	Guyra+Malpas FSL increased to 29112 ML to provide required water security	Malpas dam less than 6746 ML	**5479***	45	4.53	7.58	16/01/1935	2/7/1944
17b	205	Guyra+Malpas FSL increased to 39039 ML to provide required water security	Malpas dam less than 6746 ML	**5926***	50	5.00	6.82	16/01/1935	2/7/1944
ADDITIONAL CASES									
	192	Guyra+Malpas FSL increased by 3m + Puddledock *(cf to Phase 2 -10/190 &191)*	No release requirements	**4579***	60	3.38	9.85	14/01/2018	6/02/2020
	210	Dumaresq Dam on its own	n/a	**142**	75	4.19	9.09	15/01/2018	15/01/2020

Total Storage for existing Malpas Dam 12266 ML. Thus 55% equates to 6746 ML
Total Storage for Malpas raised 3m is 18475 ML. Total Storage for Malpas raised 3m is 27630 ML
Modelling Period 1/1/1890 to 1/9/2020
*Excludes Guyra dams secure yield. The demand on the Guyra dams was fixed at 175 ML/a being the determined historic climate secure yield for the Guyra dams only.

Assumptions

The system behaviour modelling included the following updated assumptions:

Inflows

The dam inflows were based on those developed for Run 143 as detailed in Progress Report 2 and extended in a similar way to 1/9/2020.

For the requested high level initial assessment purposes for Dumaresq Dam the dam inflows were assumed to be the same as for Puddledock Dam but factored by the ratio of their catchment areas (21/24). *The same daily rainfall and evaporation data as used for the Puddledock Dam storage to allow for storage evaporation losses was used for Dumaresq Dam.*

Storage Details

Dam	Total Storage ML	Dead Storage ML
Malpas Dam (Existing)	12,266	613
Malpas (FSL raised by 3m)	18,475	613
Malpas (FSL Raised by 6.5m)	27,630	613
South Guyra Dam (No.1)	112	33
North Guyra Dam (No.2)	352	36
Puddledock Dam	696	105
Gara Dam	218.97	140.4 *
Dumaresq Dam	440***	44**
** Effective as according to WSP can only extract water when water level above 1m below crest level* *** Assumed 10%* **** Taken from Dam Surveillance Report*		

For the requested high level initial assessment purposes for Dumaresq Dam, it was assumed to have the same water surface area as Puddledock Dam for the same storage volume.

Release Rules

No release rules were applied to the Guyra Dams and Puddledock Dam.

For Malpas Dam two sets of conditional rules were applied:

1. When inflows to Malpas Dam, as measured at the Gara River at Willow Glen gauge (206035), were:
   (a) less than 1 ML/day, a release equal to or greater than the inflows plus 1 ML/day, as measured at the Gara River downstream Malpas Dam gauge (206039), was made from Malpas Dam, or
   (b) equal to or greater than 1 ML/day and less than or equal to 6 ML/day, a release of 2 ML/day or greater, as measured at the Gara River downstream Malpas Dam gauge (206039), was made from Malpas Dam, or
   (c) greater than 6 ML/day, a release of 3 ML/day or greater, as measured at the Gara River downstream Malpas Dam gauge (206039), was be made from Malpas Dam.

   The above did not apply when the Malpas Dam was less than or equal to the stated release condition in terms of the damôs storage capacity.

2. If the inflow to Malpas Dam was greater than 0.2 ML/d, then 0.2 ML/d was released. If the inflow was less than 0.2 ML/d then the inflow was released.

In applying the rules any spill from the dam was counted as contributing towards satisfying the releases. Furthermore if any releases were made from the first set of rules these were counted towards satisfying the release under the second of rule.

For Gara Dam two sets of conditional rules were applied:

1. If the inflow to Gara Dam was greater than 0.2 ML/d, then 0.2 ML/d was released. If the inflow was less than 0.2 ML/d then the inflow was released.

2. Water could not be taken when the level of the water in the Gara Dam storage was lower than 1 m below the crest of the dam.

Operational Rule

Demand equivalent to the secure yield of the Guyra Dams was taken from the Guyra Dams.

Malpas Dam was used to supply demand until it was drawdown to 50% then Puddledock Dam was used and then Gara Dam was used and then Malpas Dam was used to meet demand that could not be met by Puddledock Dam and Gara Dam.

Demand Patterns

Whilst secure yield provides the system annual demand that can be met, the annual demand needs to be broken down into monthly patterns to reflect seasonality. The patterns used were:

	Armidale	Guyra
Jan	9.1%	11.7%
Feb	9.1%	9.4%
Mar	9.3%	9.1%
Apr	8.7%	8.5%
May	6.4%	8.8%
Jun	5.9%	6.1%
Jul	6.0%	4.7%
Aug	7.4%	5.1%
Sep	7.5%	6.9%
Oct	8.4%	9.3%
Nov	11.1%	9.5%
Dec	11.0%	10.7%

Source : PWA

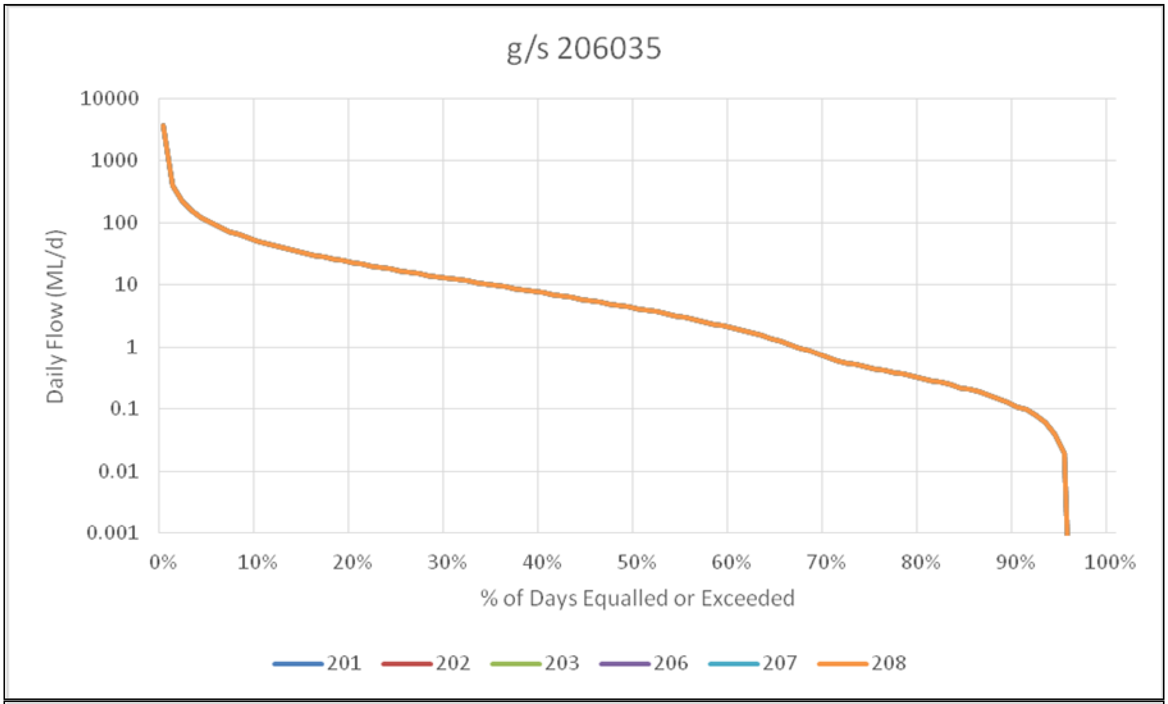
Discussion

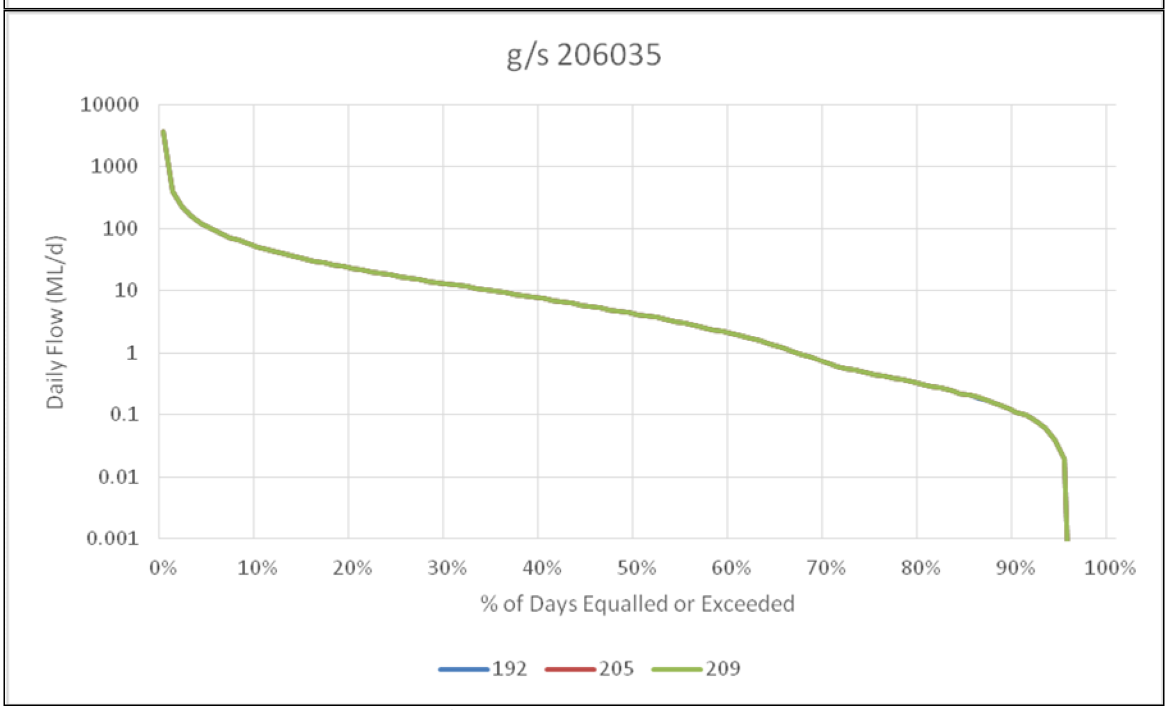
Cease to flow metrics

Table 1 provides requested cease to flow metrics. Figures 1 to 6 provide a *snap shot* of the change in the full range of flows.

It is interesting to note that the provided WSP rules generally require that at least 1 to 6 ML/d is released from Malpas Dam however the downstream Gara Dam only requires up to 0.2 ML/d to be released thus it can utilise part of the Malpas Dam releases.

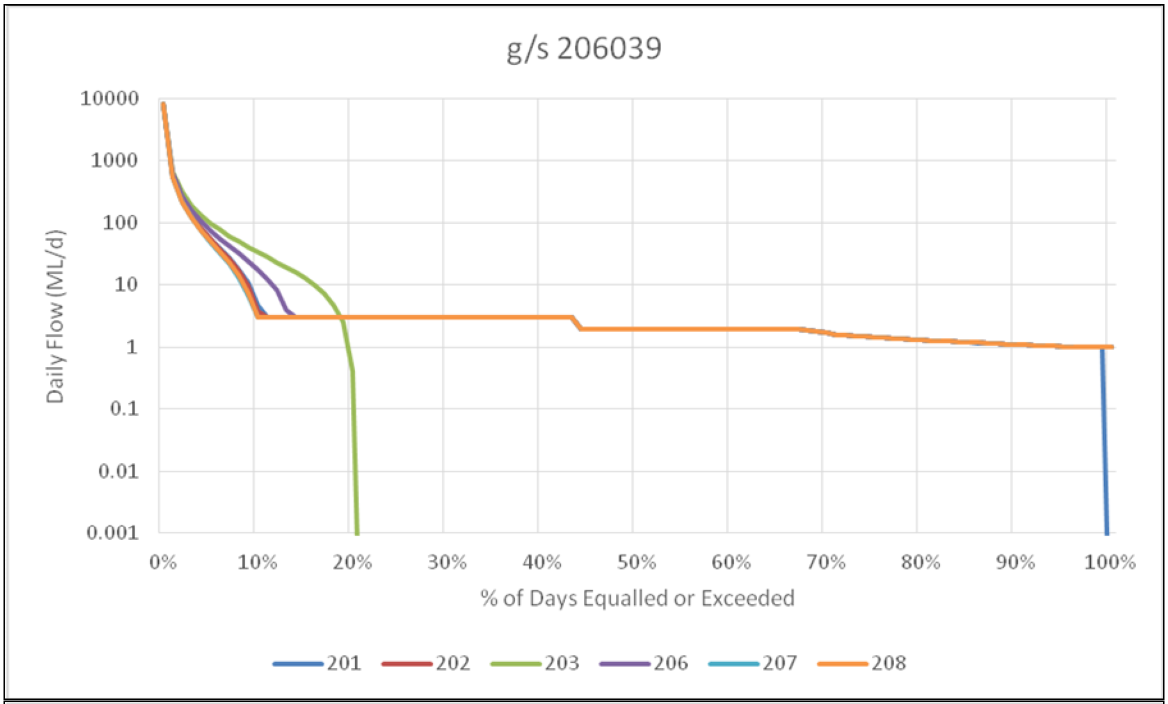
Figure 1: Modelled Flow Duration at G/S 206035 (upstream of Malpas Dam)





All the lines coincide with each other as expected for the upstream gauging station

Figure 2: Modelled Flow Duration at G/S 206039 (Just Downstream of Malpas Dam)



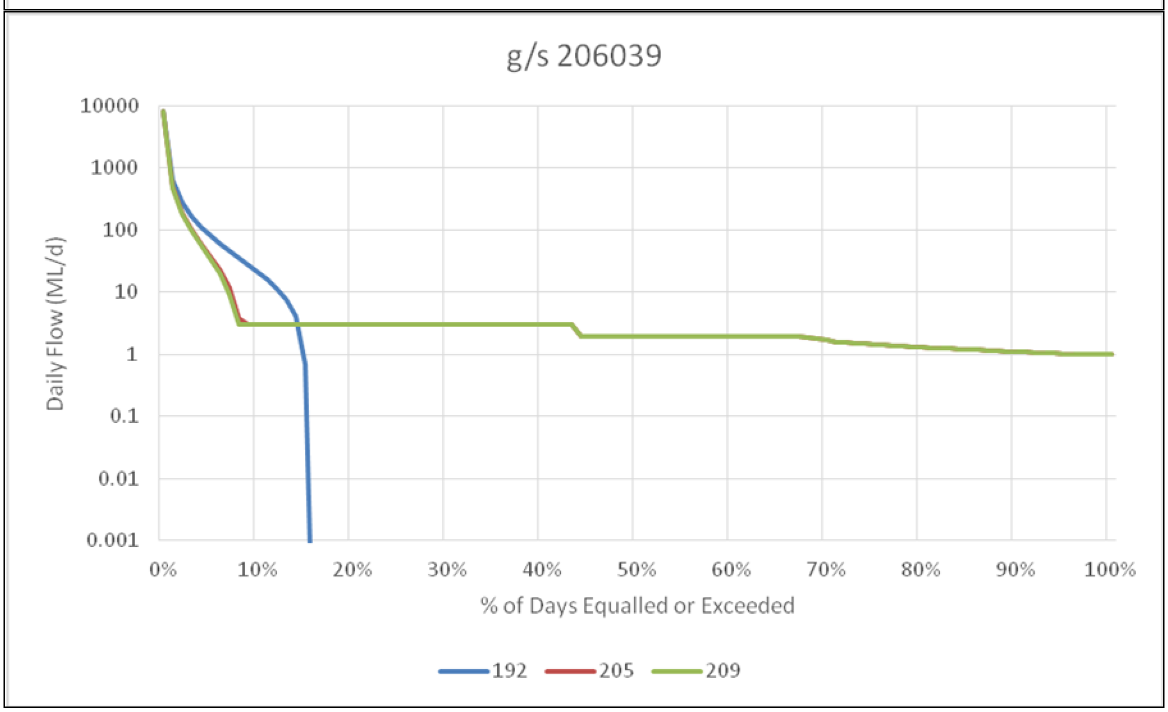
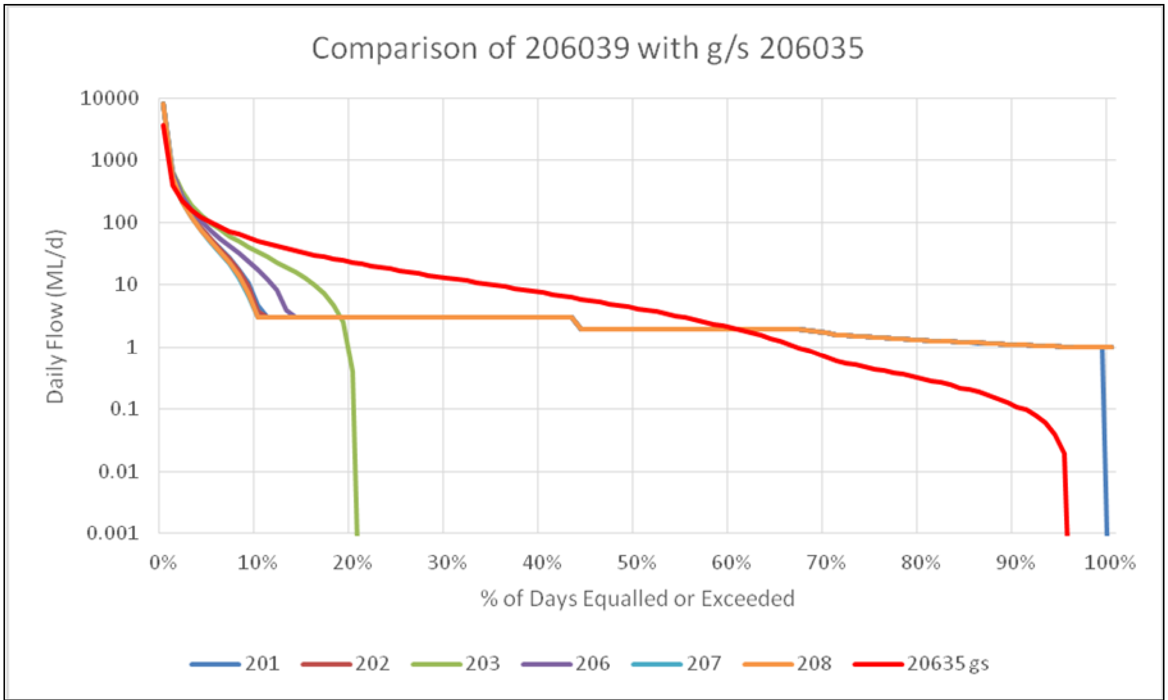


Figure 3: Modelled Flow Duration at G/S 206039 and at G/S 206035



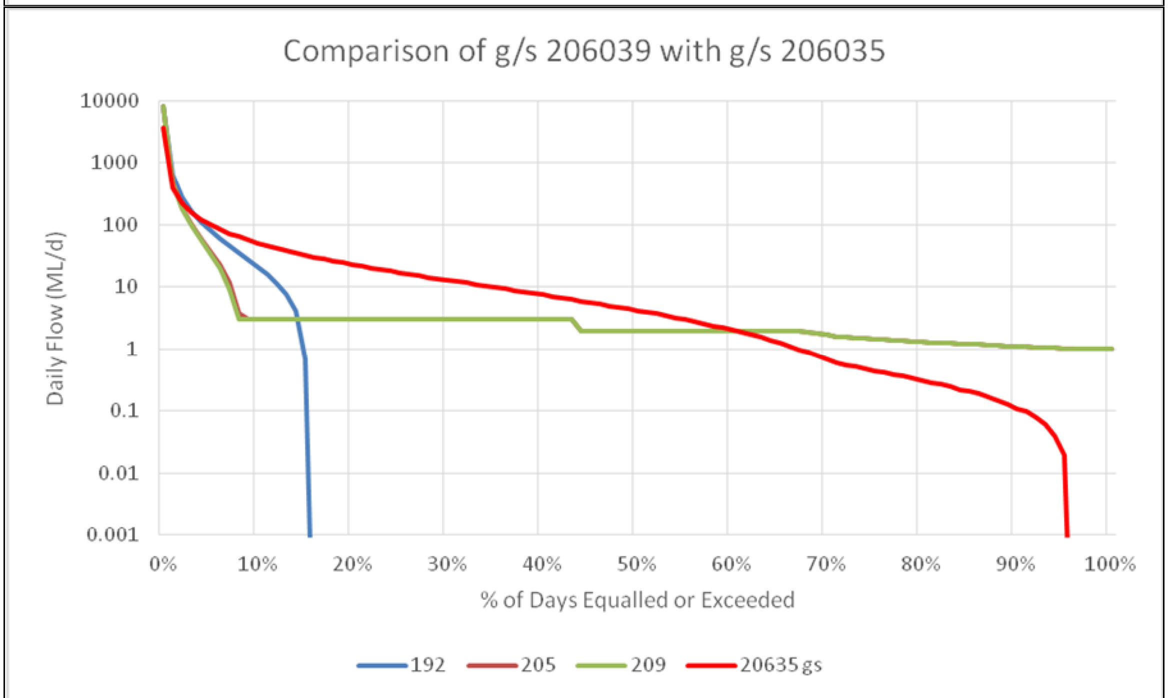
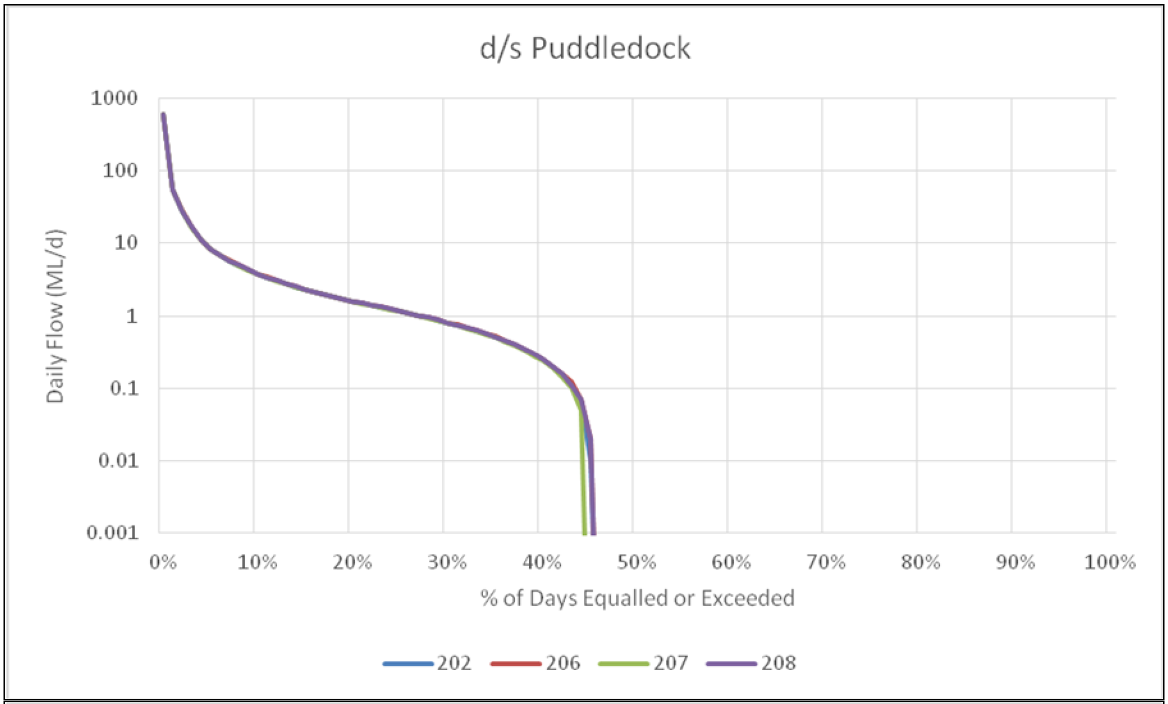


Figure 4: Modelled Flow Duration just downstream of Puddledock Dam



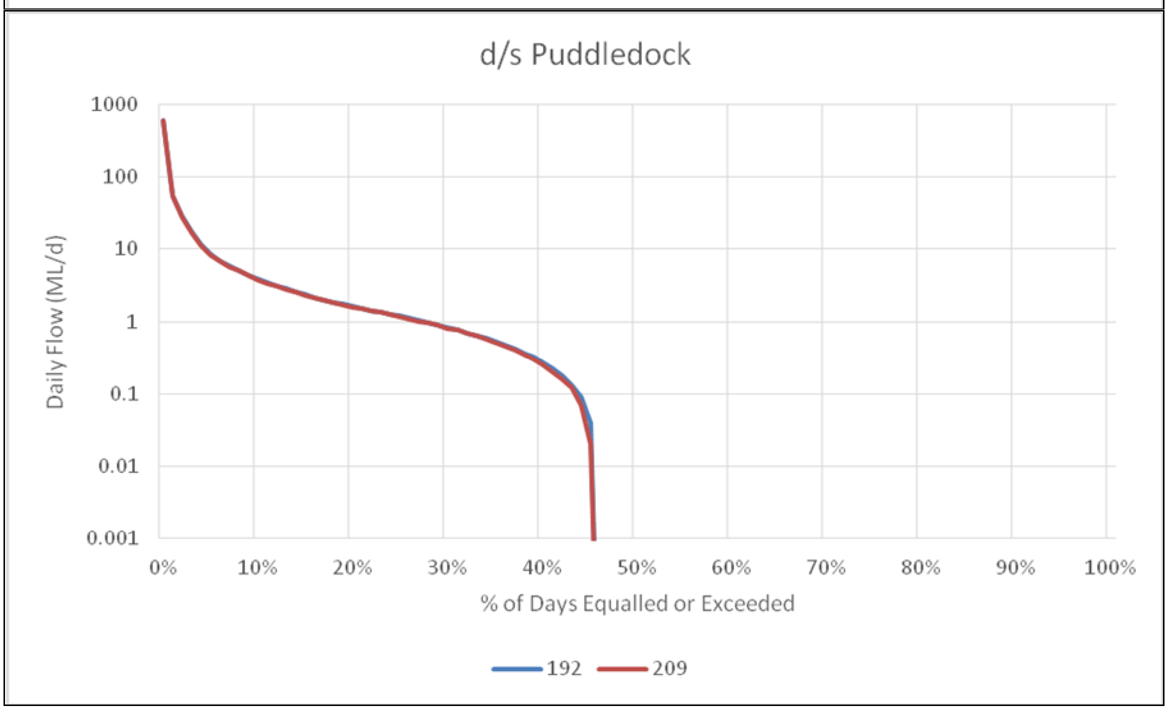
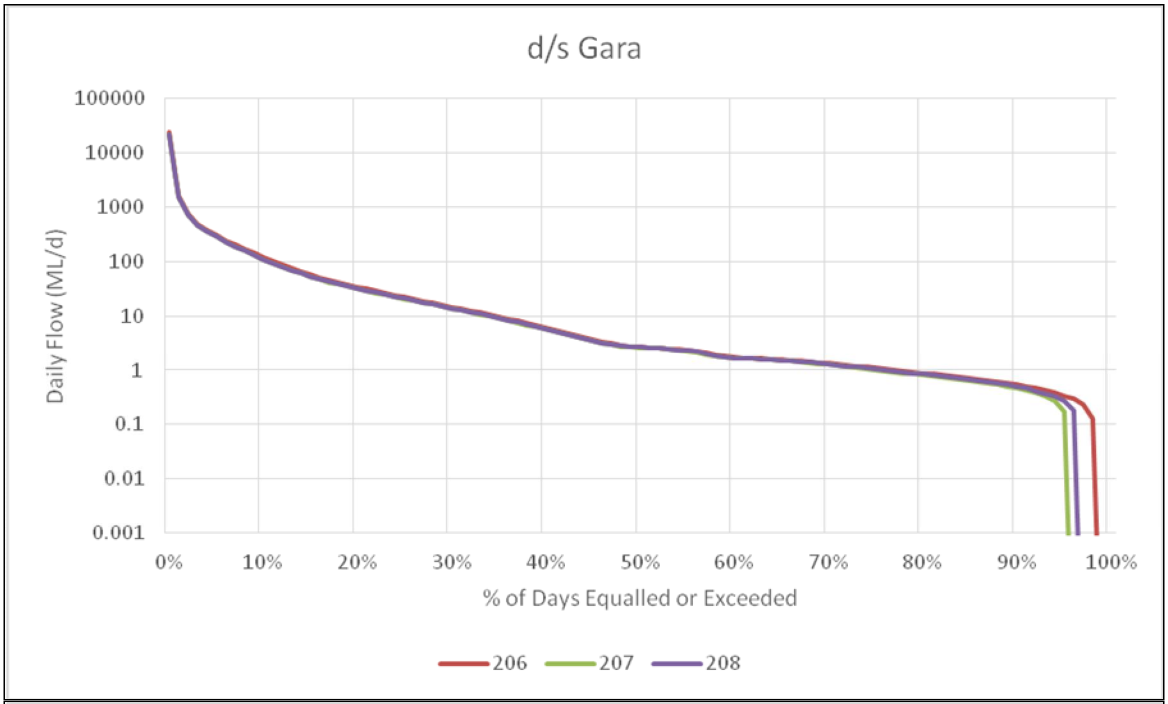


Figure 5: Modelled Flow Duration Just Downstream of Gara Dam



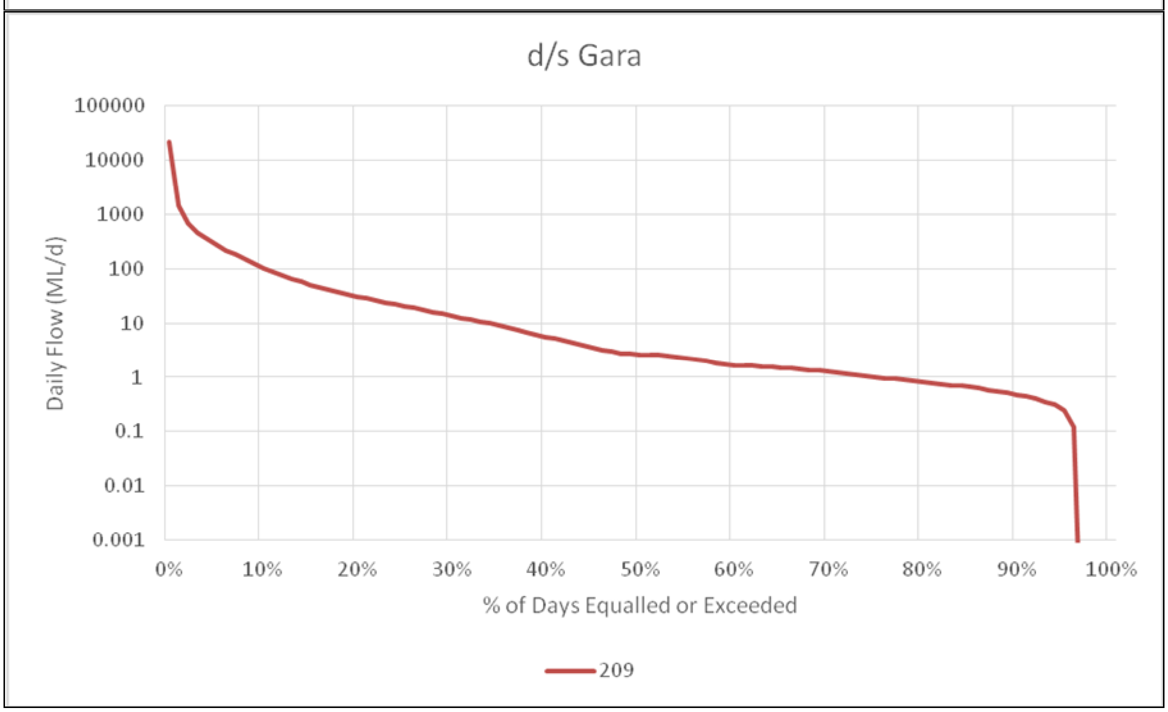
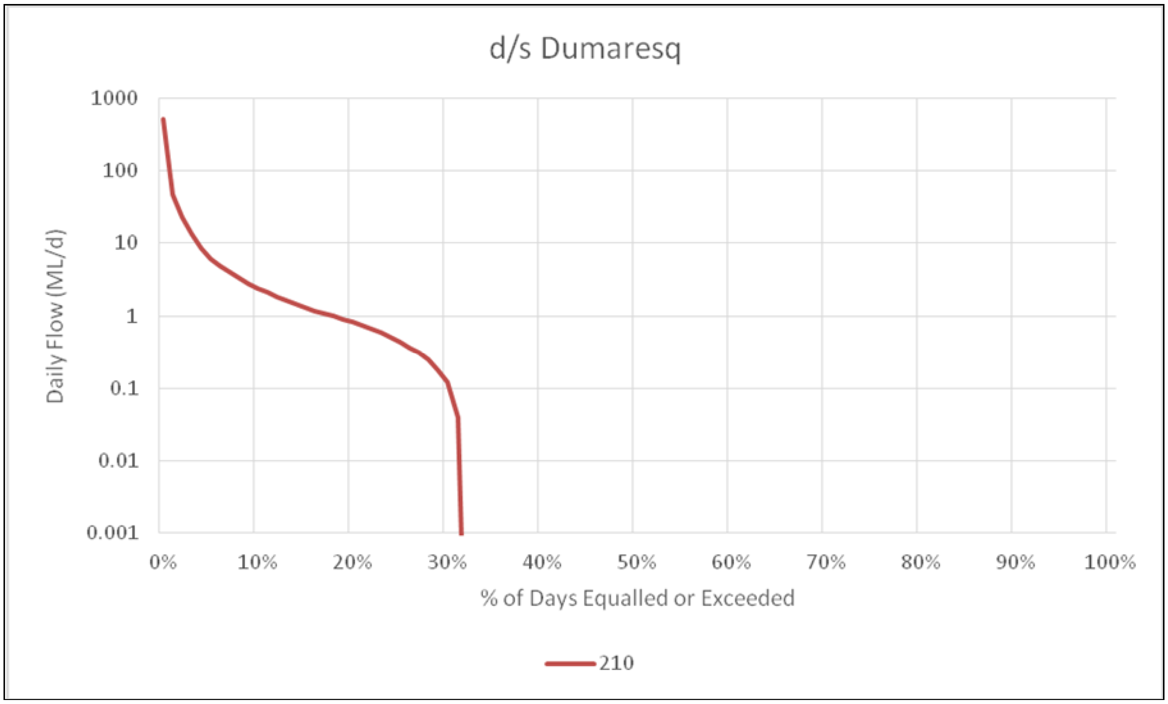


Figure 6: Modelled Flow Duration Just Downstream of Dumaresq Dam



Storage Behaviour

Figures 7 to 18 provide the modelled storage behaviour diagrams for a repeat of the historic climate supplying annual demands (with restrictions applied in accordance with 5/10/10 rules) that equate to the secure yields for that particular storage case.

The diagrams clearly show the influence of the recent severe 2019/2020 drought.

Climate Change

Attachment A provides the results of the required model runs for the 15 GCMs and comparable historic data base for assessing 1 ^{o}C climate warming.

The climate adjustment factor based on the lowest GCM with10/15/25 as well as the median GCM are provided in Table 3. It is usual practice to adopt the lower values and these are what were used for the Table 1 results. However if the less security is acceptable then the higher values may be considered.

Table 3: Climate Adjustment Factors

No	Model Run No	Scenario	Climate Change Adjustment Factor	
			10/15/25	Median
	200	Guyra Dams Only	0.5474	0.8540
PHASE 3				
11	201	Guyra+Malpas FSL increased by 6.5 m	0.6703	0.8313
12	202	Guyra+Malpas FSL increased by 6.5m +Puddledock	0.6810	0.8433
13	203	Existing (Guyra+Malpas) dams	0.7203	0.8918
14	206	Guyra+Malpas FSL increased by 3m +Puddledock +Gara	0.6685	0.8434
15	207	Guyra+Malpas FSL increased by 6.5 m +Puddledock+ Gara	0.7073	0.8582
16	208	Guyra+Malpas FSL increased to 23534 ML to provide required water security+Puddledock+Gara	0.6997	0.8548
16b	209	Guyra+Malpas FSL increased to 39039 ML to provide required water security+Puddledock+Gara	0.6674	0.8458
17b	205	Guyra+Malpas FSL increased by 39039 ML to provide required water security	0.6567	0.8288
ADDITIONAL CASES				
	192	Guyra+Malpas FSL increased by 3m + Puddledock	0.6613	0.8356
	210	Dumaresq Dam on its own	0.7105	0.8750

Figure 7: Storage Behaviour – Guyra Dams

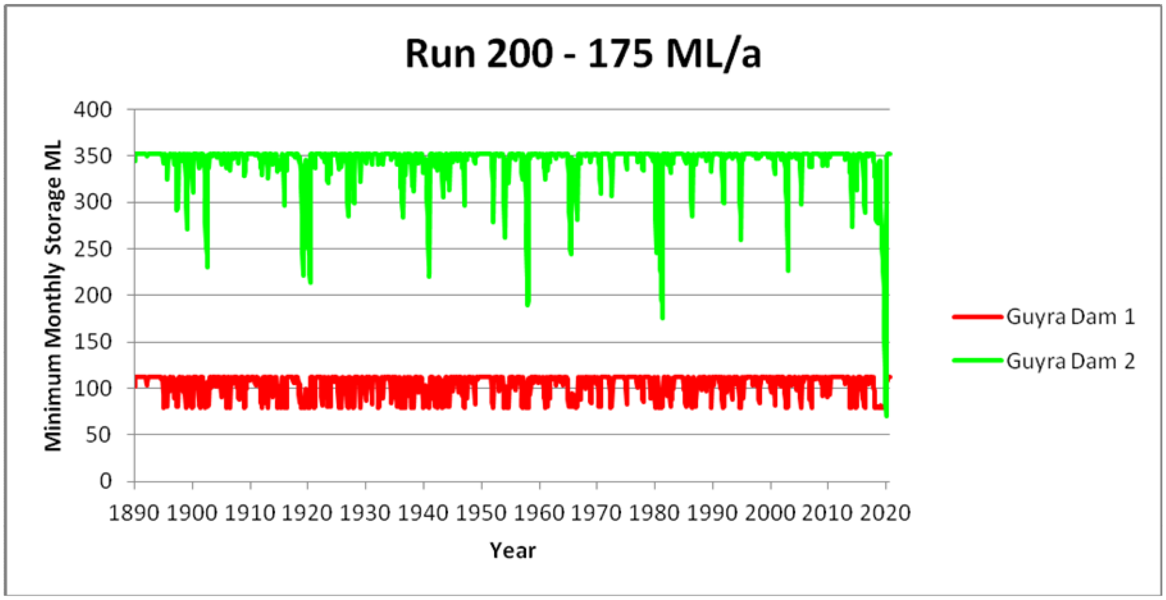


Figure 8: Storage Behaviour – Run 201

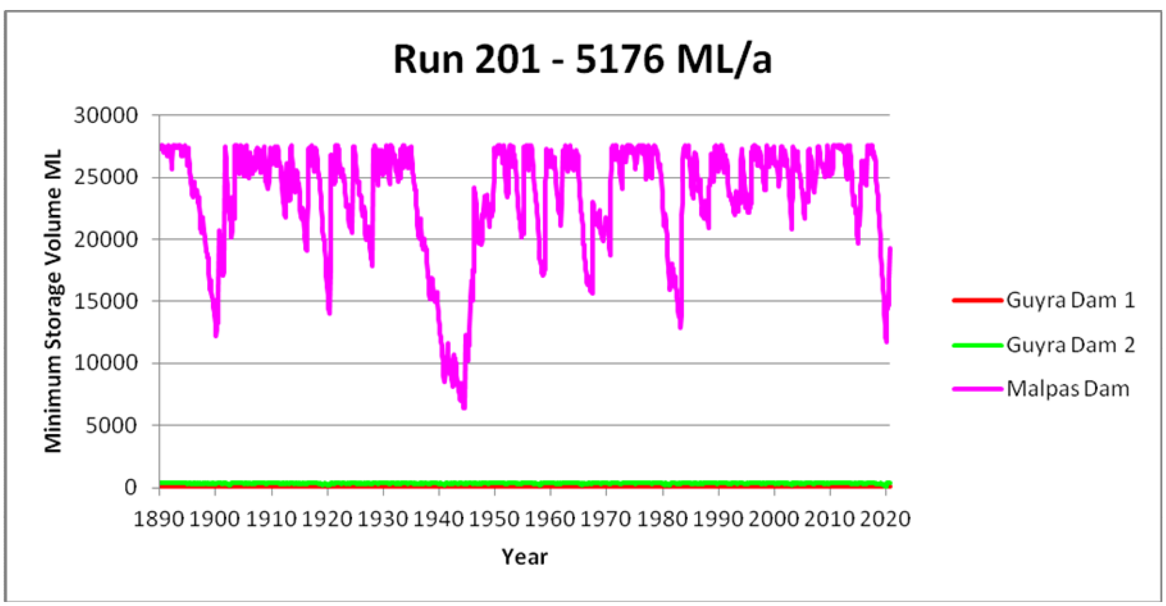
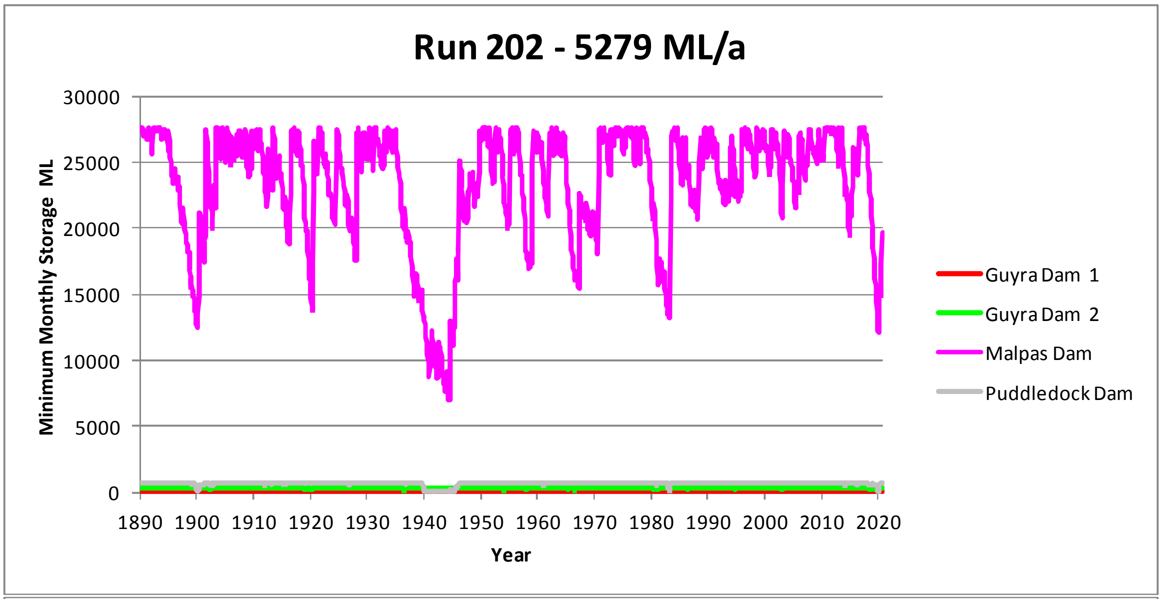


Figure 9: Storage Behaviour – Run 202



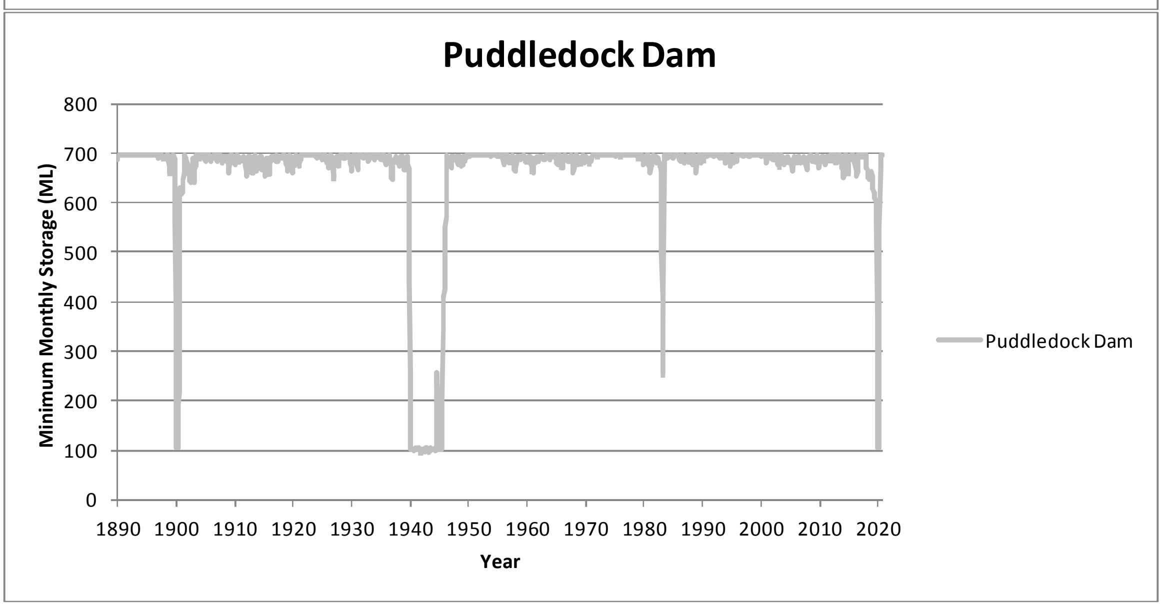


Figure 10: Storage Behaviour – Run 203

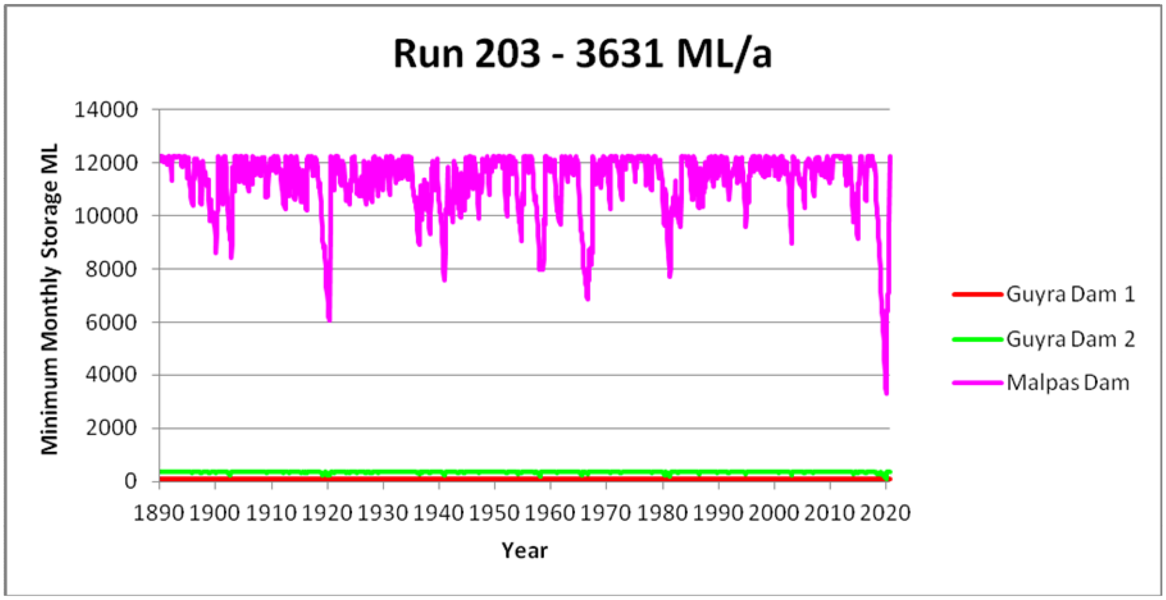


Figure 11: Storage Behaviour – Run 206

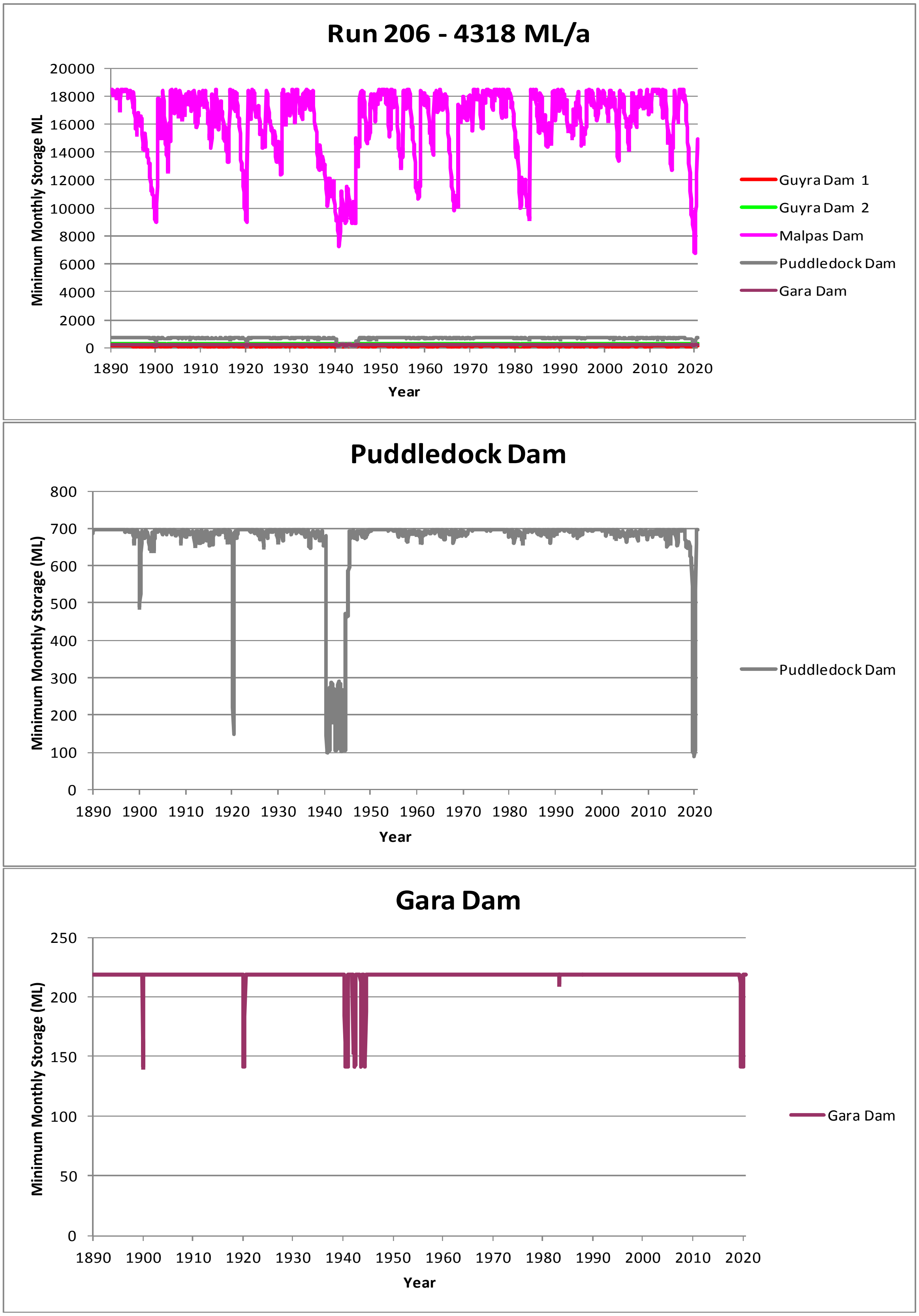
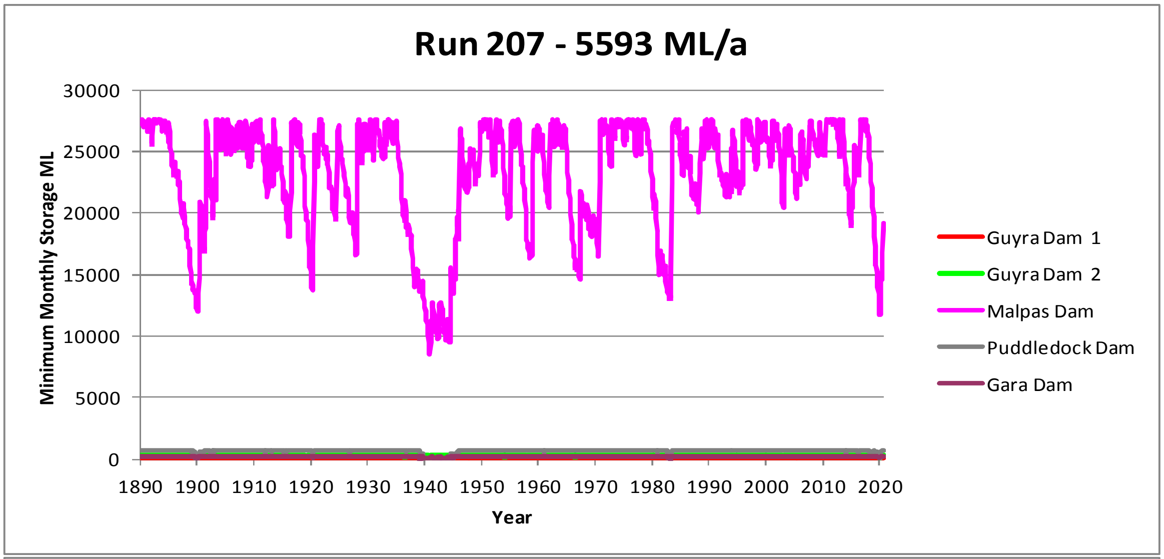
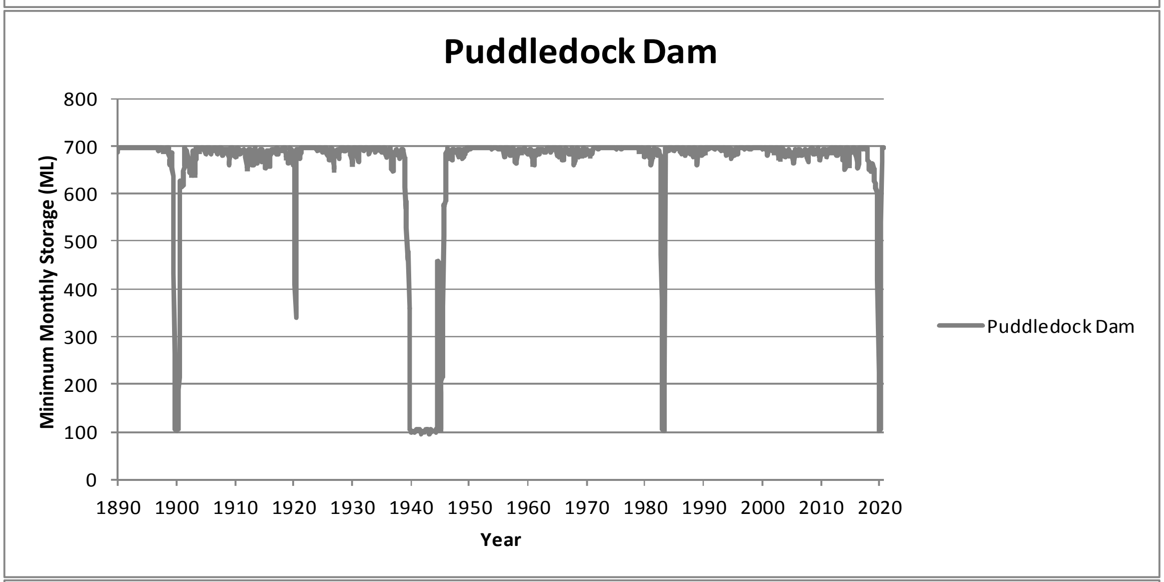


Figure 12: Storage Behaviour – Run 207





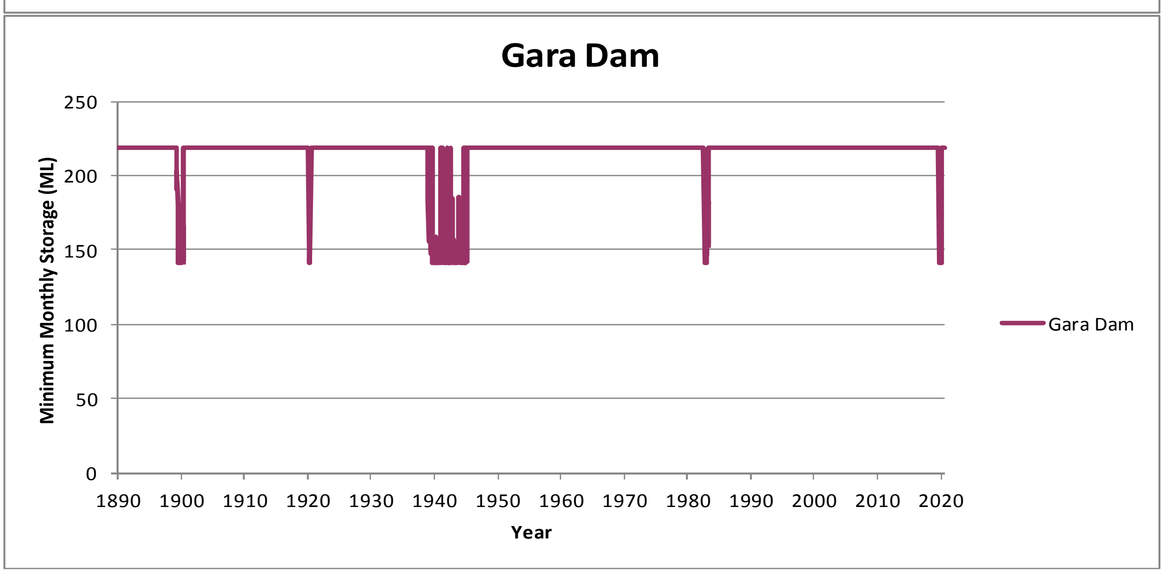
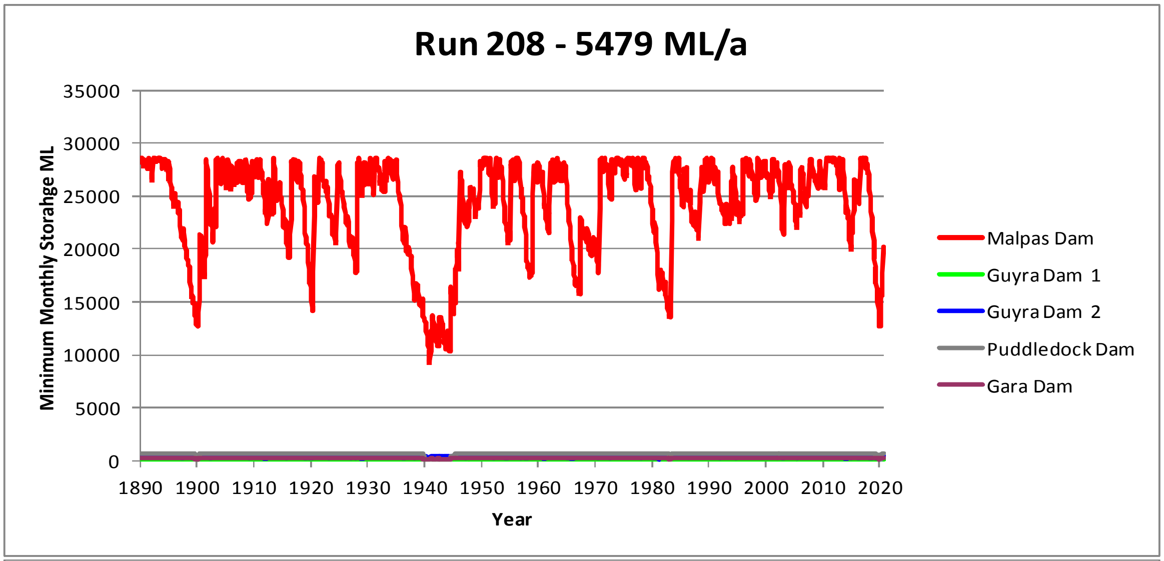
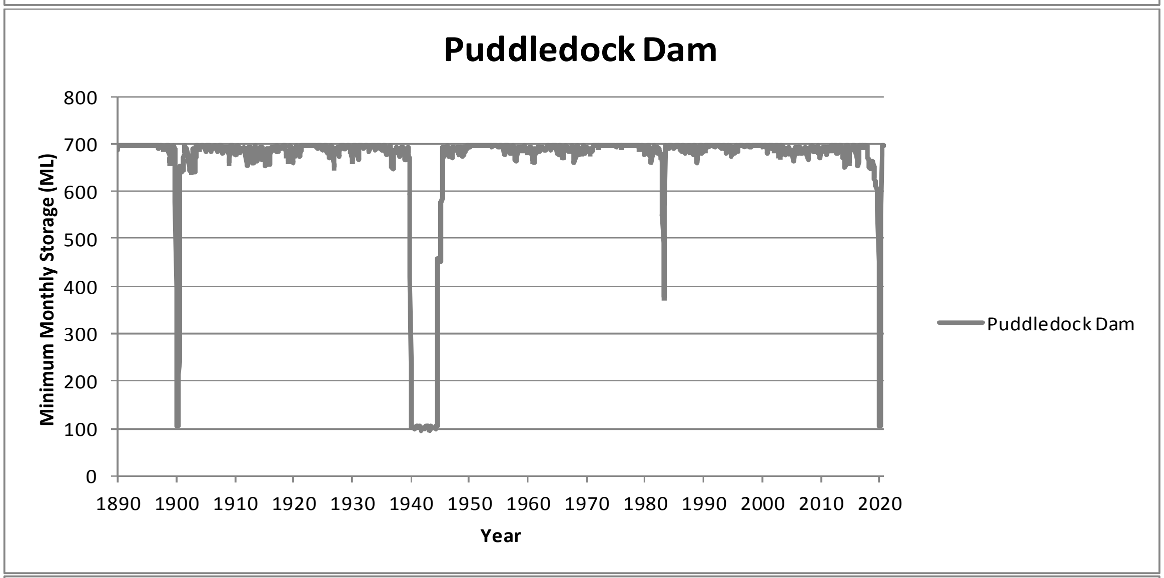


Figure 13: Storage Behaviour – Run 208





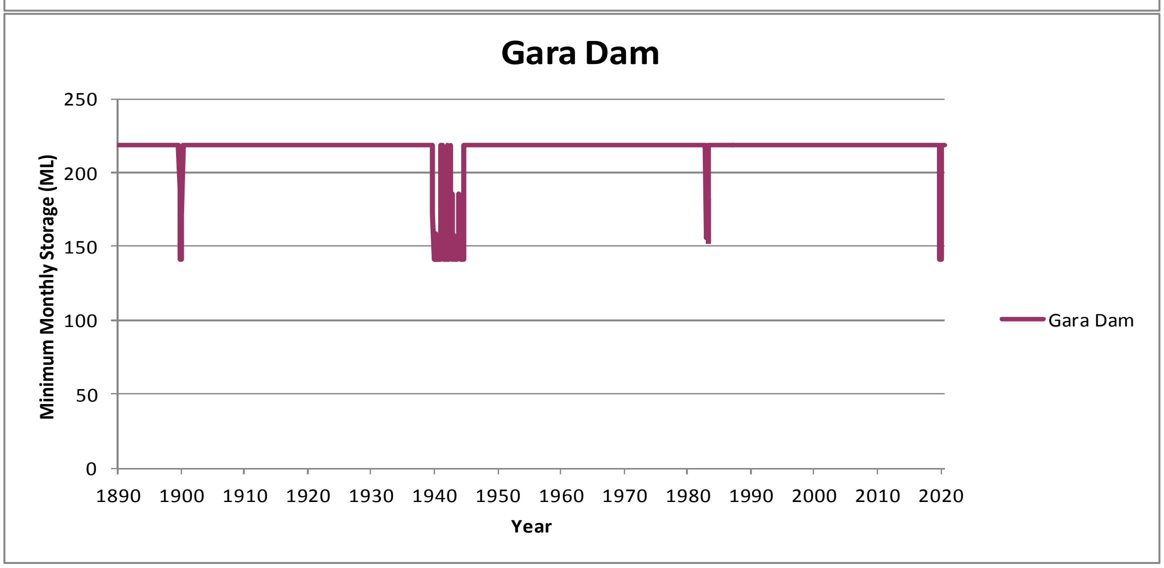
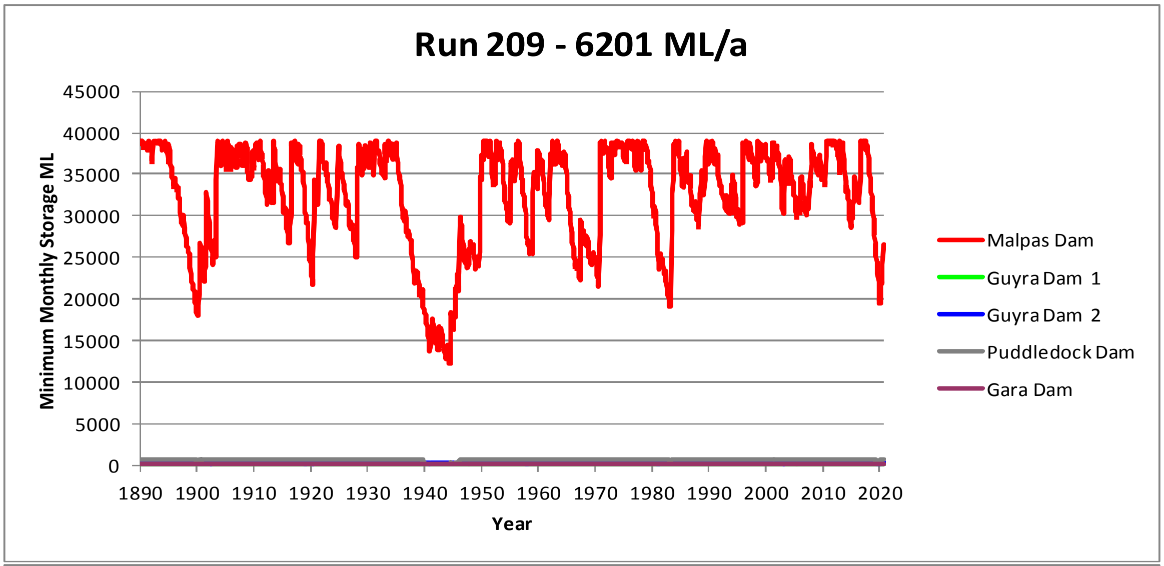
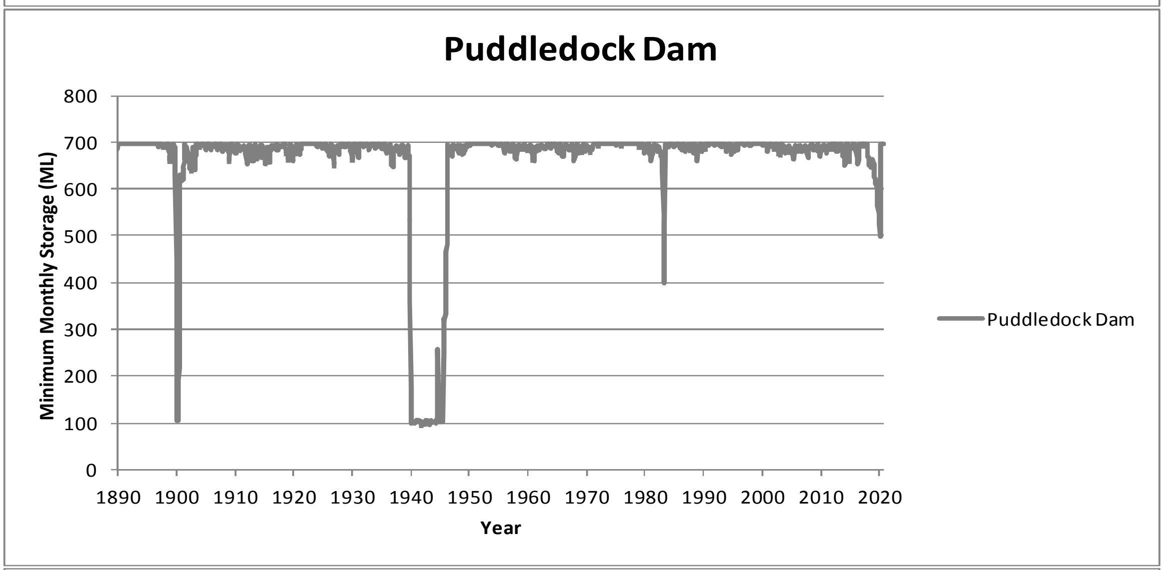


Figure 14: Storage Behaviour – Run 209





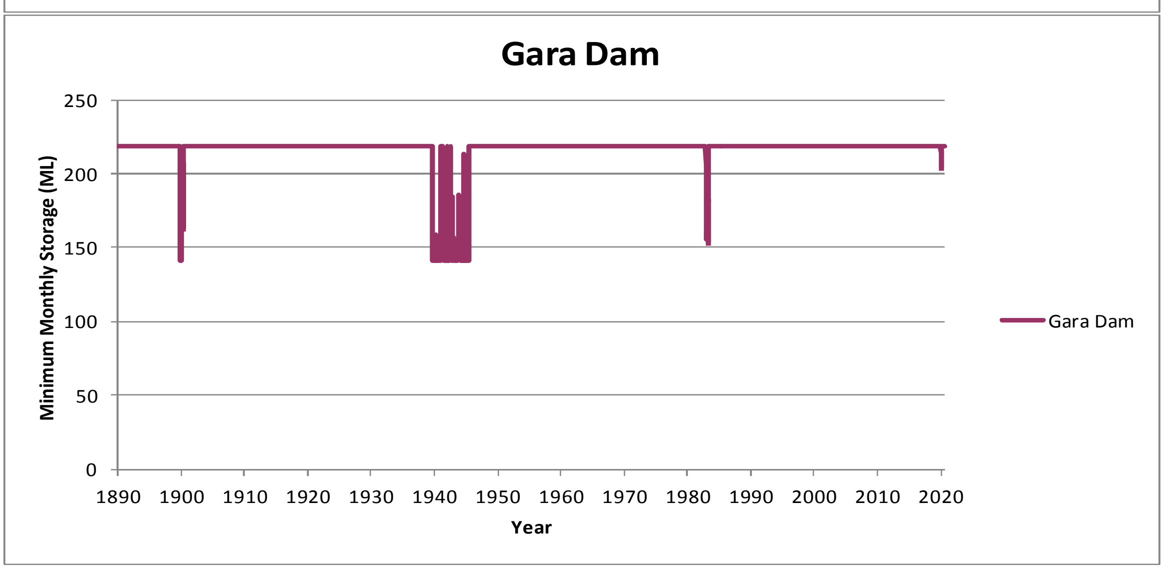


Figure 15: Storage Behaviour – Run 204

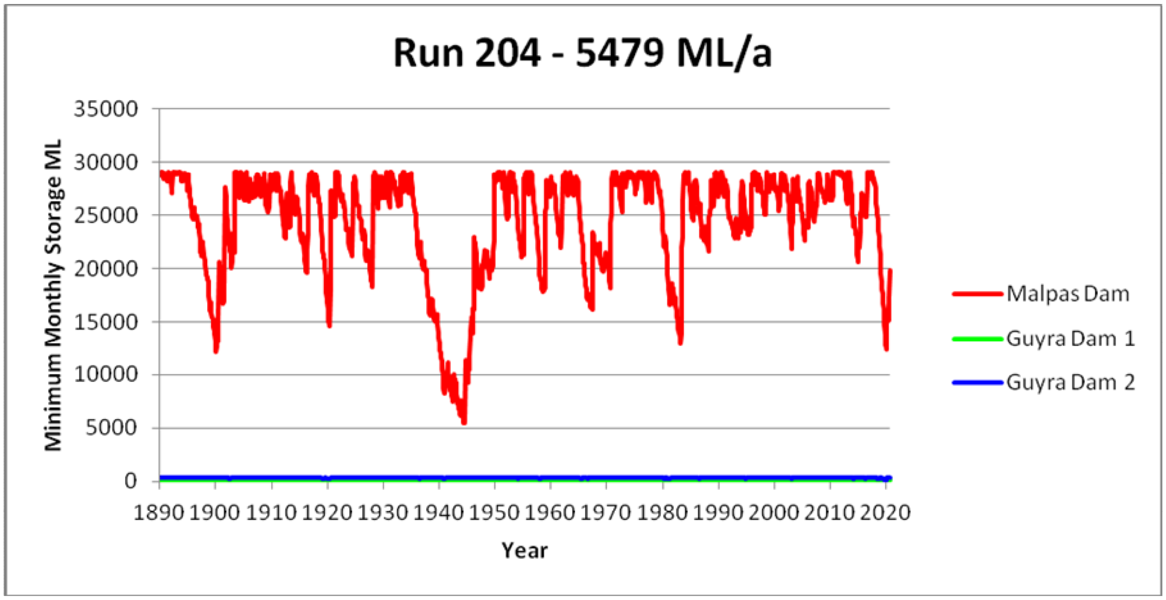


Figure 16: Storage Behaviour – Run 205

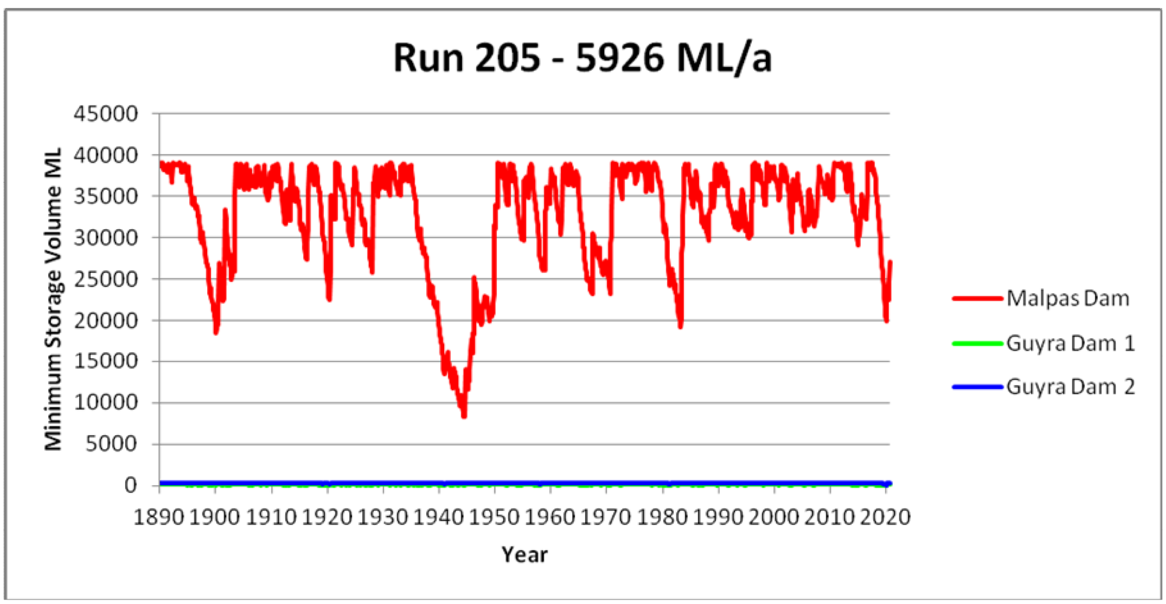


Figure 17: Storage Behaviour – Dumaresq Dam

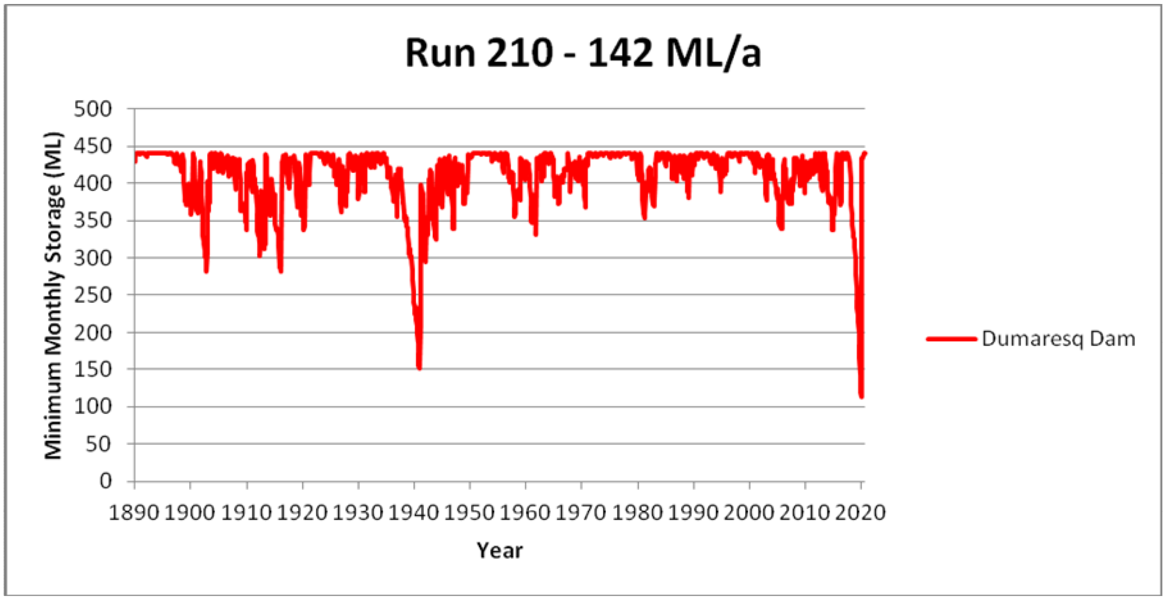
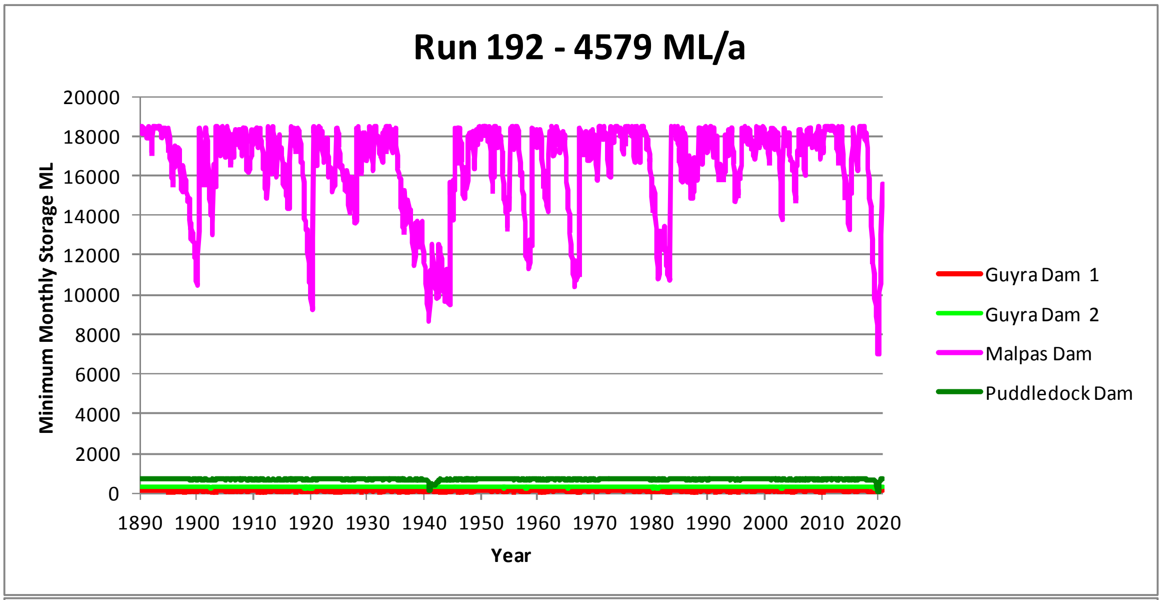
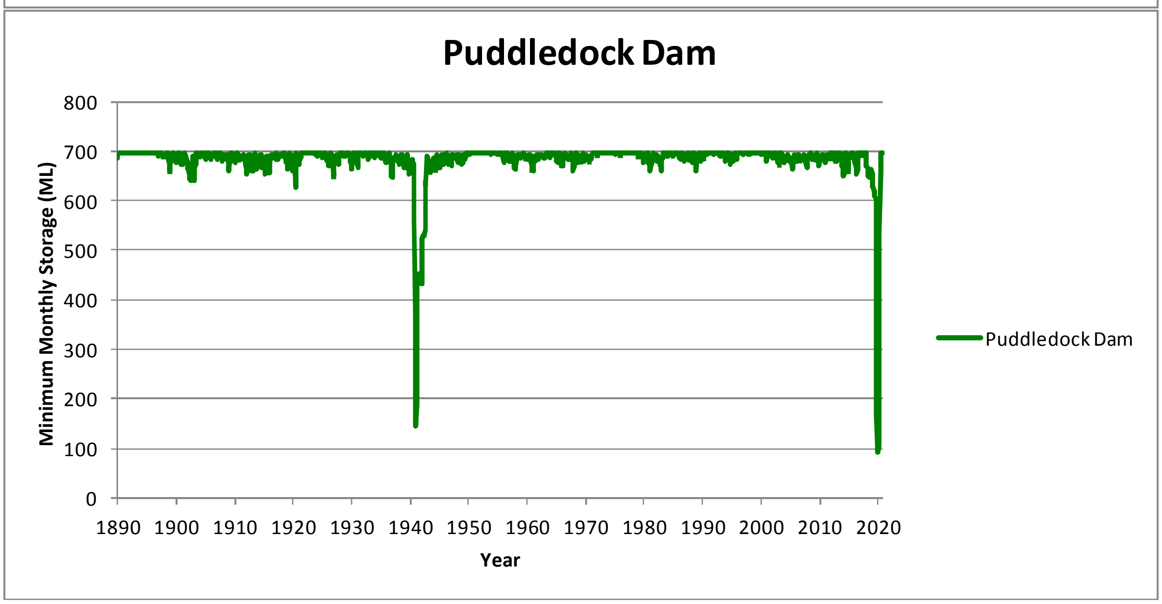


Figure 18: Storage Behaviour – Run 192





ATTACHMENT A
Model Results for 15 GCMs and corresponding Historic Base

Note that in each case shown on the following pages the data is based on modelled flow information (from a data base of daily rainfall and daily evapotranspiration) and not observed flow data. The adopted historical secure yields uses a longer period and are those in Table 2. The following data is used to adjust the yields in Table 2 in accordance with the DPIE Water Guidelines

Run 200 :Guyra Dams Only

Armidale, Run 200CC F:\Results\Armidale\Mar2020\Data\ClimateChange\Armidale_

Time: 05/10/2020 12:10:59 AM

					Restricted		Critical Drought	
		Storage	Secure	% Restricted	% of	% of		
	Run	Capacity	Yield	at	duration	years	Start	End
HISTORICAL	1	464	274	60	1.41	6.90	03/09/1918	12/06/1920
	2	464	254	60	1.04	7.76	30/11/1964	30/11/1965
	3	464	242	60	1.23	8.62	11/12/1964	30/11/1965
	4	464	177	65	2.44	9.48	31/08/1918	12/06/1920
LOWEST	5	464	118	70	2.66	9.48	23/08/1918	12/06/1920
	6	464	245	65	2.10	9.48	01/09/1918	12/06/1920
	7	464	164	70	2.24	9.48	01/09/1918	12/06/1920
	8	464	209	65	1.83	8.62	01/09/1918	12/06/1920
	9	464	150	65	1.65	6.90	31/08/1918	12/06/1920
MEDIAN	10	464	234	65	1.27	9.48	30/11/1964	30/11/1965
	11	464	288	65	1.23	9.48	20/04/1957	30/01/1958
	12	464	276	60	1.03	7.76	19/04/1957	30/01/1958
	13	464	188	65	1.93	9.48	01/09/1918	12/06/1920
	14	464	183	65	1.94	9.48	01/09/1918	12/06/1920
	15	464	242	65	2.37	9.48	01/09/1918	12/06/1920
	16	464	245	65	2.35	9.48	01/09/1918	12/06/1920
10/15/25	5	464	150	70	3.53	13.79	23/08/1918	12/06/1920

Run 201: Guyra + Malpas FSL increased by 6.5 m

Armidale, Run 201CC F:\Results\Armidale\Mar2020\Data\ClimateChange\Armidale_

Time: 05/10/2020 4:19:48 AM

					Restricted		Critical Drought	
	Run	Storage Capacity	Secure Yield	% Restricted at	% of duration	% of years	Start	End
HISTORICAL	1	27630	5068	40	4.12	6.03	16/01/1935	02/07/1944
	2	27630	4616	40	5.00	7.76	16/01/1935	02/07/1944
	3	27630	4445	40	5.00	7.76	16/01/1935	02/07/1944
	4	27630	3340	35	5.00	8.62	16/01/1935	10/02/1945
LOWEST	5	27630	2896	30	4.99	7.76	06/11/1933	22/08/1944
	6	27630	4279	35	3.61	8.62	16/01/1935	22/08/1944
	7	27630	3740	40	4.77	9.48	16/01/1935	02/07/1944
	8	27630	4036	35	4.07	7.76	16/01/1935	02/07/1944
	9	27630	3357	30	2.85	6.90	16/01/1935	02/07/1944
	10	27630	4706	45	5.00	6.90	18/01/1935	29/12/1940
	11	27630	5748	45	4.99	6.90	16/01/1935	30/12/1940
	12	27630	5141	40	4.46	6.90	16/01/1935	02/07/1944
	13	27630	3784	40	4.99	8.62	16/01/1935	22/08/1944
	14	27630	3721	35	2.93	6.03	16/01/1935	02/07/1944
MEDIAN	15	27630	4213	35	3.34	5.17	16/01/1935	02/07/1944
	16	27630	4285	40	5.00	8.62	16/01/1935	22/08/1944
10/15/25	5	27630	3397	30	9.99	13.79	06/11/1933	22/08/1944

Run 202: Guyra + Malpas FSL increased by 6.5 m + Puddledock

Armidale, Run 202CC F:\Results\Armidale\Mar2020\Data\ClimateChange\Armidale_

Time: 07/10/2020 6:04:45 AM

	Run	Storage Capacity	Secure Yield	% Restricted at	Restricted % of duration	Restricted % of years	Critical Drought Start	Critical Drought End
HISTORICAL	1	28326	5245	40	3.93	6.03	16/01/1935	30/12/1940
	2	28326	4812	40	4.96	7.76	16/01/1935	02/07/1944
	3	28326	4652	40	5.00	7.76	16/01/1935	02/07/1944
	4	28326	3578	35	5.00	8.62	16/01/1935	02/07/1944
LOWEST	5	28326	3061	30	4.23	8.62	06/11/1933	22/08/1944
	6	28326	4493	35	3.62	6.90	16/01/1935	22/08/1944
	7	28326	3941	40	5.00	8.62	16/01/1935	02/07/1944
	8	28326	4185	35	3.58	5.17	16/01/1935	04/11/1943
	9	28326	3527	35	5.00	9.48	16/01/1935	02/07/1944
	10	28326	4893	40	3.11	6.90	18/01/1935	29/12/1940
	11	28326	5995	45	4.99	6.90	16/01/1935	30/12/1940
	12	28326	5348	40	4.54	6.03	16/01/1935	02/07/1944
	13	28326	3963	40	4.99	6.90	16/01/1935	22/08/1944
	14	28326	3896	35	3.10	6.03	16/01/1935	02/07/1944
MEDIAN	15	28326	4423	40	4.99	6.90	16/01/1935	22/08/1944
	16	28326	4511	40	4.99	6.90	16/01/1935	22/08/1944
10/15/25	5	28326	3572	30	9.37	14.66	06/11/1933	22/08/1944

Run 203: Guyra + Existing Malpas (no release requirements)

Armidale, Run 203CC F:\Results\Armidale\Mar2020\Data\ClimateChange\Armidale_

Time: 07/10/2020 4:13:37 PM

	Run	Storage Capacity	Secure Yield	% Restricted at	Restricted % of duration	Restricted % of years	Critical Drought Start	Critical Drought End
HISTORICAL	1	12266	4233	55	2.52	9.48	26/01/1935	30/12/1940
	2	12266	3904	50	2.98	7.76	26/01/1935	30/12/1940
	3	12266	3853	50	3.76	9.48	21/01/1935	30/12/1940
	4	12266	3004	45	2.54	6.90	20/01/1935	30/12/1940
LOWEST	5	12266	2624	45	4.88	9.48	20/01/1935	30/12/1940
	6	12266	3796	50	3.06	8.62	14/02/1895	14/02/1900
	7	12266	3249	50	2.78	6.03	20/02/1894	14/02/1900
	8	12266	3646	50	5.00	9.48	21/01/1935	30/12/1940
	9	12266	2936	50	4.71	9.48	21/01/1935	30/12/1940
	10	12266	4155	55	4.13	7.76	26/01/1935	30/12/1940
	11	12266	4691	55	1.84	7.76	04/02/1918	12/06/1920
	12	12266	4305	55	2.89	9.48	26/01/1935	30/12/1940
	13	12266	3275	50	3.00	6.90	09/02/1895	14/02/1900
	14	12266	3234	50	3.27	8.62	14/02/1895	14/02/1900
MEDIAN	15	12266	3775	50	3.77	8.62	26/01/1935	30/12/1940
	16	12266	3800	50	3.24	8.62	26/01/1935	30/12/1940
10/15/25	5	12266	3049	40	8.02	14.66	20/01/1935	30/12/1940

Run 206: Guyra + Malpas FSL increased by 3m + Puddledock + Gara

Armidale, Run 206CC F:\Results\Armidale\Mar2020\Data\ClimateChange\Armidale_

Time: 17/10/2020 6:45:22 AM

					Restricted		Critical Drought	
		Storage	Secure	% Restricted	% of	% of		
	Run	Capacity	Yield	at	duration	years	Start	End
HISTORICAL	1	19389.97	4890	45	3.91	9.48	21/01/1935	30/12/1940
	2	19389.97	4354	45	4.44	9.48	20/01/1935	30/12/1940
	3	19389.97	4318	45	4.74	9.48	19/01/1935	30/12/1940
	4	19389.97	3271	45	4.99	8.62	19/01/1935	30/12/1940
LOWEST	5	19389.97	2840	40	4.49	8.62	19/01/1935	30/12/1940
	6	19389.97	4141	45	4.24	9.48	19/01/1935	30/12/1940
	7	19389.97	3601	45	5.00	9.48	15/02/1894	14/02/1900
	8	19389.97	3938	45	4.51	8.62	19/01/1935	30/12/1940
	9	19389.97	3274	40	2.77	6.90	19/01/1935	30/12/1940
	10	19389.97	4551	45	2.60	8.62	26/01/1935	29/12/1940
	11	19389.97	5335	45	2.20	6.90	22/01/1935	30/12/1940
	12	19389.97	4858	45	3.55	9.48	21/01/1935	30/12/1940
	13	19389.97	3676	45	4.69	8.62	19/01/1935	30/12/1940
	14	19389.97	3627	45	4.81	8.62	19/01/1935	30/12/1940
MEDIAN	15	19389.97	4124	45	4.24	8.62	19/01/1935	30/12/1940
	16	19389.97	4171	45	4.06	8.62	19/01/1935	30/12/1940
10/15/25	5	19389.97	3269	35	4.79	10.34	25/02/1934	30/12/1940

Run 207: Guyra + Malpas FSL increased by 6.5 m + Puddledock + Gara

Armidale, Run 207CC F:\Results\Armidale\Mar2020\Data\ClimateChange\Armidale_

Time: 17/10/2020 8:43:13 PM

	Run	Storage Capacity	Secure Yield	% Restricted at	Restricted % of duration	Restricted % of years	Critical Drought Start	Critical Drought End
HISTORICAL	1	28544.97	5282	45	3.42	6.90	21/01/1935	30/12/1940
	2	28544.97	4816	45	4.64	7.76	20/01/1935	30/12/1940
	3	28544.97	4728	45	4.96	7.76	19/01/1935	30/12/1940
	4	28544.97	3660	40	4.05	7.76	19/01/1935	29/12/1940
LOWEST	5	28544.97	3114	35	2.62	6.03	25/02/1934	22/08/1944
	6	28544.97	4584	40	2.98	6.90	19/01/1935	30/12/1940
	7	28544.97	4014	45	5.00	8.62	15/02/1894	14/02/1900
	8	28544.97	4275	45	5.00	6.90	19/01/1935	30/12/1940
	9	28544.97	3701	40	4.62	7.76	19/01/1935	02/07/1944
	10	28544.97	4956	45	3.18	6.90	26/01/1935	29/12/1940
	11	28544.97	6008	45	3.07	6.90	16/01/1935	30/12/1940
	12	28544.97	5372	45	3.80	6.90	20/01/1935	30/12/1940
	13	28544.97	4055	40	2.91	5.17	19/01/1935	30/12/1940
	14	28544.97	4002	40	3.13	6.03	19/01/1935	30/12/1940
MEDIAN	15	28544.97	4533	45	4.93	7.76	19/01/1935	30/12/1940
	16	28544.97	4585	45	4.66	6.90	19/01/1935	30/12/1940
10/15/25	5	28544.97	3736	35	8.18	14.66	09/11/1933	22/08/1944

Run 208: Guyra + Malpas FSL increased to 23534 ML + Puddledock + Gara

Armidale, Run 208CC F:\Results\Armidale\Mar2020\Data\ClimateChange\Armidale_

Time: 18/10/2020 9:52:37 PM

					Restricted		Critical Drought	
		Storage	Secure	% Restricted	% of	% of		
	Run	Capacity	Yield	at	duration	years	Start	End
HISTORICAL	1	29486.97	5342	45	3.51	6.90	21/01/1935	30/12/1940
	2	29486.97	4866	45	4.68	7.76	20/01/1935	30/12/1940
	3	29486.97	4755	45	4.99	7.76	19/01/1935	30/12/1940
	4	29486.97	3691	40	4.06	7.76	19/01/1935	04/11/1943
LOWEST	5	29486.97	3149	35	2.77	6.03	25/02/1934	22/08/1944
	6	29486.97	4636	40	3.10	6.90	17/01/1935	30/12/1940
	7	29486.97	4041	45	5.00	8.62	15/02/1894	14/02/1900
	8	29486.97	4293	45	5.00	6.90	19/01/1935	30/12/1940
	9	29486.97	3741	40	4.70	7.76	19/01/1935	02/07/1944
	10	29486.97	5010	45	3.26	6.90	26/01/1935	29/12/1940
	11	29486.97	6058	45	3.07	6.90	16/01/1935	30/12/1940
	12	29486.97	5426	45	3.85	6.90	21/01/1935	30/12/1940
	13	29486.97	4121	40	3.05	5.17	19/01/1935	30/12/1940
	14	29486.97	4068	40	3.24	6.03	19/01/1935	30/12/1940
MEDIAN	15	29486.97	4567	45	4.99	8.62	19/01/1935	30/12/1940
	16	29486.97	4637	45	4.81	6.90	19/01/1935	30/12/1940
10/15/25	5	29486.97	3738	35	7.98	14.66	09/11/1933	22/08/1944

Run 209: Guyra + Malpas FSL increased to 39039 ML + Puddledock + Gara

Armidale, Run 209CC F:\Results\Armidale\Mar2020\Data\ClimateChange\Armidale_

Time: 18/10/2020 6:10:09 AM

	Run	Storage Capacity	Secure Yield	% Restricted at	Restricted % of duration	Restricted % of years	Critical Drought Start	Critical Drought End
HISTORICAL	1	39953.913	5875	45	4.05	6.90	21/01/1935	30/12/1940
	2	39953.913	5319	45	5.00	7.76	20/01/1935	02/07/1944
	3	39953.913	5155	45	5.00	7.76	17/01/1935	02/07/1944
	4	39953.913	4047	40	4.99	9.48	19/01/1935	17/02/1945
LOWEST	5	39953.913	3331	35	2.66	5.17	06/11/1933	19/02/1945
	6	39953.913	5177	40	4.09	6.90	19/01/1935	22/08/1944
	7	39953.913	4532	40	2.98	6.03	19/01/1935	02/07/1944
	8	39953.913	4785	40	3.49	6.03	18/01/1935	04/11/1943
	9	39953.913	3975	40	4.09	8.62	09/11/1933	22/08/1944
	10	39953.913	5578	45	3.99	6.90	26/01/1935	29/12/1940
	11	39953.913	6551	45	3.01	6.03	19/01/1935	30/12/1940
	12	39953.913	5948	45	4.40	6.03	20/01/1935	30/12/1940
	13	39953.913	4591	40	3.22	6.90	19/01/1935	22/08/1944
	14	39953.913	4539	40	3.68	6.90	19/01/1935	22/08/1944
MEDIAN	15	39953.913	4969	40	2.91	5.17	19/01/1935	02/07/1944
	16	39953.913	5022	40	2.55	5.17	19/01/1935	02/07/1944
10/15/25	5	39953.913	3921	35	9.99	14.66	16/01/1922	19/02/1945

Run 205: Guyra + Malpas FSL increased to 39039 ML

Armidale, Run 205CC F:\Results\Armidale\Mar2020\Data\ClimateChange\Armidale_

Time: 10/10/2020 6:21:41 AM

	Run	Storage Capacity	Secure Yield	% Restricted at	Restricted % of duration	Restricted % of years	Critical Drought Start	Critical Drought End
HISTORICAL	1	39038.943	5509	40	3.93	5.17	16/01/1935	22/08/1944
	2	39038.943	4854	40	5.00	8.62	16/01/1935	02/07/1944
	3	39038.943	4743	35	3.16	6.90	16/01/1935	22/08/1944
	4	39038.943	3621	30	3.78	6.03	18/01/1935	17/02/1945
LOWEST	5	39038.943	3015	25	2.03	5.17	06/11/1933	08/01/1949
	6	39038.943	4636	35	5.00	8.62	16/01/1935	22/08/1944
	7	39038.943	4085	35	3.73	6.90	16/01/1935	02/07/1944
	8	39038.943	4358	35	4.99	7.76	16/01/1935	22/08/1944
	9	39038.943	3618	30	4.61	6.03	06/11/1933	22/08/1944
	10	39038.943	5187	45	4.99	9.48	18/01/1935	22/08/1944
	11	39038.943	6334	45	4.94	6.90	16/01/1935	22/08/1944
	12	39038.943	5568	40	4.09	5.17	16/01/1935	22/08/1944
	13	39038.943	4196	35	4.99	7.76	16/01/1935	22/08/1944
	14	39038.943	4086	35	5.00	7.76	16/01/1935	22/08/1944
MEDIAN	15	39038.943	4566	35	3.87	7.76	16/01/1935	22/08/1944
	16	39038.943	4618	35	3.33	6.90	16/01/1935	22/08/1944
10/15/25	5	39038.943	3618	25	9.35	13.79	01/01/1894	03/04/1916

Run 210: Dumaresq only

Armidale, Run 210CC F:\Results\Armidale\Mar2020\Data\ClimateChange\Armidale_

Time: 09/10/2020 11:49:34 AM

					Restricted		Critical Drought	
	Run	Storage Capacity	Secure Yield	% Restricted at	% of duration	% of years	Start	End
HISTORICAL	1	440	152	65	3.54	6.90	19/03/1937	29/12/1940
	2	440	143	65	4.65	9.48	19/03/1937	29/12/1940
	3	440	137	65	4.00	8.62	19/03/1937	29/12/1940
	4	440	108	60	4.41	9.48	19/01/1935	29/12/1940
LOWEST	5	440	90	50	3.45	7.76	19/01/1935	29/12/1940
	6	440	135	65	4.01	8.62	19/03/1937	29/12/1940
	7	440	113	60	3.97	9.48	19/01/1935	29/12/1940
	8	440	125	60	3.90	7.76	19/01/1935	29/12/1940
	9	440	103	55	3.94	8.62	19/01/1935	29/12/1940
	10	440	144	65	3.86	9.48	18/03/1937	29/11/1940
	11	440	182	70	4.33	9.48	20/03/1937	29/12/1940
	12	440	158	65	3.35	7.76	19/03/1937	29/12/1940
	13	440	116	60	3.94	8.62	19/01/1935	29/12/1940
	14	440	114	60	4.09	8.62	19/01/1935	29/12/1940
MEDIAN	15	440	133	65	4.51	9.48	19/01/1935	29/12/1940
	16	440	136	65	4.49	9.48	19/01/1935	29/12/1940
10/15/25	5	440	108	50	6.78	12.07	19/01/1935	29/12/1940

Run 192: Guyra + Malpas FSL increased by 3m+ Puddledock (no release requirements)

Armidale, Run 192CC F:\Results\Armidale\Mar2020\Data\ClimateChange\Armidale_

Time: 01/10/2020 3:33:41 AM

	Run	Storage Capacity	Secure Yield	% Restricted at	Restricted % of duration	% of years	Critical Drought Start	End
HISTORICAL	1	19171	5048	50	4.99	8.62	21/01/1935	30/12/1940
	2	19171	4504	45	3.63	6.90	20/01/1935	30/12/1940
	3	19171	4423	45	3.89	6.90	18/01/1935	30/12/1940
	4	19171	3436	45	5.00	7.76	19/01/1935	30/12/1940
LOWEST	5	19171	2891	40	3.66	6.90	19/01/1935	22/08/1944
	6	19171	4329	45	3.84	7.76	17/01/1935	30/12/1940
	7	19171	3703	45	3.08	6.03	20/02/1894	14/02/1900
	8	19171	4034	45	3.83	6.03	17/01/1935	30/12/1940
	9	19171	3405	45	5.00	8.62	18/01/1935	22/08/1944
	10	19171	4669	50	3.51	9.48	26/01/1935	29/12/1940
	11	19171	5779	50	4.26	9.48	22/01/1935	30/12/1940
	12	19171	5083	45	2.76	7.76	21/01/1935	30/12/1940
	13	19171	3745	45	3.15	6.90	11/02/1895	13/02/1900
	14	19171	3695	45	3.39	6.90	19/01/1935	30/12/1940
MEDIAN	15	19171	4218	45	3.21	6.03	19/01/1935	30/12/1940
	16	19171	4266	45	2.95	6.03	19/01/1935	30/12/1940
10/15/25	5	19171	3338	40	7.70	11.21	19/01/1935	22/08/1944

Run 191: Guyra + Malpas FSL increased by 3m (70% Trigger) + Puddledock

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	Run	Storage Capacity	Secure Yield	% Restricted at	Restricted % of duration	Restricted % of years	Critical Drought Start	Critical Drought End
HISTORICAL	1	19171	4941	45	3.92	8.62	01/09/1934	30/12/1940
	2	19171	4450	45	4.79	8.62	16/01/1935	30/12/1940
	3	19171	4346	45	4.99	8.62	16/01/1935	30/12/1940
	4	19171	3276	45	4.99	8.62	16/01/1935	29/12/1940
LOWEST	5	19171	2836	40	4.99	8.62	19/02/1934	22/08/1944
	6	19171	4249	45	4.99	8.62	01/01/1894	14/02/1900
	7	19171	3667	45	4.26	9.48	01/01/1894	14/02/1900
	8	19171	3982	45	5.00	7.76	16/01/1935	30/12/1940
	9	19171	3283	40	3.25	6.03	07/01/1935	02/07/1944
	10	19171	4597	45	2.75	8.62	16/01/1935	29/12/1940
	11	19171	5512	45	2.08	6.90	01/09/1934	30/12/1940
	12	19171	5023	45	4.23	9.48	07/01/1935	30/12/1940
	13	19171	3709	45	4.46	8.62	01/01/1894	13/02/1900
	14	19171	3659	45	4.70	8.62	01/01/1894	14/02/1900
MEDIAN	15	19171	4166	45	4.48	7.76	16/01/1935	30/12/1940
	16	19171	4214	45	4.24	7.76	16/01/1935	30/12/1940
10/15/25	5	19171	3273	35	6.79	10.34	06/11/1933	22/08/1944

NUWS

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MEMORANDUM

TO	Glenn Fernandes Principal Engineer- Planning (Water Utilities) NSW Public Works Advisory
CC	
FROM	Peter Cloke, Principal Hydrologist
DATE	16 April 2021
SUBJECT	Armidale Yield Study: Progress Report (5) ï Additional Sources

Additional cases have been modelled to assess the relative merits of additional new sources as requested in your emails of 9/4/2021, 7/4/2021 and 19/3/2021 and the results are reported herein.

Summary

The requested modelling cases results are provided in Tables 1 and Table 2.

Table 1 provides the initial preliminary modelling results whereby the pump rate from the new sources was set at 100 ML/d and the EFR releases were based on annual daily percentile flows (ie one %ile per year) and included Gara Dam.

Table 2 provides the refined initial preliminary modelling results whereby the pump rate from the new sources was reduced to 50 ML/d and the EFR releases were based on monthly daily percentile flows (ie one %ile per month) and excluded Gara Dam.

Comparing the results for comparable cases in Tables 1 and 2 suggests that their historic climate secure yields were not particularly sensitive to the refinements.

It is noted the secure yield estimates are dependent on the operating rules, data and assumptions as discussed herein and or in the previous 4 Progress Reports (30/3/2020, 26/5/2020, 18/9/2020 & 19/10/2020).

Table 1: Preliminary Secure Yield Estimates for Proposed Additional Sources

Run No	Option	Max Transfer Malpas Dam to Armidale ML/d	Historic Climate Secure Yield ML/a	Secure Yield with 1°C Climate Warming ML/a	Historic Climate Critical Drought	
					From	To
211	Pumping up to **100** ML/d from Styx River to 6.5 m raised FSL Malpas Dam	26*	**6964**	*Not modelled*	14/01/2018	6/02/2020
211b		43.97	**11777**	**9638**	27/10/2017	7/02/2020
212b	Pumping up to **100** ML/d from Aberfoyle River to 6.5 m raised FSL Malpas Dam	25.42	**6808**	*Not modelled*	20/01/1935	29/12/1940
213c	St Helena offstream storage 8460 ML Gross Storage 5% Dead storage. Pumping up to **100** ML/d from Styx River	n/a	**2629**	**2104**	19/7/2017	15/01/2020
214c	Chandler River onstream storage 36850 ML Gross storage. 5% Dead storage plus Pumping up to **100** ML/d from Styx River	n/a	**11410**	*Not modelled*	2/08/2013	15/01/2020

** The previously specified 26 ML/d transfer rate was found to be constraining the yield so unconstrained*

Malpas Dam options based on Run 207 (*which includes Guyra, Malpas, Puddledock & Gara Dams*) as detailed in Progress Report 4 of 19 October 2020

EFR rules for individually Styx , Aberfoyle and Chandler River :

1. For January to July can only transfer /store when flow above 90% ile
2. For August to December can only transfer/store when flow above 80% ile
3. Can only extract 30% of the flow above the % ile flows.
4. If Malpas or St Helena Dam or Chandler Dam as applicable less than 60% full then above 90% ile is relaxed to 95%ile and 80% ile relaxed to 90% ile .

Note : % ile flows based on all flows (ie only one value for the year)

Table 2: Refined Preliminary Secure Yield Estimates for Proposed Additional Sources

Run No	Option	Max Transfer Malpas Dam to Armidale ML/d	Historic Climate Secure Yield ML/a	Secure Yield with 1°C Climate Warming ML/a	Historic Climate Critical Drought	
					From	To
216	Pumping up to **50** ML/d from Styx River to 6.5 m raised FSL Malpas Dam	26*	**6964**	**6964*****	14/01/2018	6/02/2020
215		37.95	**10164**	**7843**	28/10/2017	7/02/2020
218	Chandler River onstream storage **3552 ML**** Gross storage. 5% Dead storage plus Pumping up to **50** ML/d from Styx River	n/a	**3323**	**3101**	28/12/2018	9/01/2020
** The previously specified 26 ML/d transfer rate was found to be constraining the yield so unconstrained*						
*** Storage size was varied to result in a target secure yield of about 3000 ML/a*						
**** No change occurred from climate change as the secure yield was constrained by the 26 ML/d transfer from Malpas Dam to Armidale*						
Malpas Dam options based on Run 202 (*which includes Guyra, Malpas, & Puddledock Dams*) as detailed in Progress Report 4 of 19 October 2020						
EFR rules for individually Styx and Chandler River : 1. For January to July can only transfer /store when flow above 90% ile 2. For August to December can only transfer/store when flow above 80% ile 3. Can only extract 30% of the flow above the % ile flows. 4. If Malpas or Chandler Dam as applicable less than 60% full then above 90% ile is relaxed to 95%ile and 80% ile relaxed to 90% ile . **Note : % ile flows based on flows in each month (ie twelve monthly values for the year)**						

Assumptions

The system behaviour modelling included updated assumptions and key ones are provided below.

As specified the pumping sites and new on stream storages were assumed to be at the relevant gauging stations in terms of the flows used.

Figures 1 to 2 provide the modelled catchments and Figures 3 to 5 provide daily flow duration curves of the modelled and the corresponding modelled flows suggesting reasonable calibration was achieved for the purposes in-hand. It is noted for the Styx River and Aberfoyle River the historical critical drought was based on the observed daily flows. Table 3 provides the basis of the rainfall runoff modelling.

Table 3: Flow Modelling Details

Catchment	G/S	Area km^2	Station Status	Rainfall Runoff Model Used
Styx River at Jeogla	206001	163	Open	Sacramento (from Macleay River Basin Model)
Aberfoyle River at Aberfoyle	204030	200	Open	Sacramento for this study
Chandler River at Chandler	206003	311	Closed	Sacramento (from Macleay River Basin Model)

It is acknowledged that the models for Chandler River and Styx River would normally be more detailed if being considered individually rather than as subareas for a large basin. However for the purposes in-hand of assessing feasibility of proposed sources they were considered of sufficient detail and furthermore the critical drought turned out to be based on the observed flows.

Table 4 provides the percentile flows which were determined from the historic flow series used as model input that were used for the EFR rules.

Table 4 : EFR Daily Percentile Flows (ML/d)

	Styx River at Jeogla (206001)				Aberfoyle River at Aberfoyle(204030)				Chandler River at Chandler (206003)		
	80%	90%	95%		80%	90%	95%		80%	90%	95%
Jan	35.156	19.58	12.23	1	1.432	0.42	0	1	3.752	1.67	0.42
Feb	57.714	34.25	20.635	2	2.12	0.787	0.08	2	4.384	2.45	1.26
Mar	78.054	46.222	33.154	3	2.124	0.74	0.091	3	4.978	2.4	1.531
Apr	72.94	46.49	29.6205	4	1.37	0.47	0.05	4	4.748	2.138	0.98
May	54.7	38.06	27.82	5	1.12	0.37	0.05	5	3.22	1.62	0.76
Jun	51.714	36.549	26.3925	6	1.57	0.67	0.17	6	2.72	1.189	0.48
Jul	49.06	34.25	26.87	7	2.39	0.77	0.27	7	2.17	0.87	0.27
Aug	37.96	28.54	21.28	8	2.06	0.93	0.31	8	1.71	0.49	0.11
Sep	30.916	20.865	15.7435	9	1.68	0.73	0.15	9	1.37	0.439	0.0345
Oct	26.6	17.13	12.32	10	1.17	0.38	0	10	1.22	0.24	0
Nov	23.24	12.78	8.56	11	1.33	0.19	0	11	1.35	0.37	0
Dec	26.99	16.77	9.78	12	1.39	0.38	0	12	2.47	0.82	0.28
Annual	39.64	25.05	16.89	Annual	1.57	0.55	0.05	Annual	2.49	0.97	0.28

Figure 1: Styx and Chandler River Modelled Catchments

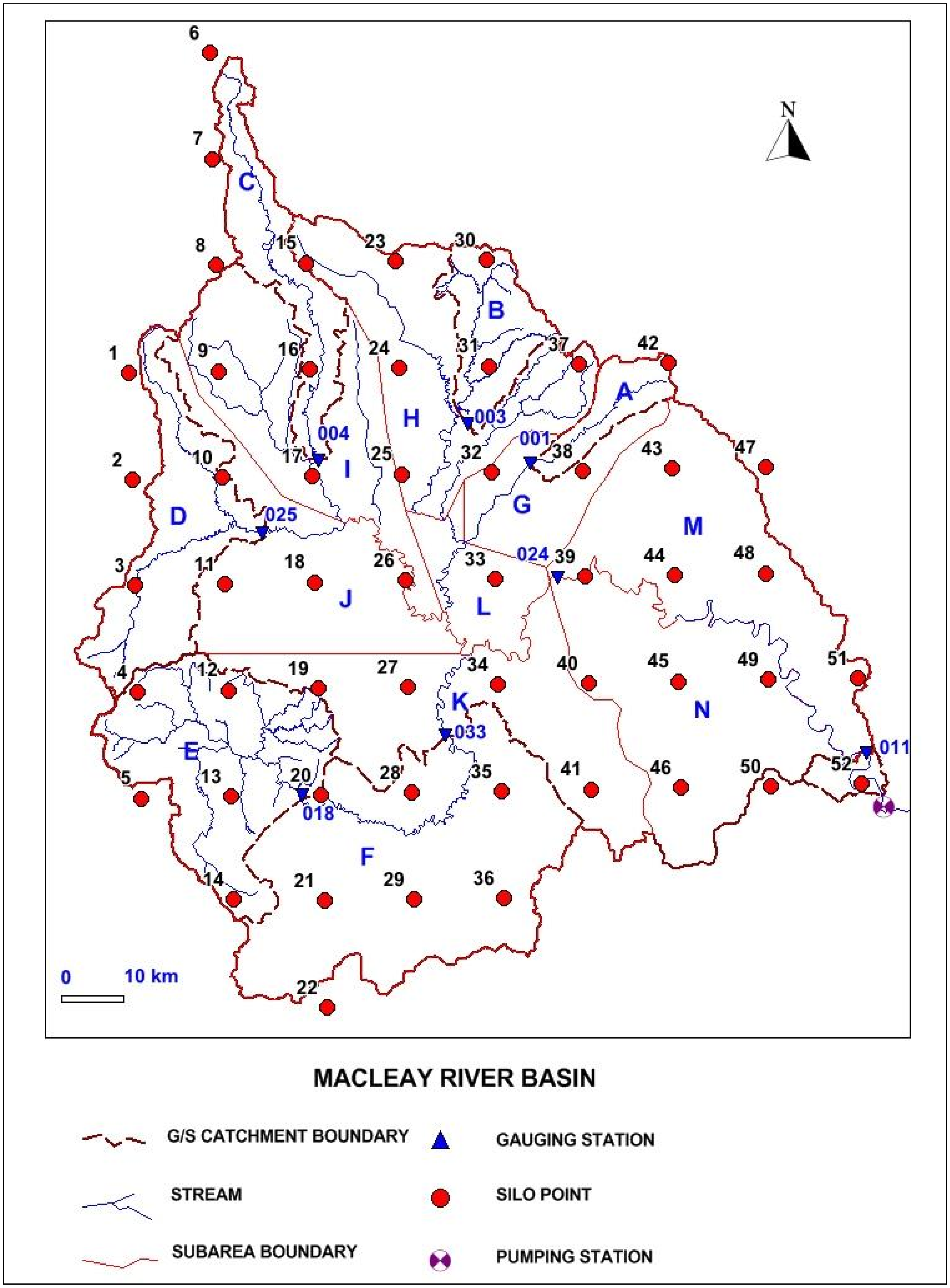


Figure 2: Aberfoyle River Modelled Catchment

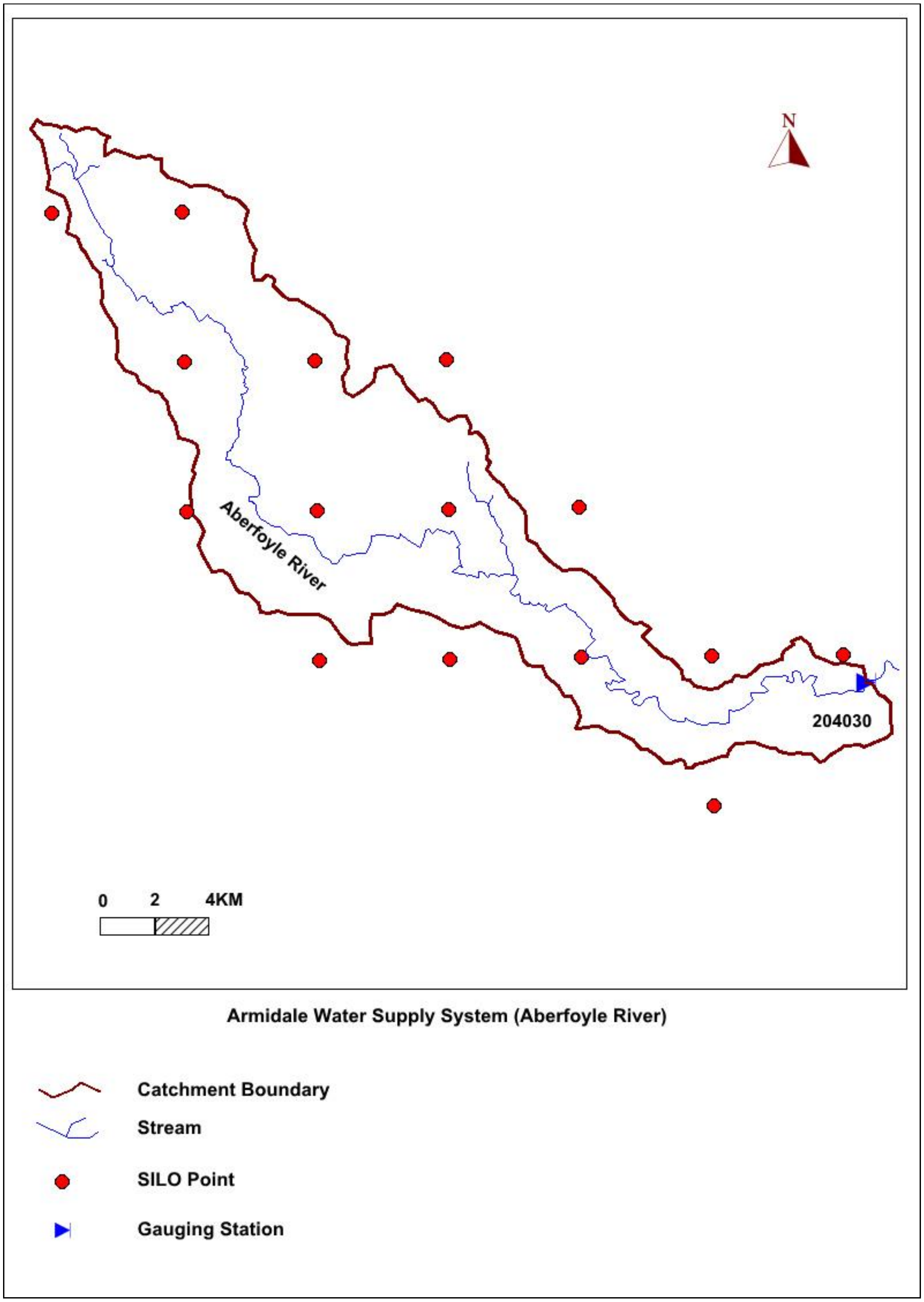


Figure 3: Flow Duration Curve- Styx River

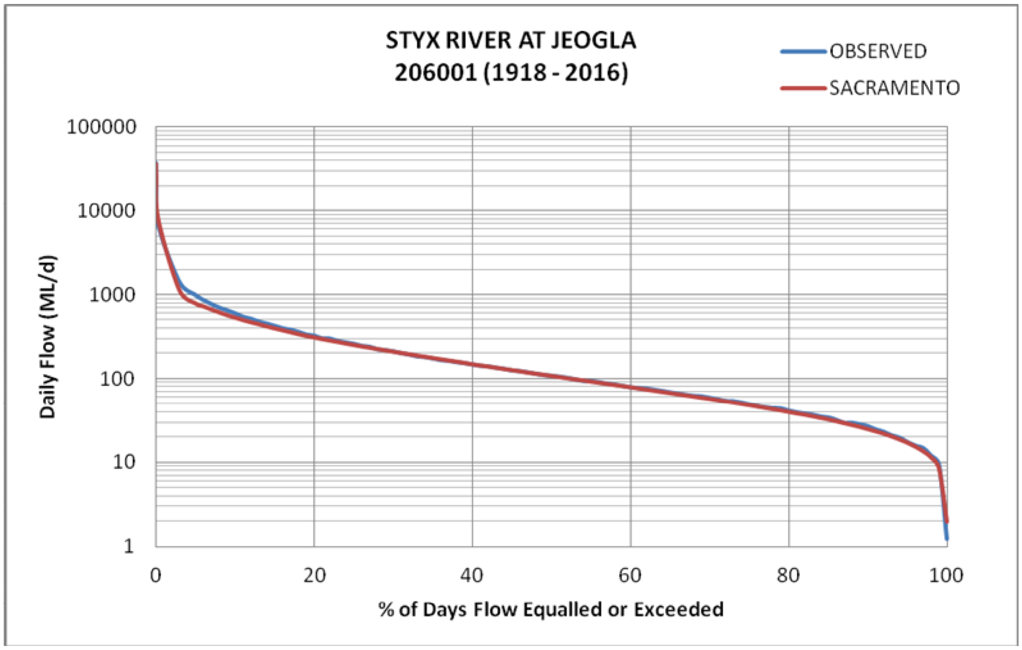


Figure 4: Flow Duration Curve- Chandler River

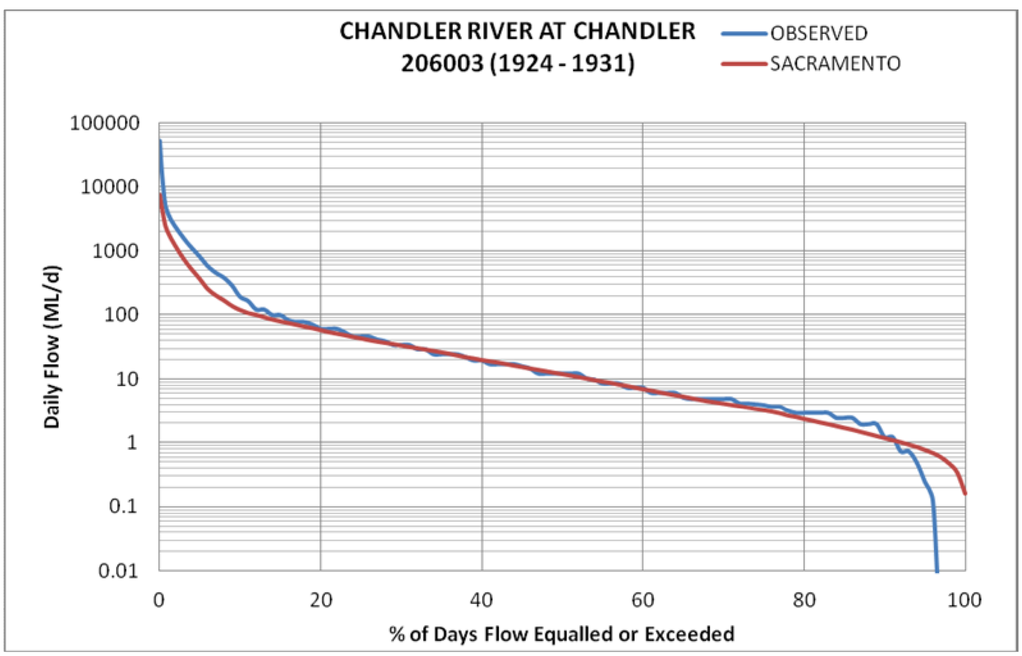
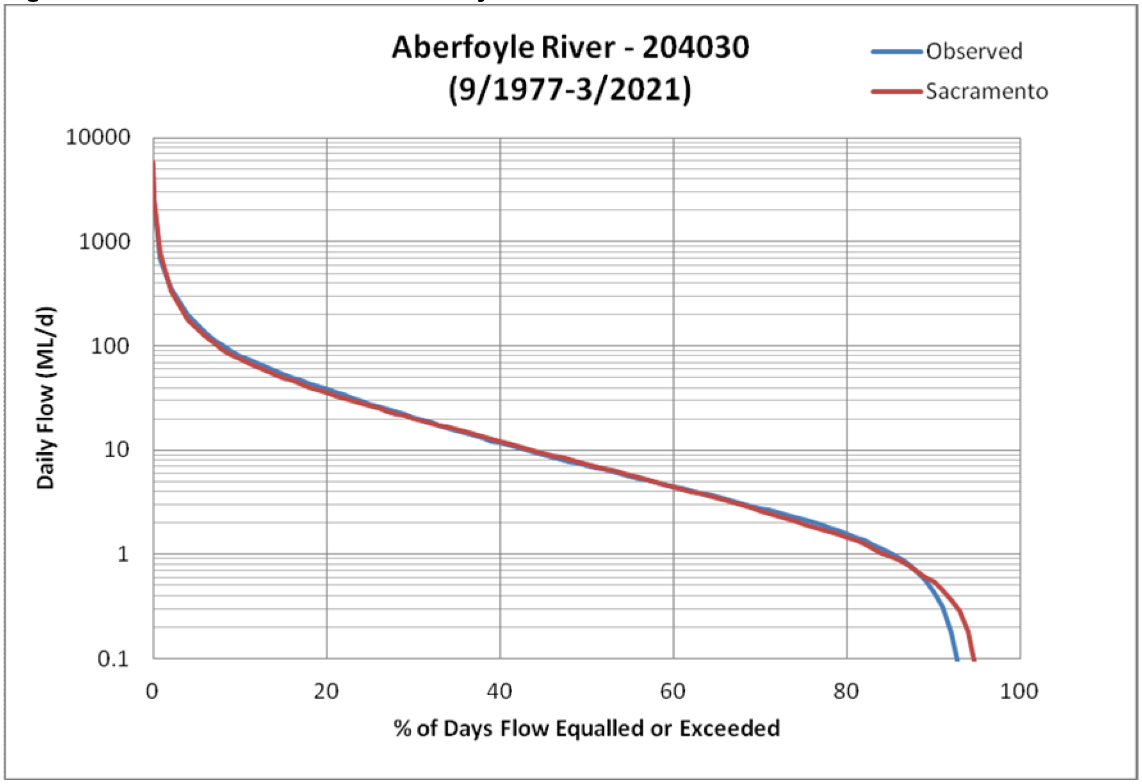


Figure 5: Flow Duration Curve – Aberfoyle River



Discussion

Storage Behaviour

Figures 6 to 13 provide the modelled storage behaviour diagrams for a repeat of the historic climate supplying annual demands (with restrictions applied in accordance with 5/10/10 rules) that equate to the secure yields for that particular storage case.

The diagrams clearly show the influence of the recent severe 2019/2020 drought.

.Figure 6: Storage Behaviour – Run 211

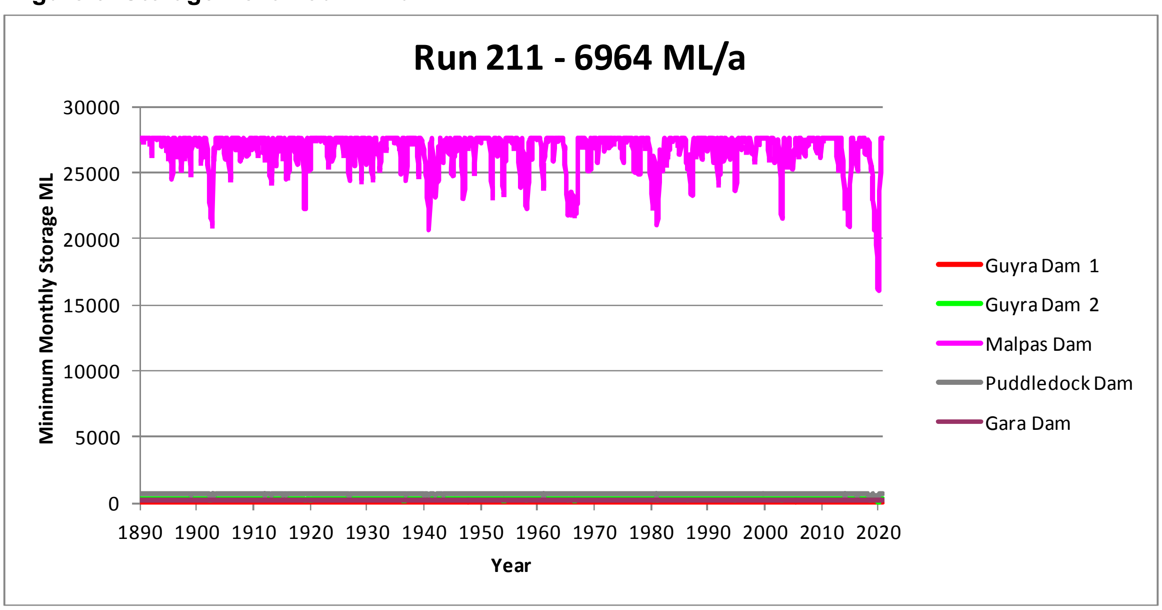


Figure 7: Storage Behaviour – Run 211b

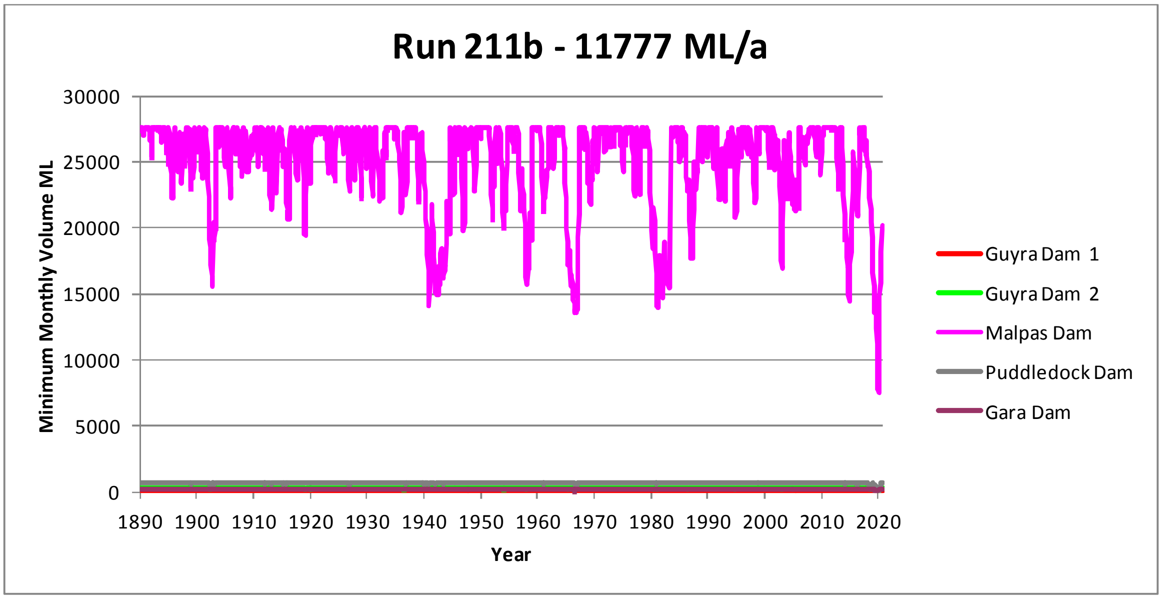


Figure 8: Storage Behaviour – Run 212b

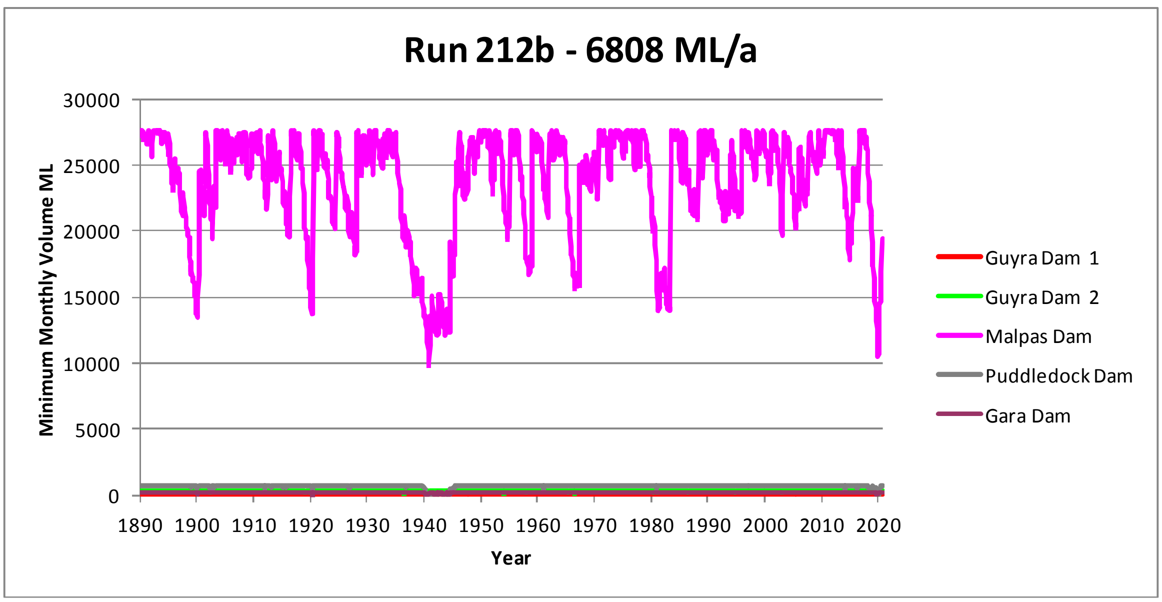


Figure 9: Storage Behaviour – Run 213c

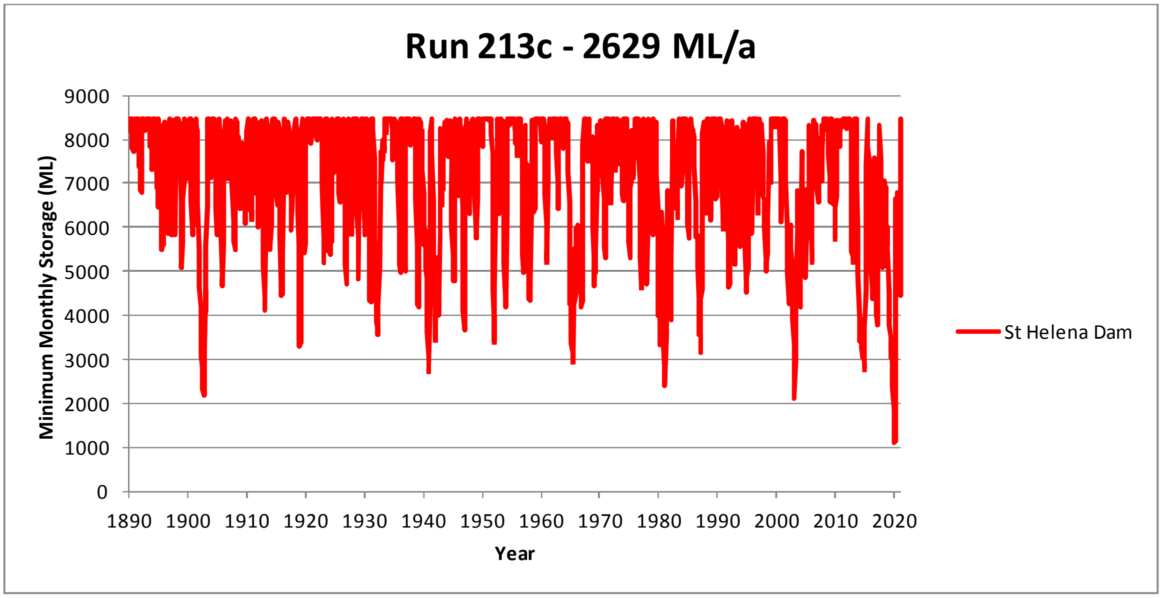


Figure 10: Storage Behaviour – Run 214c

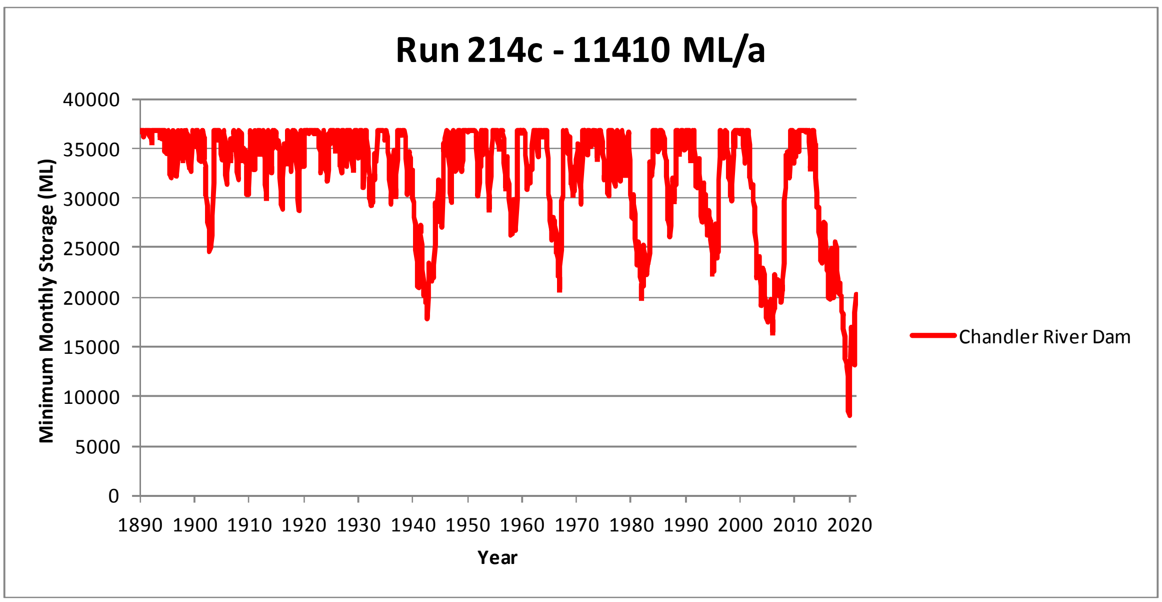


Figure 11: Storage Behaviour – Run 216

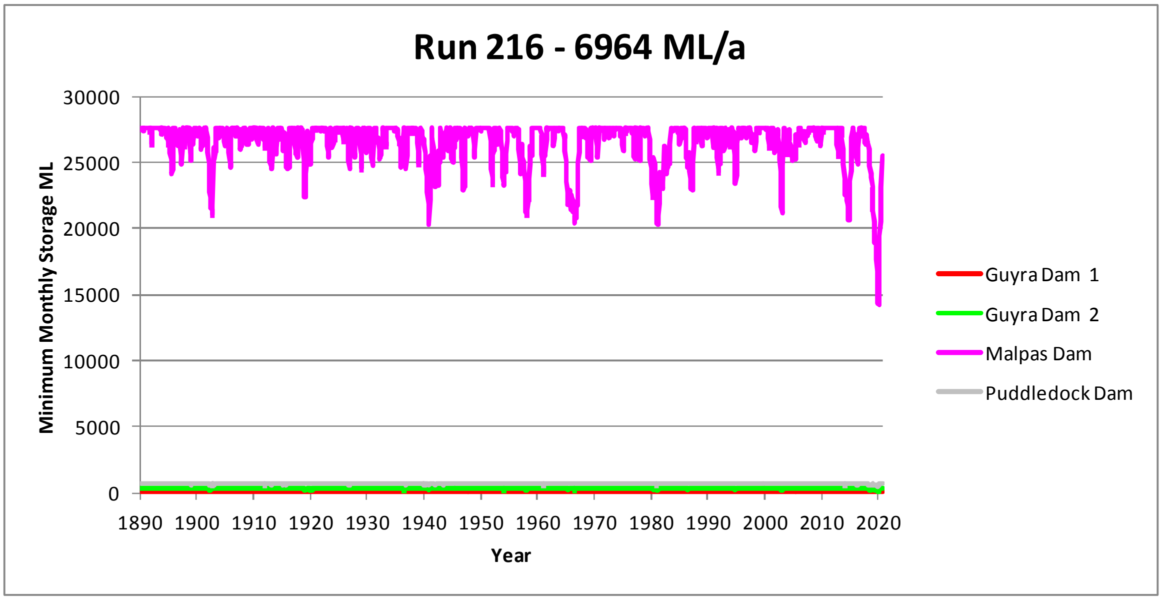


Figure 12: Storage Behaviour – Run 215

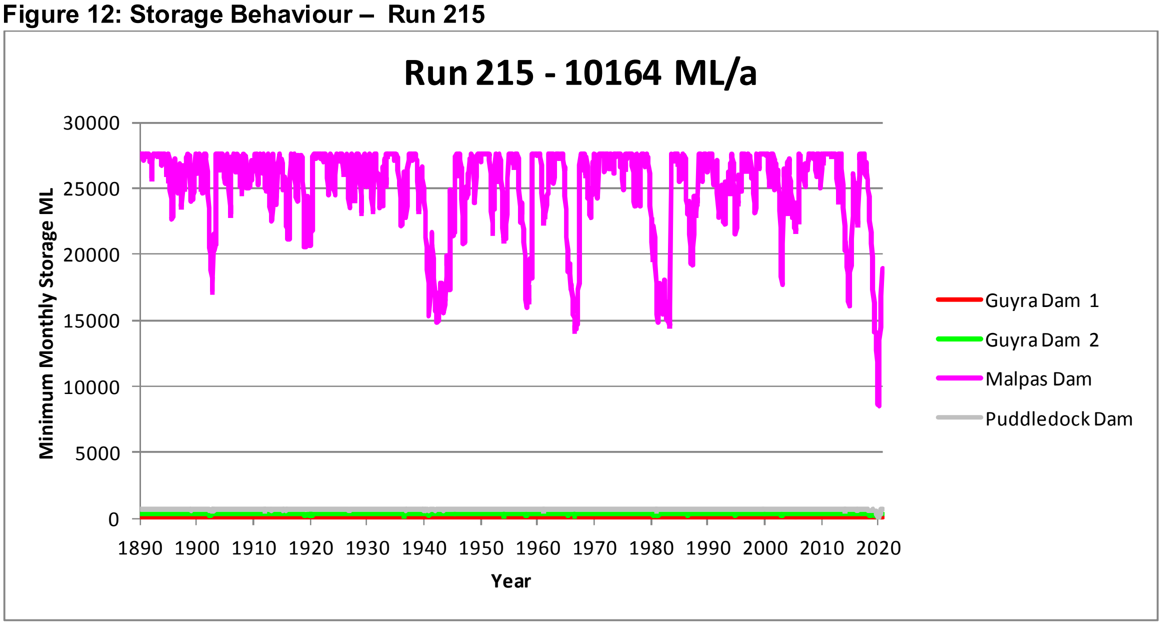
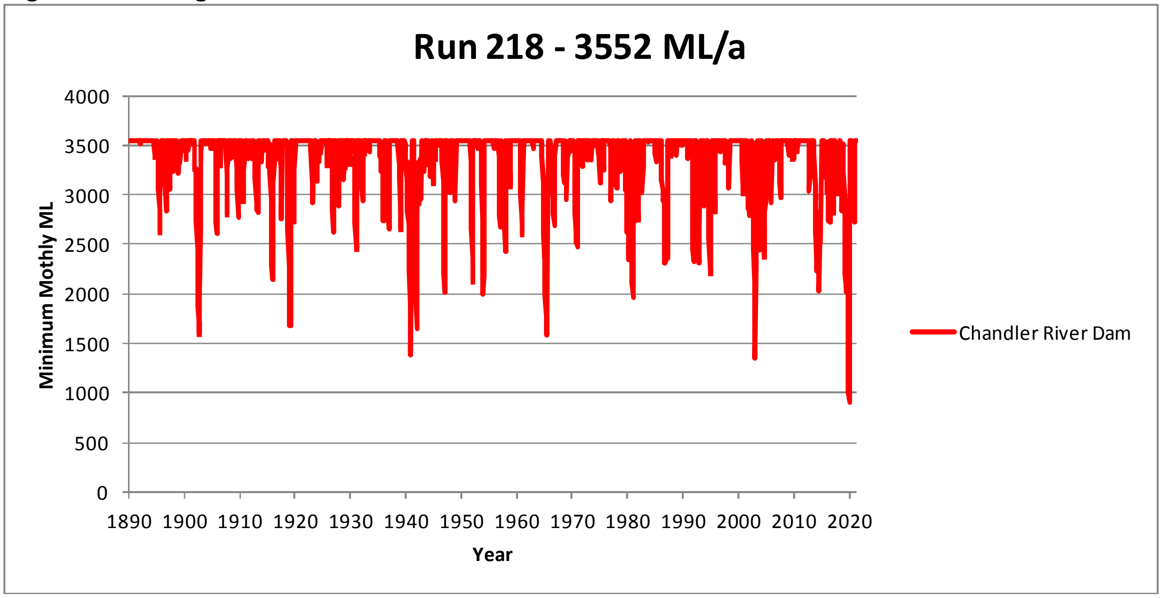


Figure 13: Storage Behaviour – Run 218



Climate Change

Attachment A provides the results of the required model runs for the 15 GCMs and comparable historic data base for assessing 1 ^{o}C climate warming.

The climate adjustment factor based on the lowest GCM with10/15/25 as well as the median GCM are provided in Table 5. It is usual practice to adopt the lower values and these are what were used for the Table 1 and 2 results. However if less security is acceptable then the higher values may be considered.

Table 5: Climate Adjustment Factors

Model Run No	Scenario	Climate Change Adjustment Factor	
		10/15/25	Median
211b	Raised Malpas Dam with Styx River Pumping. Unconstrained from Malpas Dam.	**0.8184**	**0.9226**
213c	St Helena Off-Stream Storage with Styx River Pumping..	**0.8004**	**0.8739**
216	Raised Malpas Dam with Styx River Pumping. Constrained to 26 ML/d from Malpas Dam.	**1***	**1***
215	Raised Malpas Dam with Styx River Pumping. Unconstrained from Malpas Dam.	**0.7717**	**0.8970**
218	Chandler On-Stream Storage with Styx River Pumping	**0.9333**	**0.9356**
** No change occurred from climate change as the secure yield was constrained by the 26 ML/d transfer from Malpas Dam to Armidale*			

ATTACHMENT A
Model Results for 15 GCMs and corresponding Historic Base

Note that in each case shown on the following pages the data is based on modelled flow information (from a data base of daily rainfall and daily evapotranspiration) and not observed flow data. The adopted historical secure yields uses a longer period and are those in Tables 1 and 2. The following data is used to adjust the yields in Tables 1 and 2 in accordance with the DPIE Water Guidelines

Run 211b : Raised Malpas with Styx River Pumping

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	Run	Storage Capacity	Secure Yield	% Restricted at	Restricted % of duration	Restricted % of years	Critical Drought Start	Critical Drought End
HISTORICAL	1	28544.97	14652	55	4.12	9.48	21/07/1978	06/02/1981
	2	28544.97	13926	50	2.94	8.62	21/07/1978	06/02/1981
	3	28544.97	13818	50	2.45	6.03	20/07/1978	06/02/1981
	4	28544.97	12022	50	3.55	9.48	23/02/1895	28/11/1902
LOWEST	5	28544.97	10835	45	3.05	9.48	11/02/1895	28/11/1902
	6	28544.97	13617	50	2.71	9.48	20/07/1978	06/02/1981
	7	28544.97	12440	50	2.70	9.48	20/07/1978	06/02/1981
MEDIAN	8	28544.97	13518	50	3.47	9.48	23/02/1895	28/11/1902
	9	28544.97	11629	45	2.03	6.90	11/02/1895	28/11/1902
	10	28544.97	13117	50	2.67	7.76	20/07/1978	06/02/1981
	11	28544.97	16110	55	4.04	9.48	21/07/1978	05/02/1981
	12	28544.97	14785	55	4.45	9.48	21/07/1978	06/02/1981
	13	28544.97	12403	50	3.04	9.48	20/07/1978	06/02/1981
	14	28544.97	11680	45	1.86	6.90	11/02/1895	28/11/1902
	15	28544.97	13780	50	3.16	9.48	23/02/1895	28/11/1902
	16	28544.97	14286	50	3.29	9.48	20/07/1978	06/02/1981
10/15/25	5	28544.97	11991	40	4.91	14.66	11/02/1895	28/11/1902

Run 213c: St Helena Off Stream Storage with Styx River Pumping

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					Restricted		Critical Drought	
		Storage	Secure	% Restricted	% of	% of		
	Run	Capacity	Yield	at	duration	years	Start	End
HISTORICAL	1	8460	2886	45	1.55	9.48	06/09/1901	11/10/1902
	2	8460	2673	40	1.12	5.17	06/09/1901	22/11/1902
	3	8460	2622	40	1.09	6.03	05/09/1901	22/11/1902
	4	8460	2405	40	1.20	6.90	02/09/1901	22/11/1902
LOWEST	5	8460	1804	40	1.49	9.48	14/08/1900	22/11/1902
	6	8460	2605	45	1.36	9.48	05/09/1901	11/10/1902
	7	8460	2310	40	1.16	6.90	04/09/1901	09/10/1902
MEDIAN	8	8460	2522	40	0.94	5.17	05/09/1901	09/10/1902
	9	8460	2089	40	1.35	8.62	04/09/1901	22/11/1902
	10	8460	2465	40	1.18	6.90	04/09/1901	22/11/1902
	11	8460	3307	45	1.30	8.62	06/09/1901	11/10/1902
	12	8460	2684	40	1.06	6.03	06/09/1901	22/11/1902
	13	8460	2338	40	1.39	7.76	05/09/1901	22/11/1902
	14	8460	1888	40	1.68	9.48	15/08/1900	22/11/1902
	15	8460	2738	45	1.44	9.48	05/09/1901	09/10/1902
	16	8460	3011	45	1.41	9.48	06/09/1901	09/10/1902
10/15/25	5	8460	2310	40	2.31	14.66	13/08/1900	22/11/1902

Run 216: Raised Malpas with Styx River Pumping

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					Restricted		Critical Drought	
	Run	Storage Capacity	Secure Yield	% Restricted at	% of duration	% of years	Start	End
HISTORICAL	1	28326	6964	80	1.02	4.31	01/09/1901	22/11/1902
	2	28326	6964	80	2.02	7.76	04/07/1979	05/02/1981
	3	28326	6964	80	1.99	7.76	03/07/1979	05/02/1981
	4	28326	6964	75	2.69	6.90	13/07/1978	05/02/1981
	5	28326	6964	65	2.49	5.17	11/02/1895	28/11/1902
	6	28326	6964	80	2.17	7.76	02/07/1979	05/02/1981
	7	28326	6964	75	1.53	4.31	29/07/1978	06/02/1981
MEDIAN	8	28326	6964	80	2.21	8.62	18/03/1979	06/02/1981
	9	28326	6964	70	1.80	5.17	16/07/1978	06/02/1981
	10	28326	6964	75	0.89	4.31	01/07/1979	05/02/1981
	11	28326	6964	80	0.47	1.72	02/09/1901	28/11/1902
	12	28326	6964	80	1.06	4.31	01/09/1901	28/11/1902
	13	28326	6964	75	1.87	6.90	29/07/1978	06/02/1981
	14	28326	6964	70	1.62	6.03	29/07/1978	31/03/1981
LOWEST	15	28326	6964	80	1.88	7.76	18/03/1979	05/02/1981
	16	28326	6964	80	1.37	6.90	30/08/1901	22/11/1902
10/15/25	15	28326	6964	80	1.60	7.76	18/03/1979	05/02/1981

Run 215: Raised Malpas with Styx River Pumping

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	Run	Storage Capacity	Secure Yield	% Restricted at	Restricted % of duration	Restricted % of years	Critical Drought Start	Critical Drought End
HISTORICAL	1	28326	12824	45	4.10	9.48	23/02/1895	28/11/1902
	2	28326	11952	45	3.35	6.90	22/07/1978	31/03/1981
	3	28326	11914	45	3.64	7.76	21/07/1978	20/09/1982
	4	28326	10174	45	4.44	8.62	23/02/1895	28/11/1902
LOWEST	5	28326	8957	40	2.79	9.48	11/02/1895	28/11/1902
MEDIAN	6	28326	11503	40	1.24	5.17	23/02/1895	28/11/1902
	7	28326	10687	45	3.92	9.48	10/02/1895	28/11/1902
	8	28326	11511	45	4.30	9.48	23/02/1895	28/11/1902
	9	28326	9727	45	3.62	9.48	11/02/1895	28/11/1902
	10	28326	11354	50	4.62	9.48	04/03/1896	28/11/1902
	11	28326	13861	45	2.46	6.90	21/07/1978	31/03/1981
	12	28326	12821	45	3.54	8.62	21/07/1978	31/03/1981
	13	28326	10644	45	3.68	9.48	11/02/1895	28/11/1902
	14	28326	9848	40	1.54	6.90	11/02/1895	28/11/1902
	15	28326	11686	40	1.98	6.03	23/02/1895	28/11/1902
	16	28326	12015	45	3.59	9.48	23/02/1895	28/11/1902
10/15/25	5	28326	9896	30	4.95	13.79	11/02/1895	28/11/1902

Run 218: Chandler On Stream Storage with Styx River Pumping

Armidale, Run 218CC F:\Results\Armidale\Data\ChandlerCC\CHANDLER_

Time: 15/04/2021 2:58:47 PM

	Run	Storage Capacity	Secure Yield	% Restricted at	Restricted % of duration	Restricted % of years	Critical Drought Start	Critical Drought End
HISTORICAL	1	3552	3432	60	1.23	9.48	23/10/1901	09/10/1902
	2	3552	3443	60	1.20	9.48	23/10/1901	09/10/1902
	3	3552	3362	60	1.30	9.48	12/10/1901	09/10/1902
	4	3552	3039	55	0.84	6.90	15/09/1901	09/10/1902
LOWEST	5	3552	2730	55	1.01	6.90	14/09/1901	22/11/1902
	6	3552	3237	60	1.20	9.48	23/10/1901	09/10/1902
	7	3552	2972	55	0.74	5.17	27/09/1901	09/10/1902
MEDIAN	8	3552	3211	60	1.17	9.48	27/09/1901	09/10/1902
	9	3552	2856	55	0.83	6.90	27/09/1901	22/11/1902
	10	3552	3109	55	0.83	7.76	17/09/1901	28/10/1902
	11	3552	3793	60	1.27	9.48	23/10/1901	09/10/1902
	12	3552	3463	60	1.30	9.48	23/10/1901	28/10/1902
	13	3552	3085	55	0.87	5.17	23/10/1901	28/10/1902
	14	3552	2791	55	1.00	6.03	27/09/1901	28/10/1902
	15	3552	3345	60	1.33	9.48	27/09/1901	09/10/1902
	16	3552	3501	60	1.29	9.48	23/10/1901	09/10/1902
10/15/25	5	3552	3203	55	1.97	14.66	13/09/1901	22/11/1902

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MEMORANDUM

TO	Glenn Fernandes Principal Engineer- Planning (Water Utilities) NSW Public Works Advisory
CC	
FROM	Peter Cloke, Principal Hydrologist
DATE	22 April 2021
SUBJECT	Armidale Yield Study: Progress Report (6) ï Additional Sources

The additional case (*after consideration of the results in NUWS Progress Report 5 of 16/4/2021*) requested in your email of 16/4/2021 has been modelled and the results are reported herein.

Summary

The requested modelling case results are provided in Table 1.

It is noted the secure yield estimates are dependent on the operating rules, data and assumptions as discussed herein and or in the previous 5 Progress Reports (30/3/2020, 26/5/2020, 18/9/2020, 19/10/2020 & 16/4/2021).

Table 1: Preliminary Secure Yield Estimates for Proposed Additional Sources

<table>
<tr><th rowspan="2">Run No</th><th rowspan="2">Option</th><th rowspan="2">Max Transfer Malpas Dam to Armidale ML/d</th><th rowspan="2">Historic Climate Secure Yield ML/a</th><th rowspan="2">Secure Yield with 1°C Climate Warming ML/a</th><th colspan="2">Historic Climate Critical Drought</th></tr>
<tr><th>From</th><th>To</th></tr>
<tr><td>220</td><td>Pumping up to 50 ML/d from Aberfoyle River to 6.5 m raised FSL Malpas Dam</td><td>24.29</td><td>6507</td><td>4824</td><td>20/01/1935</td><td>29/12/1940</td></tr>
<tr><td colspan="7">Malpas Dam options based on Run 202 (which includes Guyra, Malpas, & Puddledock Dams) as detailed in Progress Report 4 of 19 October 2020</td></tr>
<tr><td colspan="7">EFR rules for Aberfoyle River pumping :
1. For January to July can only transfer /store when flow above 90% ile
2. For August to December can only transfer/store when flow above 80% ile
3. Can only extract 30% of the flow above the % ile flows.
4. If Malpas Dam less than 60% full then above 90% ile is relaxed to 95%ile and 80% ile relaxed to 90% ile (except January kept as 90%ile as 95%ile was zero).
Note : % ile flows based on flows in each month (ie twelve monthly values for the year)</td></tr>
</table>

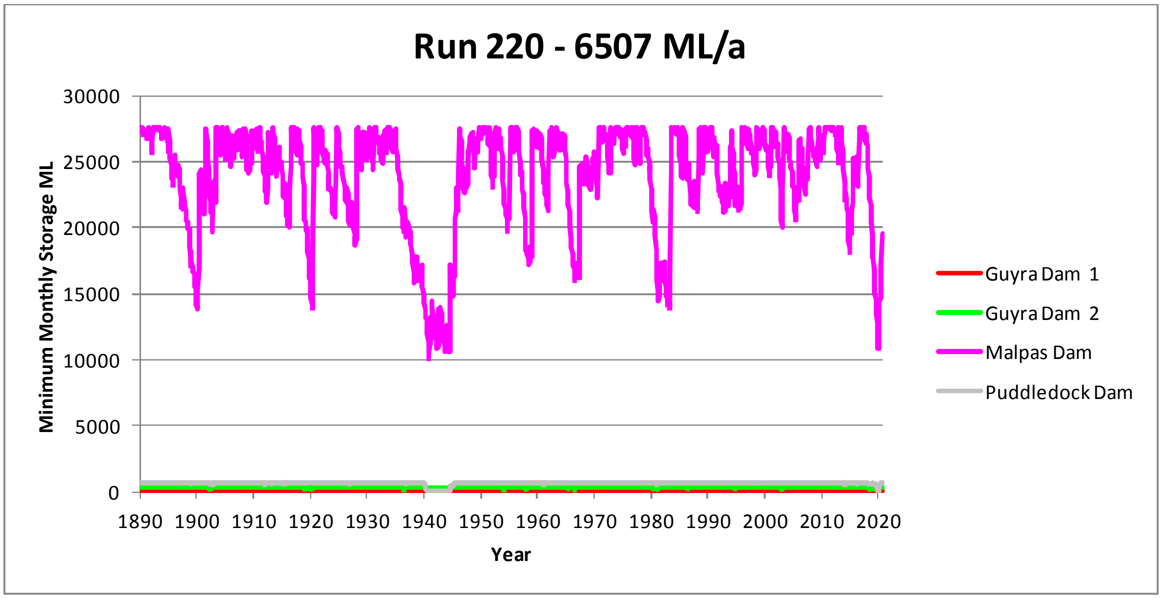
Discussion

Storage Behaviour

Figure 1 provides the modelled storage behaviour diagrams for a repeat of the historic climate supplying annual demands (with restrictions applied in accordance with 5/10/10 rules) that equate to the secure yields for that particular storage case.

The diagrams clearly show the influence of the recent severe 2019/2020 drought.

Figure 1: Storage Behaviour – Run 219



Climate Change

Attachment A provides the results of the required model runs for the 15 GCMs and comparable historic data base for assessing 1 ^{o}C climate warming.

The climate adjustment factor based on the lowest GCM with10/15/25 as well as the median GCM are provided in Table 2. It is usual practice to adopt the lower values and these are what was used for the Table 1 result. However if less security is acceptable then the higher values may be considered.

Table 1: Climate Adjustment Factors

Model Run No	Scenario	Climate Change Adjustment Factor	
		10/15/25	Median
220	Raised Malpas Dam with Aberfoyle River pumping	**0.7414**	**0.8801**

ATTACHMENT A
Model Results for 15 GCMs and corresponding Historic Base

Note that in each case shown on the following pages the data is based on modelled flow information (from a data base of daily rainfall and daily evapotranspiration) and not observed flow data. The adopted historical secure yield uses a longer period and is those in Table 1. The following data is used to adjust the yields in Table 1 in accordance with the DPIE Water Guidelines

Run 220 : Raised Malpas with Aberfoyle River Pumping

Armidale, Run 220CC F:\Results\Armidale\Data\ClimateChange_Aberfoyle\Armidale_

Time: 21/04/2021 10:55:15 PM

	Run	Storage Capacity	Secure Yield	% Restricted at	Restricted % of duration	Restricted % of years	Critical Drought Start	Critical Drought End
HISTORICAL	1	28326	6964	45	4.95	6.90	21/01/1935	29/12/1940
	2	28326	6482	40	4.62	6.03	20/01/1935	02/07/1944
	3	28326	6343	40	4.86	6.03	19/01/1935	02/07/1944
	4	28326	5003	35	4.12	6.03	19/01/1935	04/11/1943
LOWEST	5	28326	4375	35	5.00	7.76	19/01/1935	22/08/1944
	6	28326	6207	35	3.80	6.03	19/01/1935	04/11/1943
	7	28326	5454	40	5.00	7.76	19/01/1935	04/11/1943
	8	28326	5891	40	4.97	7.76	19/01/1935	04/11/1943
	9	28326	4993	35	4.04	6.03	19/01/1935	02/07/1944
	10	28326	6665	45	5.00	6.90	26/01/1935	29/12/1940
	11	28326	6964	55	2.58	6.90	26/01/1935	29/12/1940
	12	28326	6964	40	3.39	6.03	21/01/1935	29/12/1940
	13	28326	5523	40	5.00	6.90	19/01/1935	02/07/1944
	14	28326	5315	35	3.40	5.17	19/01/1935	02/07/1944
MEDIAN	15	28326	6129	40	4.82	6.90	19/01/1935	29/12/1940
	16	28326	6314	40	4.51	6.03	19/01/1935	29/12/1940
10/15/25	5	28326	5163	30	7.65	13.79	25/02/1934	22/08/1944

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MEMORANDUM

TO	Glenn Fernandes Principal Engineer- Planning (Water Utilities) NSW Public Works Advisory
CC	
FROM	Peter Cloke, Principal Hydrologist
DATE	22 April 2021
SUBJECT	Armidale Yield Study: Progress Report (6) ï Additional Sources

The additional case (*after consideration of the results in NUWS Progress Report 5 of 16/4/2021*) requested in your email of 16/4/2021 has been modelled and the results are reported herein.

Summary

The requested modelling case results are provided in Table 1.

It is noted the secure yield estimates are dependent on the operating rules, data and assumptions as discussed herein and or in the previous 5 Progress Reports (30/3/2020, 26/5/2020, 18/9/2020, 19/10/2020 & 16/4/2021).

Table 1: Preliminary Secure Yield Estimates for Proposed Additional Sources

Run No	Option	Max Transfer Malpas Dam to Armidale ML/d	Historic Climate Secure Yield ML/a	Secure Yield with 1°C Climate Warming ML/a	Historic Climate Critical Drought	
					From	To
220	Pumping up to **50** ML/d from Aberfoyle River to 6.5 m raised FSL Malpas Dam	24.29	**6507**	**4824**	20/01/1935	29/12/1940
Malpas Dam options based on Run 202 (*which includes Guyra, Malpas, & Puddledock Dams*) as detailed in Progress Report 4 of 19 October 2020						

EFR rules for Aberfoyle River pumping :

1. For January to July can only transfer /store when flow above 90% ile
2. For August to December can only transfer/store when flow above 80% ile
3. Can only extract 30% of the flow above the % ile flows.
4. If Malpas Dam less than 60% full then above 90% ile is relaxed to 95%ile and 80% ile relaxed to 90% ile (*except January kept as 90%ile as 95%ile was zero*).

Note : % ile flows based on flows in each month (ie twelve monthly values for the year)

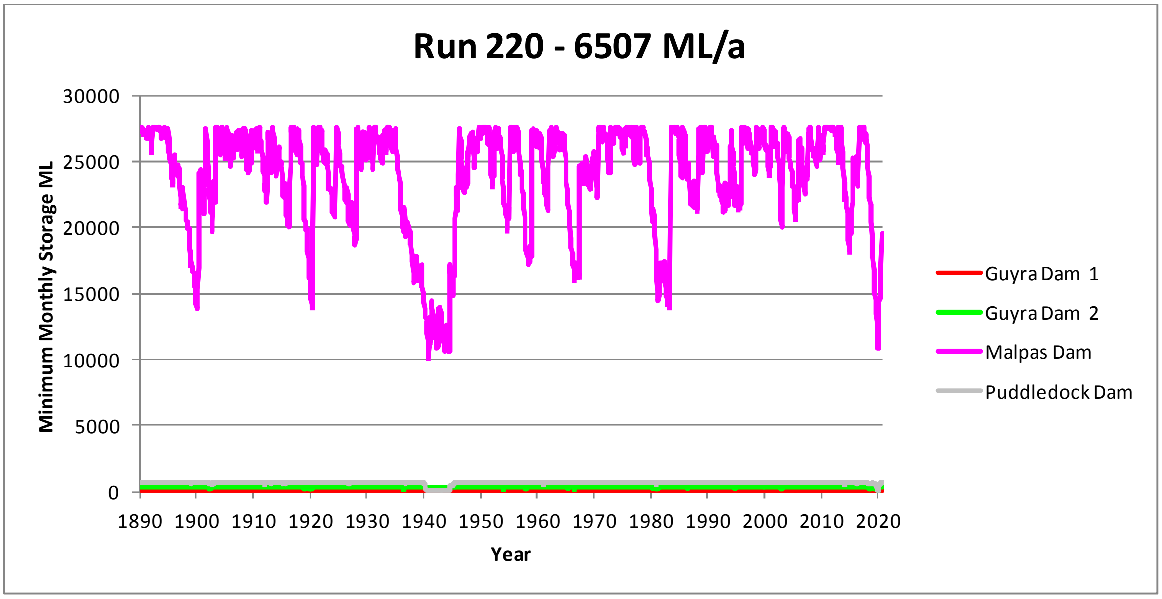
Discussion

Storage Behaviour

Figure 1 provides the modelled storage behaviour diagrams for a repeat of the historic climate supplying annual demands (with restrictions applied in accordance with 5/10/10 rules) that equate to the secure yields for that particular storage case.

The diagrams clearly show the influence of the recent severe 2019/2020 drought.

Figure 1: Storage Behaviour – Run 219



Climate Change

Attachment A provides the results of the required model runs for the 15 GCMs and comparable historic data base for assessing 1 ^{o}C climate warming.

The climate adjustment factor based on the lowest GCM with10/15/25 as well as the median GCM are provided in Table 2. It is usual practice to adopt the lower values and these are what was used for the Table 1 result. However if less security is acceptable then the higher values may be considered.

Table 1: Climate Adjustment Factors

Model Run No	Scenario	Climate Change Adjustment Factor	
		10/15/25	Median
220	Raised Malpas Dam with Aberfoyle River pumping	**0.7414**	**0.8801**

ATTACHMENT A
Model Results for 15 GCMs and corresponding Historic Base

Note that in each case shown on the following pages the data is based on modelled flow information (from a data base of daily rainfall and daily evapotranspiration) and not observed flow data. The adopted historical secure yield uses a longer period and is those in Table 1. The following data is used to adjust the yields in Table 1 in accordance with the DPIE Water Guidelines

Run 220 : Raised Malpas with Aberfoyle River Pumping

Armidale, Run 220CC F:\Results\Armidale\Data\ClimateChange_Aberfoyle\Armidale_

Time: 21/04/2021 10:55:15 PM

	Run	Storage Capacity	Secure Yield	% Restricted at	Restricted % of duration	Restricted % of years	Critical Drought Start	Critical Drought End
HISTORICAL	1	28326	6964	45	4.95	6.90	21/01/1935	29/12/1940
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	8	28326	5891	40	4.97	7.76	19/01/1935	04/11/1943
	9	28326	4993	35	4.04	6.03	19/01/1935	02/07/1944
	10	28326	6665	45	5.00	6.90	26/01/1935	29/12/1940
	11	28326	6964	55	2.58	6.90	26/01/1935	29/12/1940
	12	28326	6964	40	3.39	6.03	21/01/1935	29/12/1940
	13	28326	5523	40	5.00	6.90	19/01/1935	02/07/1944
	14	28326	5315	35	3.40	5.17	19/01/1935	02/07/1944
MEDIAN	15	28326	6129	40	4.82	6.90	19/01/1935	29/12/1940
	16	28326	6314	40	4.51	6.03	19/01/1935	29/12/1940
10/15/25	5	28326	5163	30	7.65	13.79	25/02/1934	22/08/1944

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MEMORANDUM

TO	Glenn Fernandes Principal Engineer- Planning (Water Utilities) NSW Public Works Advisory
CC	
FROM	Peter Cloke, Principal Hydrologist
DATE	8 June 2021
SUBJECT	Armidale Yield Study: Progress Report (8) ï Additional Sources with Reduced Transfers Rate

The additional cases varying the transfer rates from the new sources to meet the target demands requested in your email of 21 May 2021 have been modelled and the results are reported herein.

Summary

The requested modelling case results are provided in Table 1.

It is noted the secure yield estimates are dependent on the operating rules, data and assumptions as discussed herein and or in the previous 7 Progress Reports (30/3/2020, 26/5/2020, 18/9/2020, 19/10/2020,16/4/2021,22/04/2021 & 30/04/2021).

The requested target demand for the systems based on Malpas Dam was 5560 ML/a and the target demand for the Chandler River Dam system was 3227 ML/a.

Due to the nature of the modelling it was not feasible (*as would have taken a considerable amount of time*) to iterate to find the exact transfer rate to meet the exact target demands. For the purposes in hand of identifying a preferred option it was considered appropriate to obtain the transfer rate to within 5 ML/d of the target demand.

For the case with Aberfoyle River and Nowlands backwater with the existing Malpas Dam the modelled transfer rate (100 ML/d) did not satisfy the target demand . From the modelling undertaken it is considered unlikely that a transfer rate would be found for this case to satisfy the target demand with the existing Malpas Dam.

It is noted for the climate change cases it was apparent that the CSIRO GCM resulted in the lowest secure yield so for most cases to reduce modelling time only this case was modelled with the 10/15/25 rule rather than modelling all 15 GCM cases with the 5/10/10 rule.

Table 1: Preliminary Secure Yield Estimates for Proposed Additional Sources

Run No	Option	Transfer Rate from New Source ML/d	Historic Climate Secure Yield ML/a	Secure Yield with 1°C Climate Warming ML/a	Historic Climate Critical Drought	
					From	To
230-5	Pumping from Styx River to 6.5 m raised FSL Malpas Dam	5	**6660**	**4847**	20/01/1935	2/07/1944
230-10		10	**6964***	**5967**	28/10/2017	6/02/2020
230-15		15	**6964***	**6776**	28/10/2017	6/02/2020
231-10	Pumping from Aberfoyle River and Nowlands Backwater 6.5 m raised FSL Malpas Dam	10 *(each source)*	**6869**	**5534**	20/01/1935	29/12/1940
232-15	Pumping from Styx River to 3 m raised FSL Malpas Dam	15	**6832**	**6357**	14/01/2018	7/02/2020
232-10		10	**6178**	**5032**	14/01/2018	7/02/2020
233-15	Pumping from Aberfoyle River and Nowlands Backwater 3m raised FSL Malpas Dam	15 *(each source)*	**5794**	*Not done as anticipated would not meet target*	15/01/2018	15/01/2020
233-20		20 *(each source)*	**5944**	**4947**	15/01/2018	15/01/2020
233-30		30 *(each source)*	**5971**	**5160**	15/01/2018	15/01/2020
233-55		55*(each source)*	**6306**	**5710**	19/01/1935	29/12/2020
234-20	Pumping from Styx River to Existing Malpas Dam	20	**5821**	*Not done as anticipated would not meet target*	12/01/2018	7/02/2020
234-25		25	**6190**	**5721**	12/01/2018	7/02/2020
235-100	Pumping from Aberfoyle River and Nowlands Backwater to Existing Malpas Dam	100 *(each source)*	**4756**	*Not done as anticipated would not meet target*	15/01/2018	15/01/2020
236	Chandler River onstream storage 5% Dead storage plus Pumping up to 10 ML/d from Styx River	**5280 ML** Gross Storage	**3227**	*Not done as anticipated would not meet target*	5/08/2017	9/01/2020
237		**7766 ML** Gross Storage	**3800**	**3241**	30/07/2017	9/01/2020

** The specified 26 ML/d transfer rate from Malpas Dam to Armidale was constraining the yield*

Malpas Dam options based on Run 202 (*which includes Guyra, Malpas, & Puddledock Dams*) as detailed in Progress Report 4 of 19 October 2020

No Release Required from Malpas Dam when less than 6746 ML

EFR rules for Styx River and Aberfoyle River and Nowlands Backwater pumping :

1. For January to July can only transfer /store when flow above 90% ile
2. For August to December can only transfer/store when flow above 80% ile
3. Can only extract 30% of the flow above the % ile flows.
4. If Malpas Dam less than 60% full then above 90% ile is relaxed to 95%ile and 80% ile relaxed to 90% ile (*except January kept as 90%ile as 95%ile was zero for Aberfoyle and Nowlands Backwater*).

Note : % ile flows based on flows in each month (ie twelve monthly values for the year)

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MEMORANDUM

TO	Glenn Fernandes Principal Engineer- Planning (Water Utilities) NSW Public Works Advisory
CC	
FROM	Peter Cloke, Principal Hydrologist
DATE	7 September 2021
SUBJECT	Armidale Yield Study: Progress Report (9) ï Additional Sources with Reduced Transfers Rate

The additional case of transferring up to 15 ML/d from the Styx River with the existing (ie unraised) Malpas Dam requested in your email of 21 May 2021 has been modelled and the results are reported herein.

Summary

The requested modelling case results are provided in Table 1.

It is noted the secure yield estimates are dependent on the operating rules, data and assumptions as discussed herein and or in the previous 8 Progress Reports (30/3/2020, 26/5/2020, 18/9/2020, 19/10/2020,16/4/2021,22/04/2021,30/04/2021 & 8/6/2021).

It is noted for the previous climate change cases it was apparent that the CSIRO GCM resulted in the lowest secure yield so to reduce modelling time only this case was modelled with the 10/15/25 rule rather than modelling all 15 GCM cases with the 5/10/10 rule.

Table 1: Preliminary Secure Yield Estimates for Proposed Additional Sources

Run No	Option	Transfer Rate from New Source ML/d	Historic Climate Secure Yield ML/a	Secure Yield with 1°C Climate Warming ML/a	Historic Climate Critical Drought	
					From	To
234-15	Pumping from Styx River to Existing Malpas Dam	15	**5632**	**4533**	14/01/2018	7/02/2020
Malpas Dam options based on Run 202 (*which includes Guyra, Malpas, & Puddledock Dams*) as detailed in Progress Report 4 of 19 October 2020						
No Release Required from Malpas Dam when less than 6746 ML						
EFR rules for Styx pumping : 1. For January to July can only transfer /store when flow above 90% ile 2. For August to December can only transfer/store when flow above 80% ile 3. Can only extract 30% of the flow above the % ile flows. 4. If Malpas Dam less than 60% full then above 90% ile is relaxed to 95%ile and 80% ile relaxed to 90% ile **Note : % ile flows based on flows in each month (ie twelve monthly values for the year)**						

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MEMORANDUM

TO	Jennifer Blaikie Project Engineer ï Water Resources Management NSW Public Works Advisory
CC	
FROM	Peter Cloke, Principal Hydrologist
DATE	15 November 2022
SUBJECT	Armidale Yield Study: Progress Report (10) ï Addition of Oaky Dam **DRAFT**

With reference to your email of 9 November 2022, modelling has been undertaken towards assessing the potential secure yield benefit of Oaky Dam. Initial results and findings are reported herein.

Summary

While the modelled inflows (See Figure 1) were less into Oaky Dam than at the proposed previous Styx River pumping location, the effect of the Oaky Dam storage resulted in secure yield estimates for the **historic climate** similar to that for system that included Malpas Dam raised by 6.5 m. (*Due to your timing constraints, the climate change modelling has not yet been done, but the required data has been requested from DPE Water*). The Oaky Dam storage allows pumping (from the stored water) during low flows when this could not be done from the Styx River due to the nominated EFR rules.

It may be worthwhile to explore whether further optimisation of the scheme with the use of the Oaky Dam results in higher secure yield than the previous Styx River option (Run 230-15). It is noted for both the previous Styx River option and the new option with Oaky Dam, the historic climate secure yield is constrained by the transfer capacity of 26 ML/d from Malpas Dam to Armidale although this may not be the case when modelling the effects of climate change.

As part of model development and testing, secure yield estimates for Oaky Dam as a standalone scheme were modelled and the results are provided in Table 2 as they may give additional insights into the potential benefits of Oaky Dam.

It is noted the secure yield estimates are dependent on the operating rules, data and assumptions as discussed herein and or in the previous 9 Progress Reports (30/3/2020, 26/5/2020, 18/9/2020, 19/10/2020,16/4/2021,22/04/2021,30/04/2021,8/6/2021 & 7/9/2021).

It is noted the analysis is very reliant on the observed Oaky River and observed Styx River flows. The provided Oaky River flows were quality coded unknown.

Figure 1: Comparison of Modelled Oaky Dam Inflows and Styx River Flows

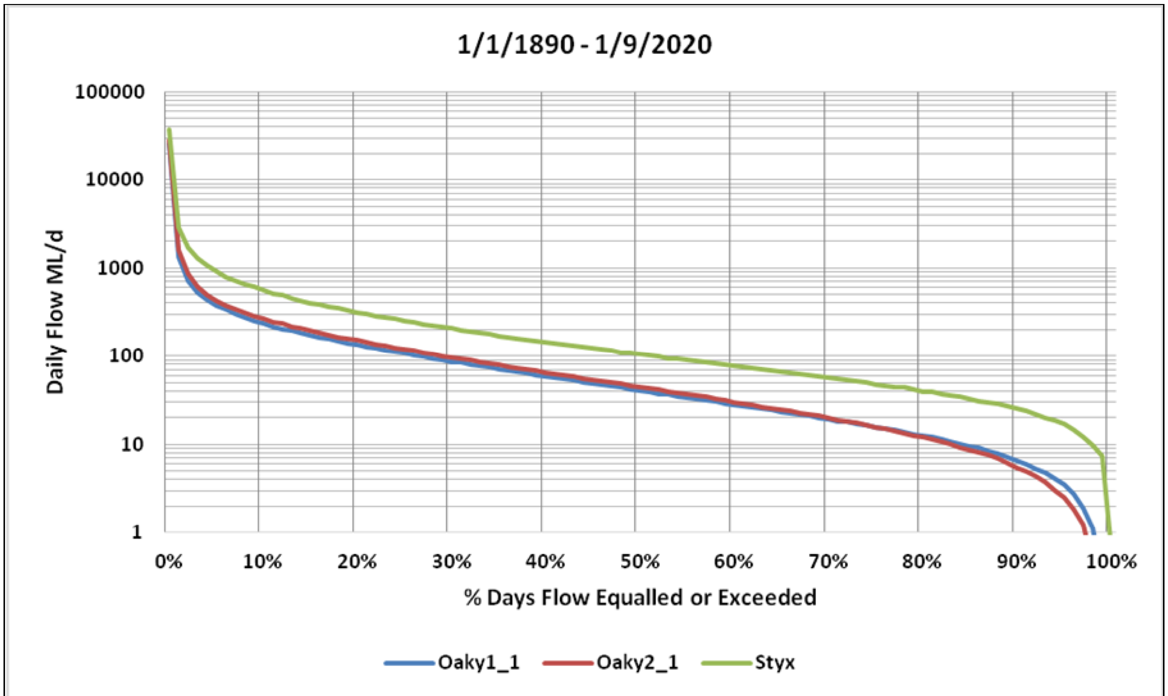


Table 1: Preliminary Secure Yield Estimates for Proposed Oaky Dam Additional Source

Run No	Option	Oaky Flow Series	Oaky Dam Gross** Storage GL	Transfer Rate from New Source ML/d	Historic Climate Secure Yield ML/a	Secure Yield with 1°C Climate Warming ML/a	Historic Climate Critical Drought	
							From	To
254	Pumping from Oaky Dam to 6.5m raised FSL Malpas Dam	Oaky1_1	2.78	25	**6964***	*Not yet modelled*	8/08/2017	7/02/2020
255		Oaky2_1	2.78	25	**6964***	*Not yet modelled*	13/01/2018	6/02/2020
256		Oaky1_1	0.55	25	**6964***	*Not yet modelled*	14/01/2018	7/01/2020

** The specified 26 ML/d transfer rate from Malpas Dam to Armidale was constraining the yield*

*** Dead storage 0.235 GL*

Malpas Dam options based on Run 202 (*which includes Guyra, Malpas, & Puddledock Dams*) as detailed in Progress Report 4 of 19 October 2020

No Release Required from Malpas Dam when less than 6746 ML

EFR rules for Oaky Dam :

1. For January to July can only store when flow above 90% ile
2. For August to December can only store when flow above 80% ile
3. Can only extract 30% of the flow above the % ile flows.
4. If Malpas Dam less than 60% full then above 90% ile is relaxed to 95%ile and 80% ile relaxed to 90% ile

Note : % ile flows based on flows in each month (ie twelve monthly values for the year)

Table 2: Preliminary Secure Yield Estimates for Oaky Dam Standalone Source

Run No	Option	Oaky Flow Series	Oaky Dam Gross** Storage GL	Transfer Rate from New Source ML/d	Historic Climate Secure Yield ML/a	Secure Yield with 1°C Climate Warming ML/a	Historic Climate Critical Drought	
							From	To
251r	Oaky Dam	Oaky1_1	2.78	25	**3425**	*Not yet modelled*	3/11/1964	18/07/1965
255		Oaky2_1	2.78	25	**3493**	*Not yet modelled*	3/11/1964	18/07/1965

*** Dead storage 0.235 GL*

EFR rules for Oaky Dam :

1. For January to July can only store when flow above 90% ile
2. For August to December can only store when flow above 80% ile
3. Can only extract 30% of the flow above the % ile flows.
4. If Oaky Dam less than 60% full then above 90% ile is relaxed to 95%ile and 80% ile relaxed to 90% ile

Note : % ile flows based on flows in each month (ie twelve monthly values for the year)

Oaky Dam Inflows

The secure yield estimates are dependent on the modelled inflows time series. To obtain the required inflow series for Oaky Dam a Sacramento rainfall runoff model was set up for the Oaky Dam catchment. The required model parameter values were obtained by calibration to the provided (12/7/1956 - 1/11/1983) observed daily flows at the gauging station Oaky River Above Oaky Dam (Station number 206021). The gauging station has a reported catchment area of 135 km^2 while the reported catchment area for the Dam was 200 km^2.

The required daily rainfalls and daily evapotranspiration were obtained from the SILO Data Drill. Figure 2 shows the modelled catchment.

Reasonable calibration was achieved as shown by the calibration statistics in Tables 3 and 4, and the flow duration comparison in Figure 3 and 4. Two calibrations were used to develop the required inflow series:

1. Oaky1_1: based on focusing on calibration statistics comparison
2. Oaky2-1: based on focusing on flow duration curves comparison

It was subsequently found that the secure yield estimates were similar for both inflow series calibrations.

It is noted the observed flows were merged with the modelled inflows thus giving preference to the observed flows when available. The observed flows were factored to the dam from a consideration of the modelled flows at the gauging station and the modelled dam inflows. The factors were less than if they were factored by their catchment areas.

Figures 5 to 14 provide time series comparisons of the modelled and observed flows.

Table 3: Calibration Statistics – Oaky1_1

Comparative statistics for runoff

Variable	Start	End	Length	Relative differ	Absolute diffe	Nash-Sutcliffe	Correlation
Calibration	6/12/1958	1/11/1983	9097	-0.471%	-33.820	0.708	0.857

Univariate statistics

Variable	Start	End	Length	Missing	Total (mm)	Mean (mm)	Std. Dev. (m	Skew (mm)
Calib. Observ	6/12/1958	1/11/1983	9097	0	7173.935	0.789	2.598	16.064
Runoff	6/12/1958	1/11/1983	9097	0	7140.116	0.785	2.638	11.706

Table 4: Calibration Statistics – Oaky2_1

Comparative statistics for runoff

Variable	Start	End	Length	Relative differ	Absolute diffe	Nash-Sutcliffe	Correlation
Calibration	6/12/1958	1/11/1983	9097	13.249%	950.446	0.606	0.848

Univariate statistics

Variable	Start	End	Length	Missing	Total (mm)	Mean (mm)	Std. Dev. (m	Skew (mm)
Calib. Observ	6/12/1958	1/11/1983	9097	0	7173.935	0.789	2.598	16.064
Runoff	6/12/1958	1/11/1983	9097	0	8124.381	0.893	3.069	11.379

Figure 2: Oaky Dam Modelled Catchment

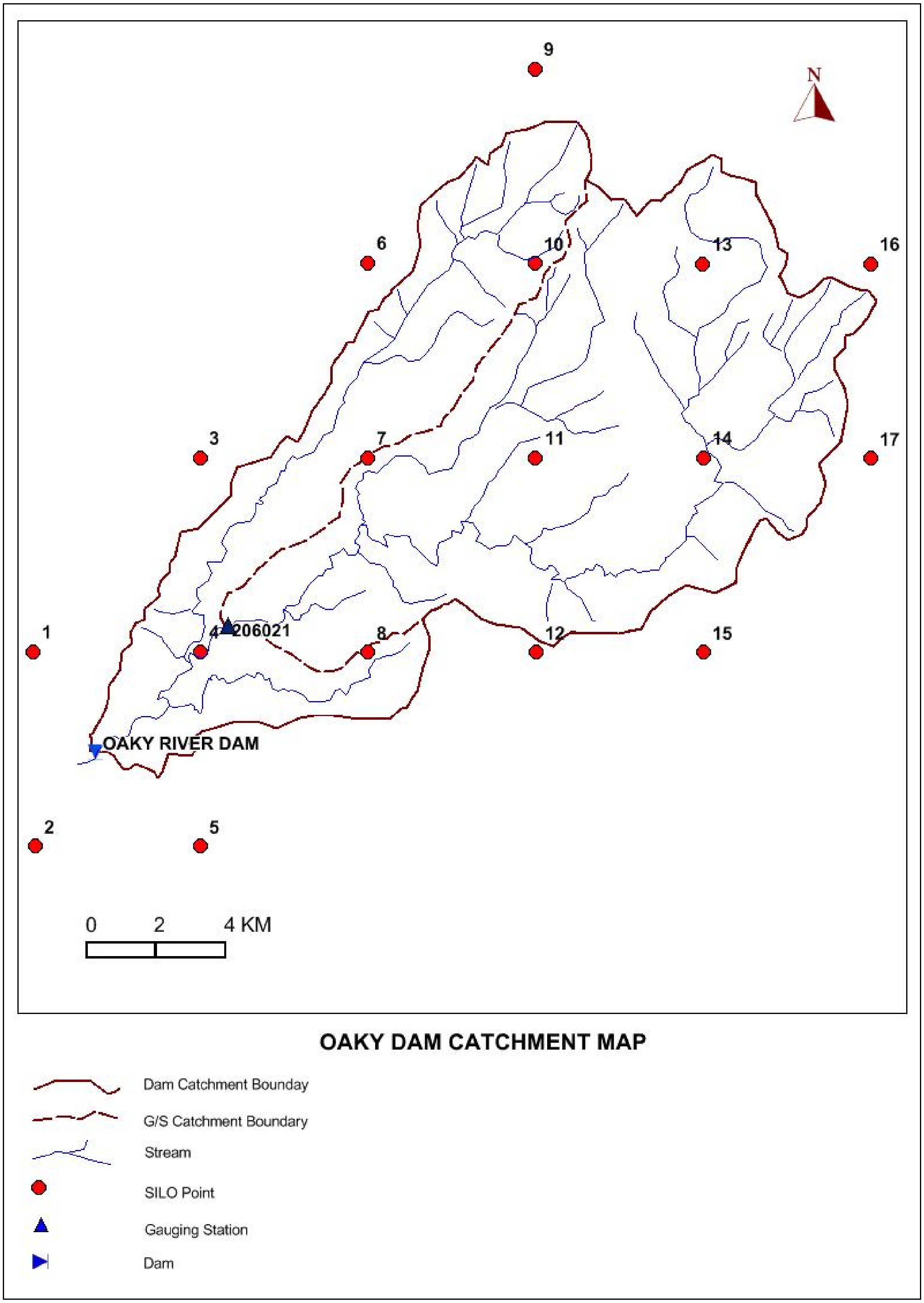


Figure 3: Flow Duration Curve Comparison – Oaky1_1

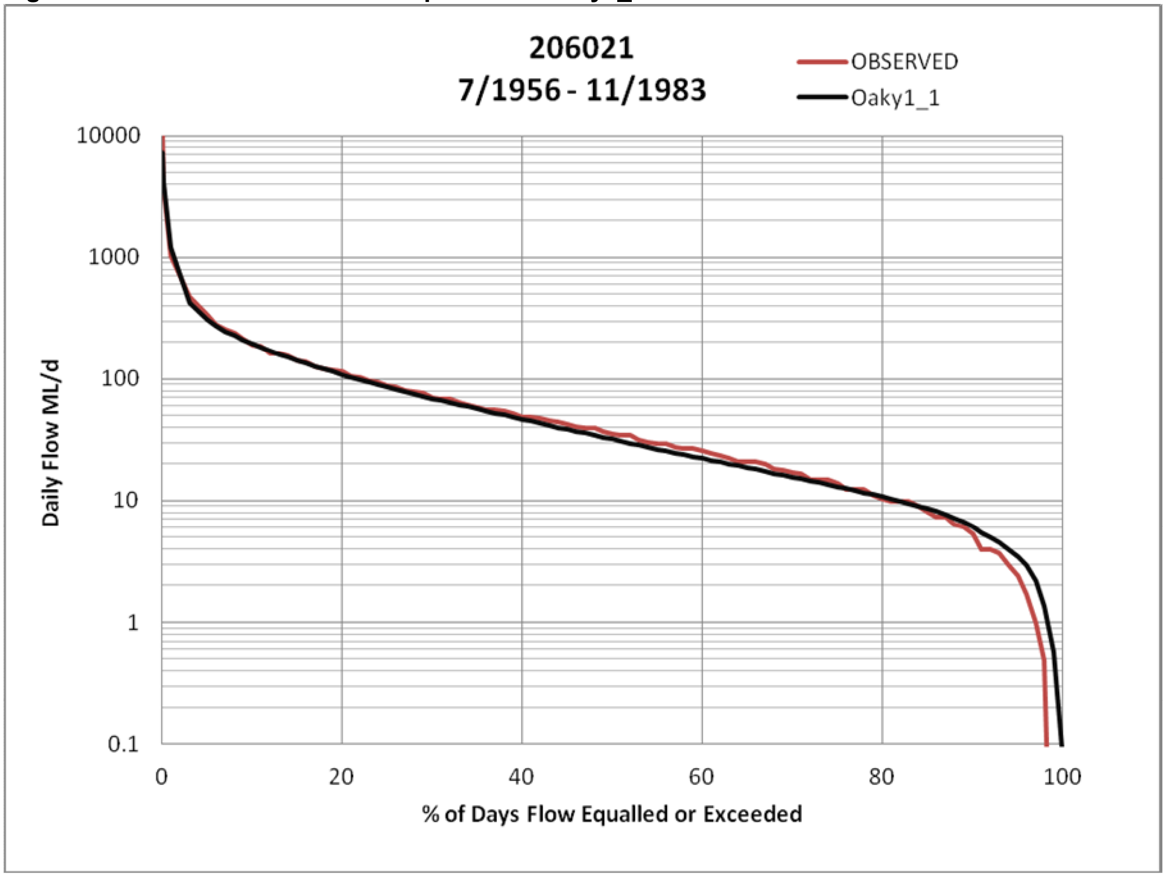


Figure 4: Flow Duration Curve Comparison – Oaky2_1

Figure 5 : Comaprison of Daily Flows at Gauging Station (2160210) – 1956-58

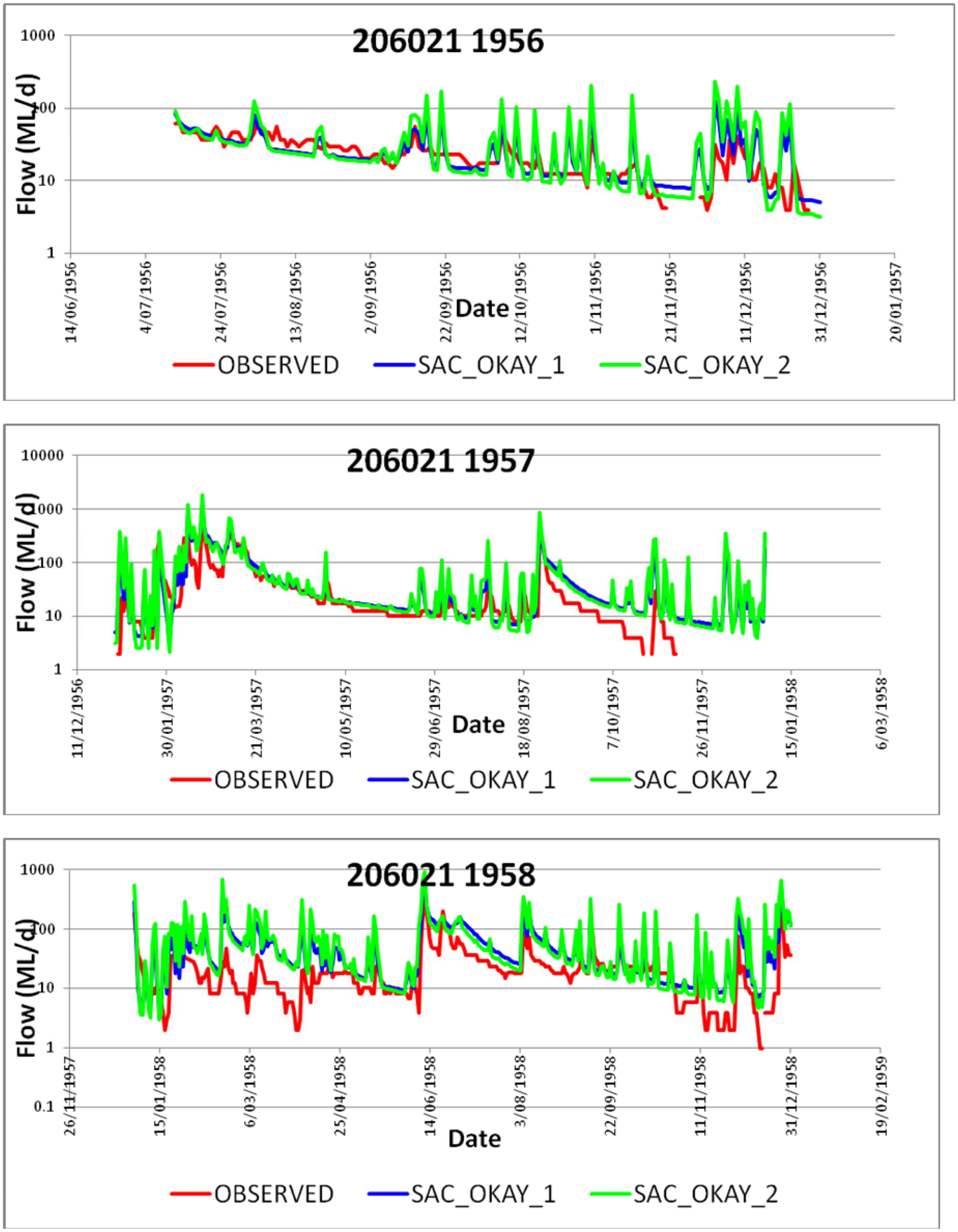
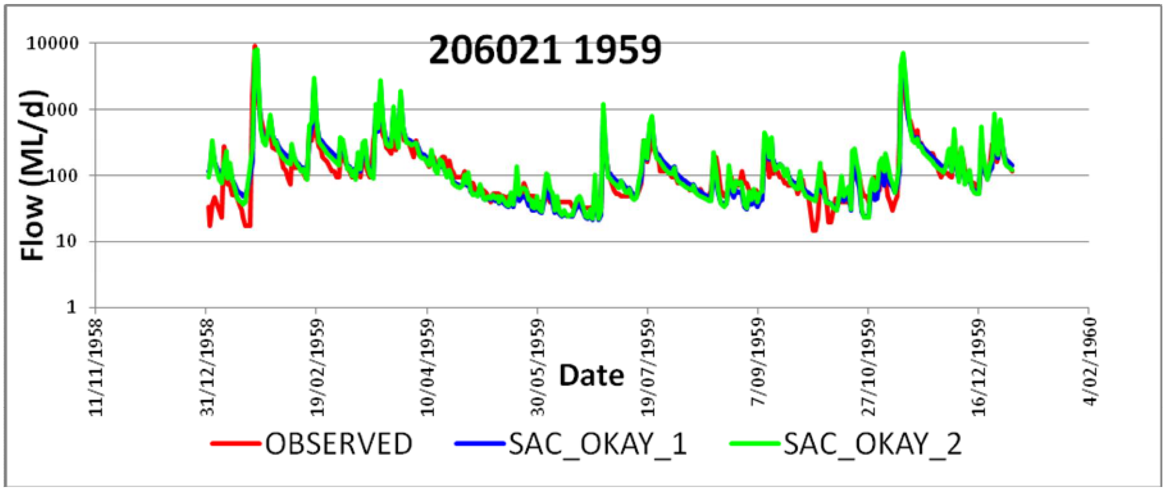
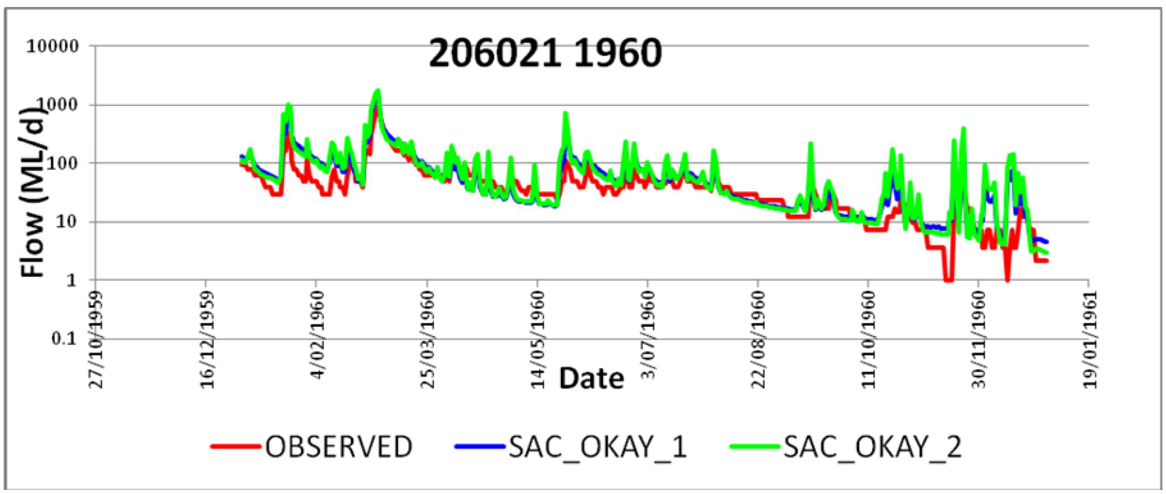


Figure 6 : Comaprison of Daily Flows at Gauging Station (2160210) – 1959-61





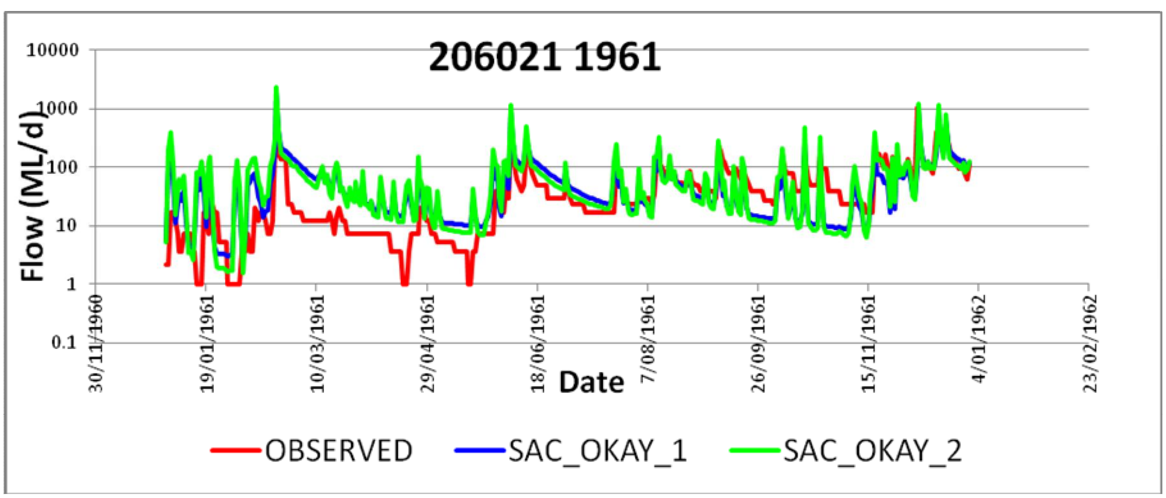
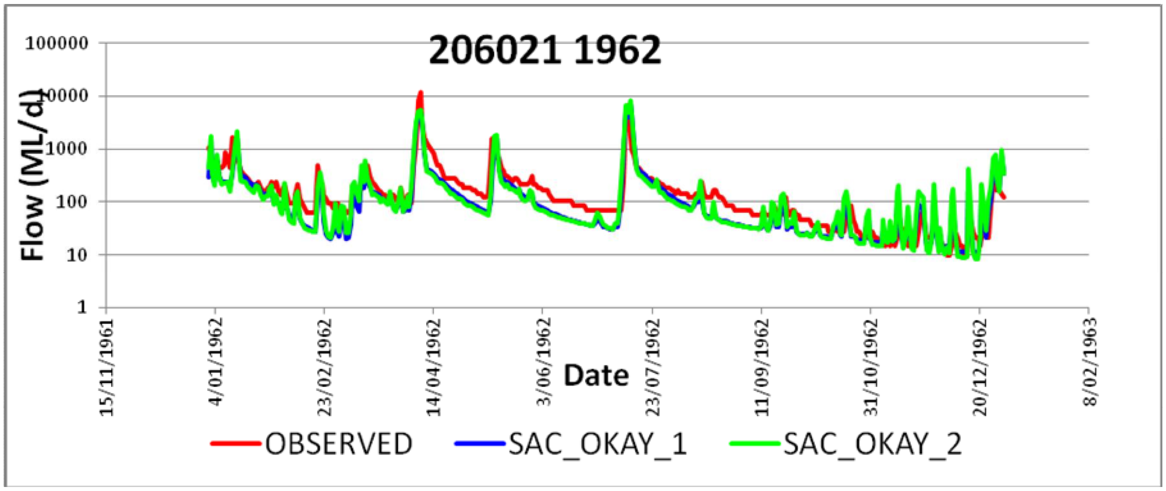
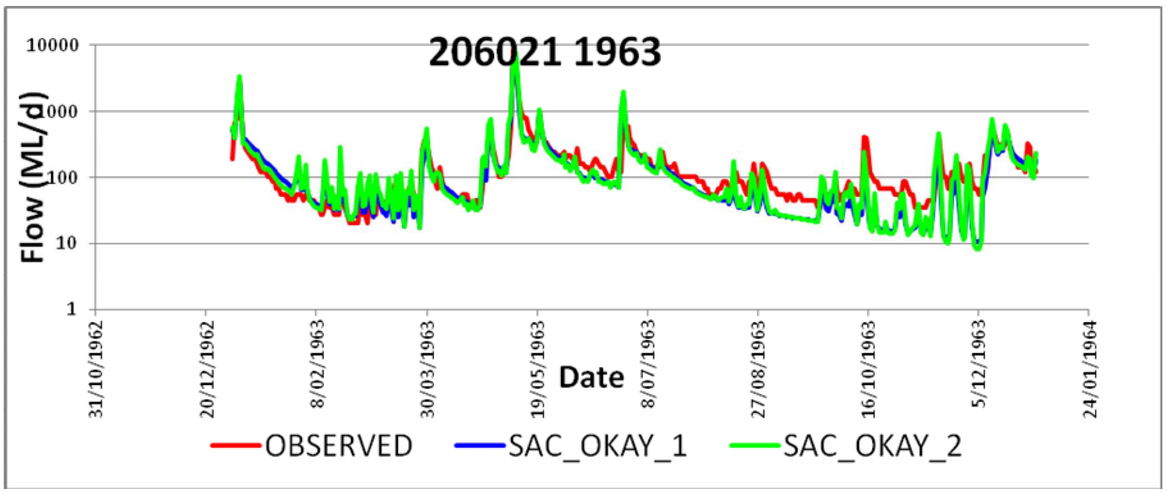


Figure 7 : Comaprison of Daily Flows at Gauging Station (2160210) – 1962-64





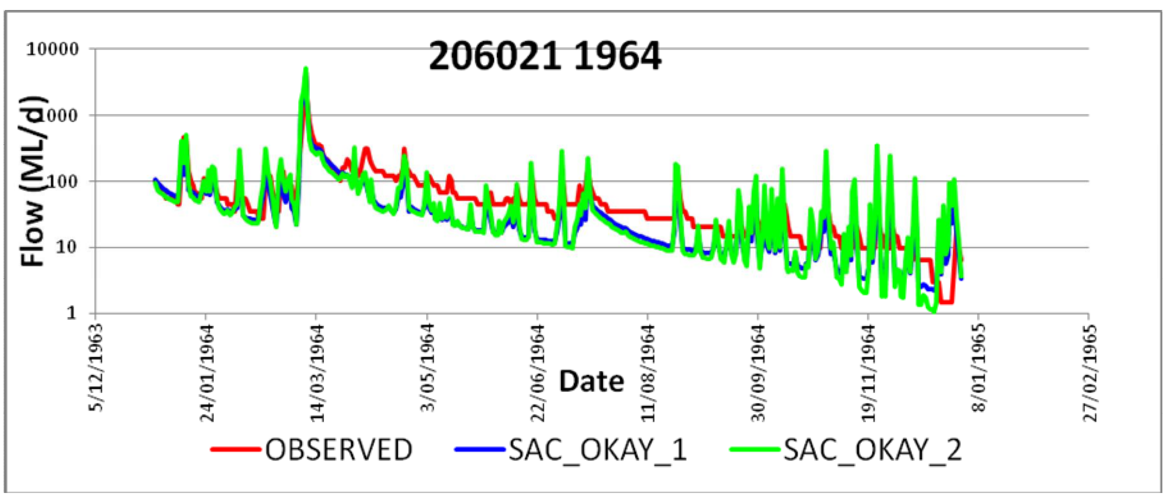
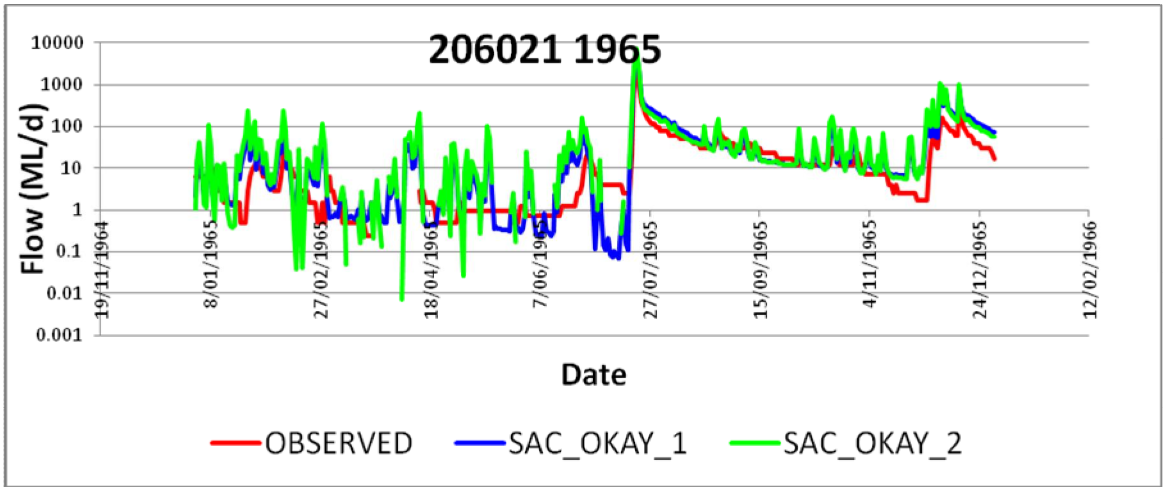
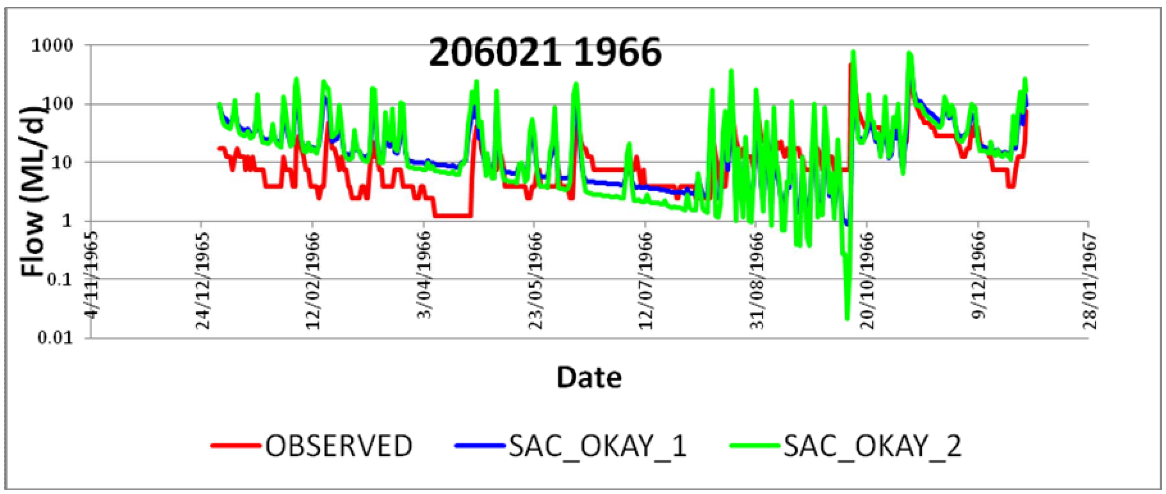


Figure 8 : Comaprison of Daily Flows at Gauging Station (2160210) – 1965-67





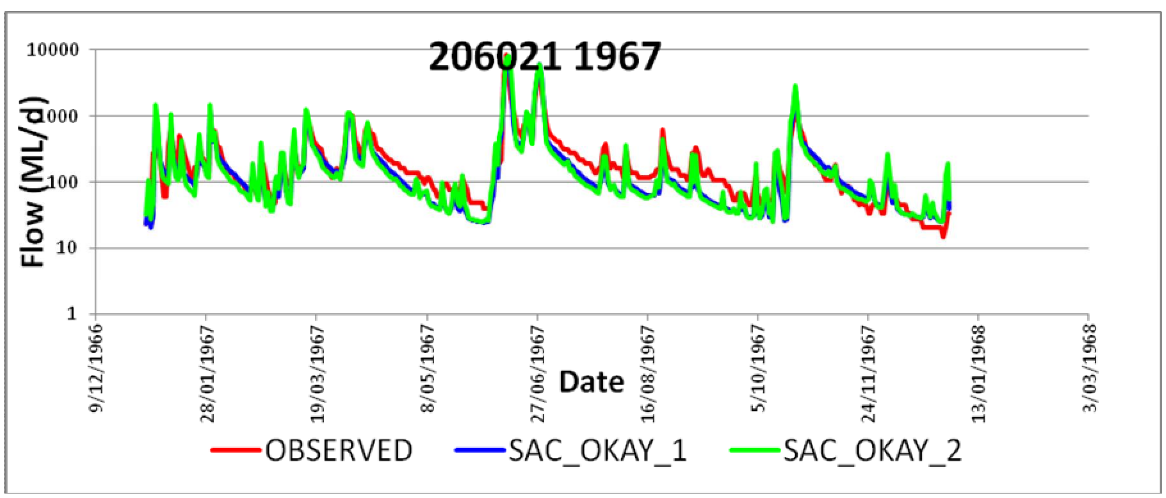
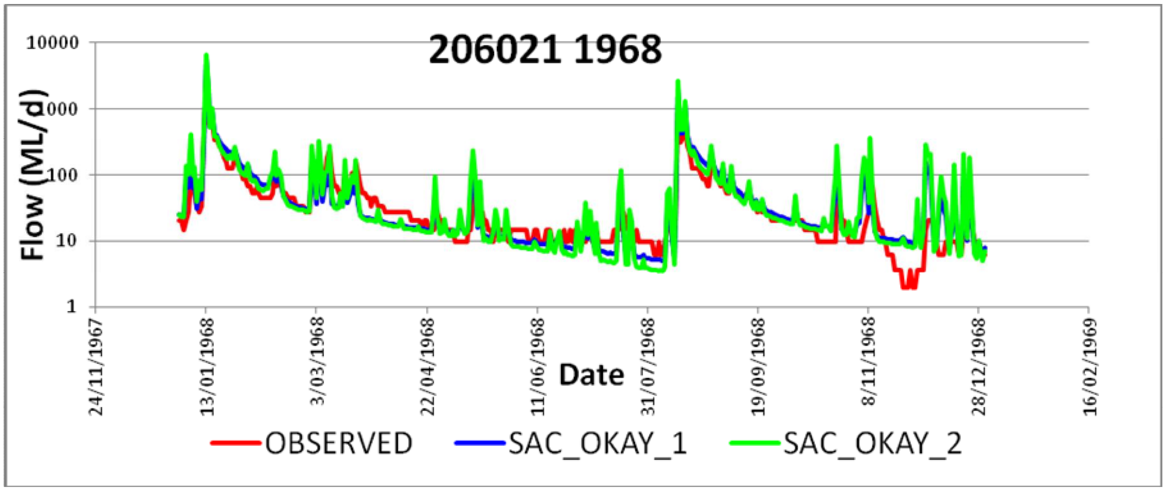
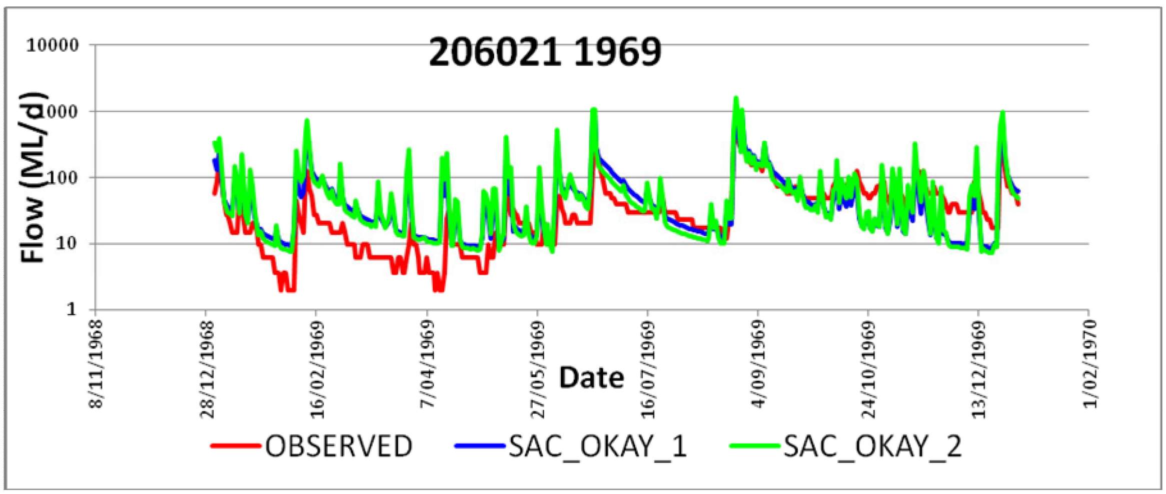


Figure 9 : Comaprison of Daily Flows at Gauging Station (2160210) – 1968-69





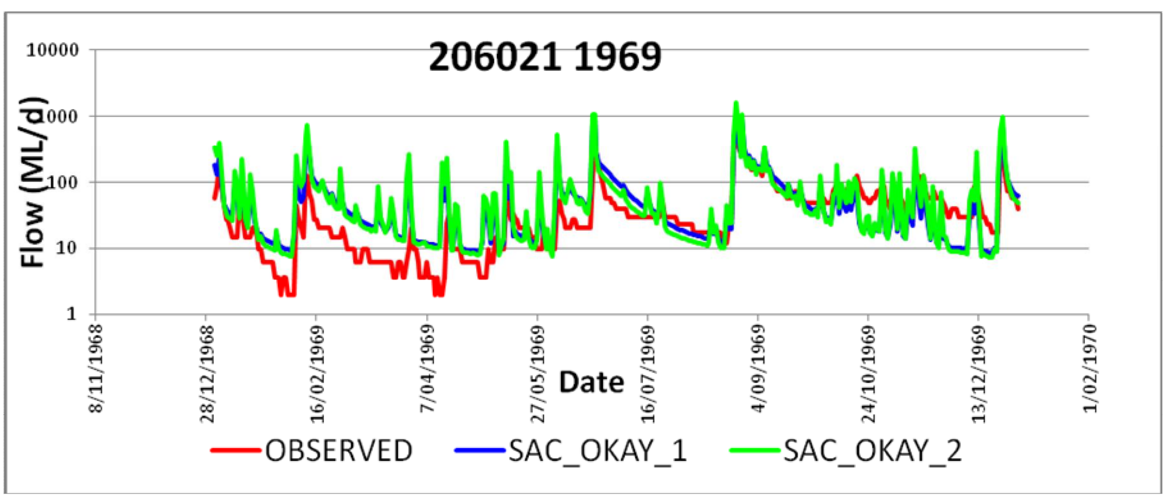
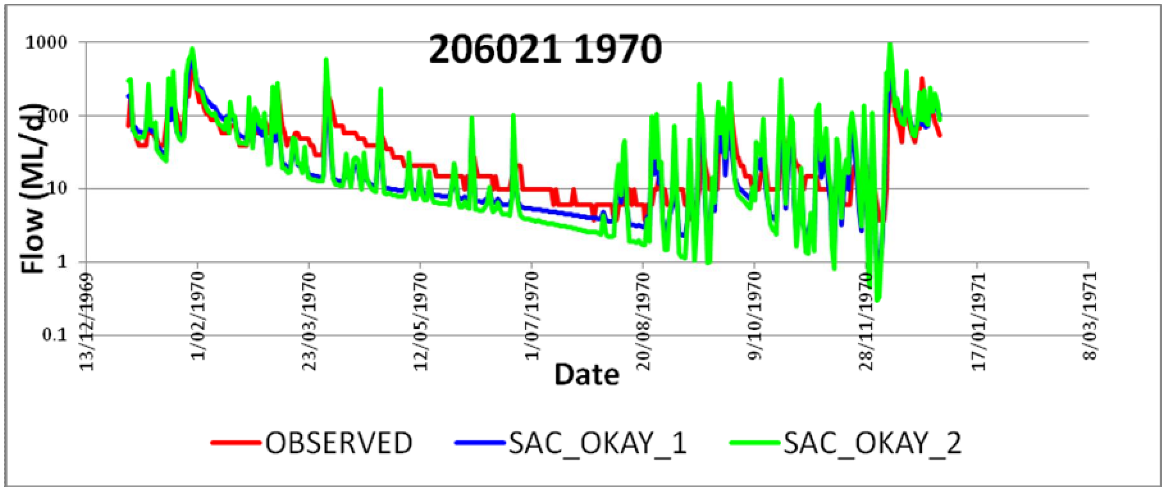
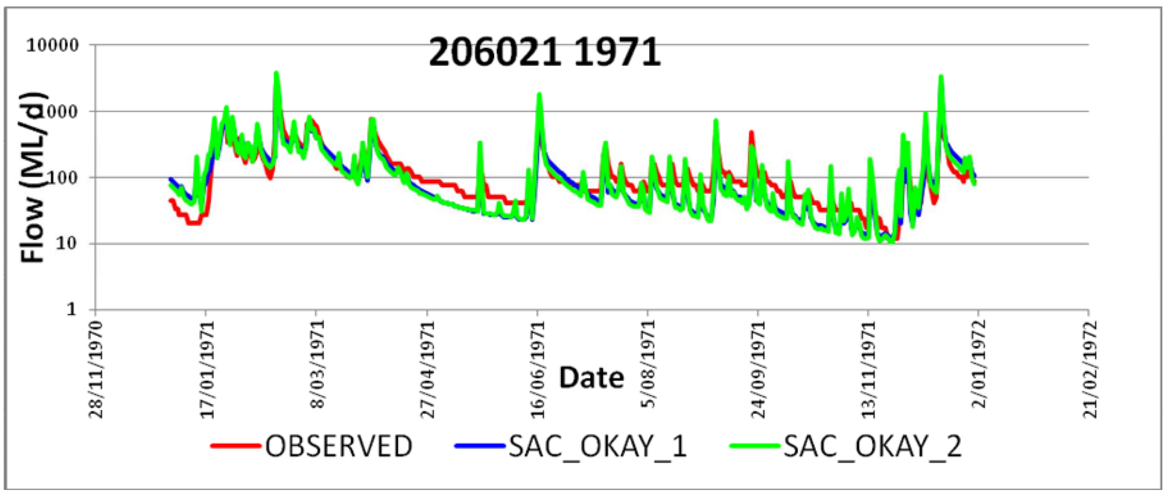


Figure 10 : Comaprison of Daily Flows at Gauging Station (2160210) – 1970-72





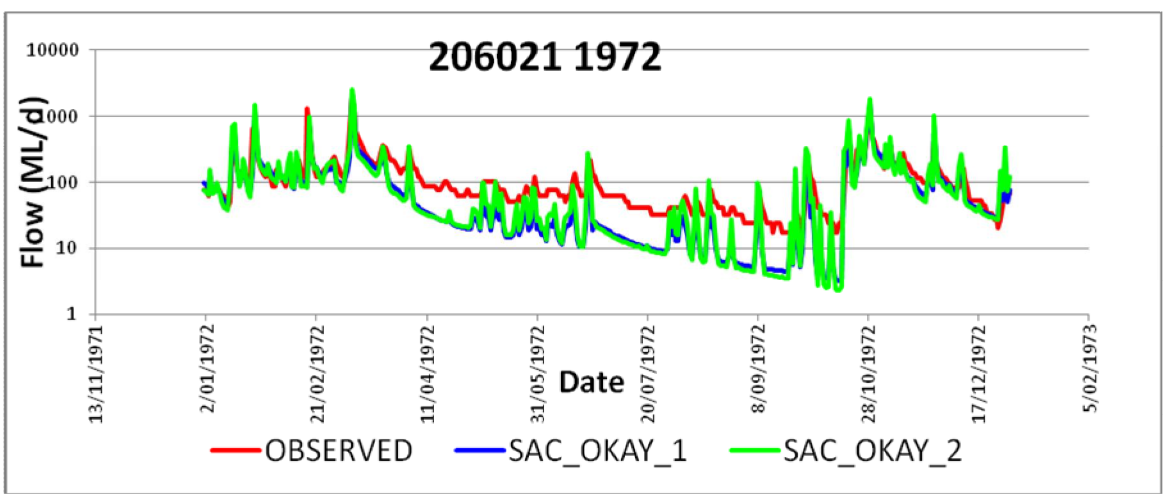
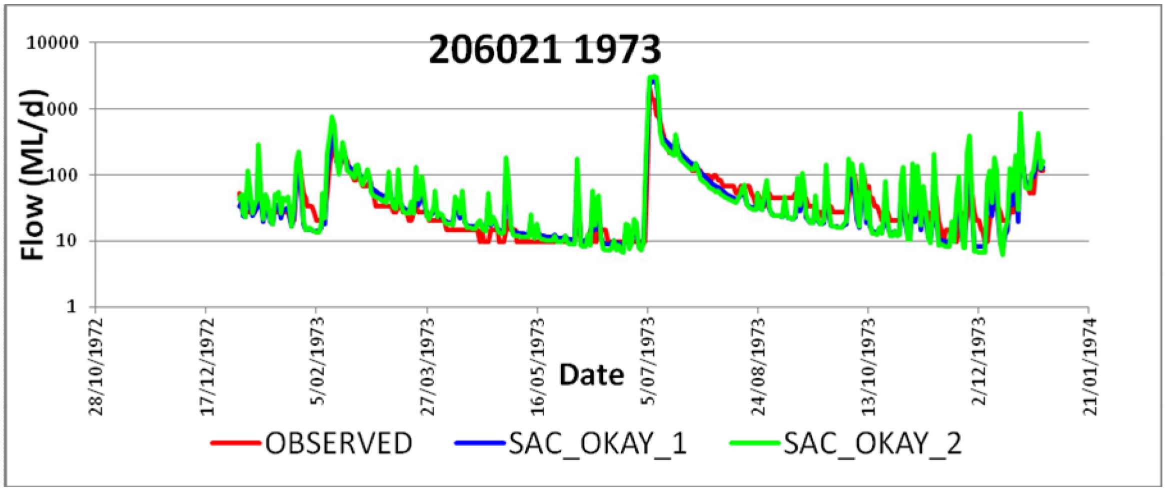
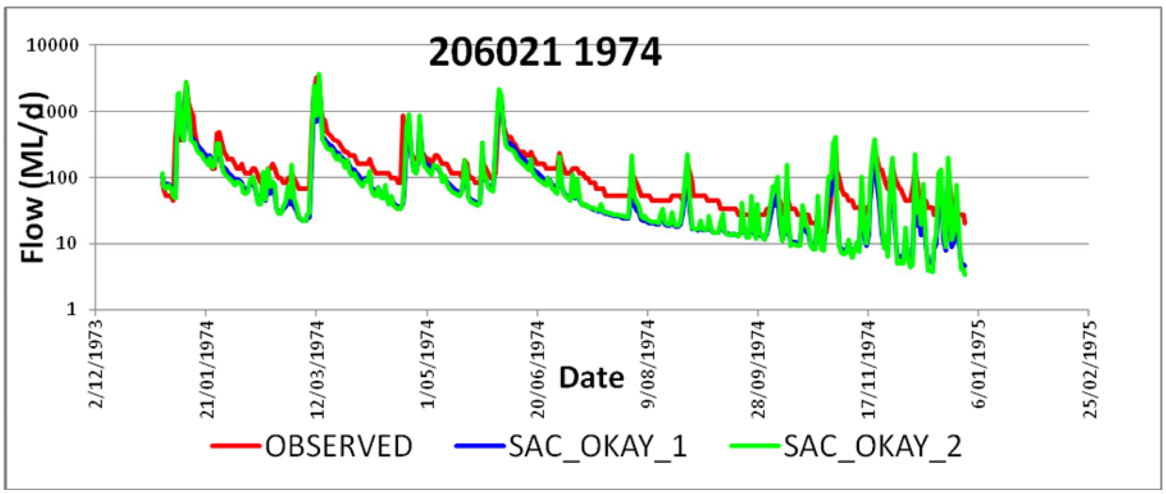


Figure 11 : Comaprison of Daily Flows at Gauging Station (2160210) – 1973-75





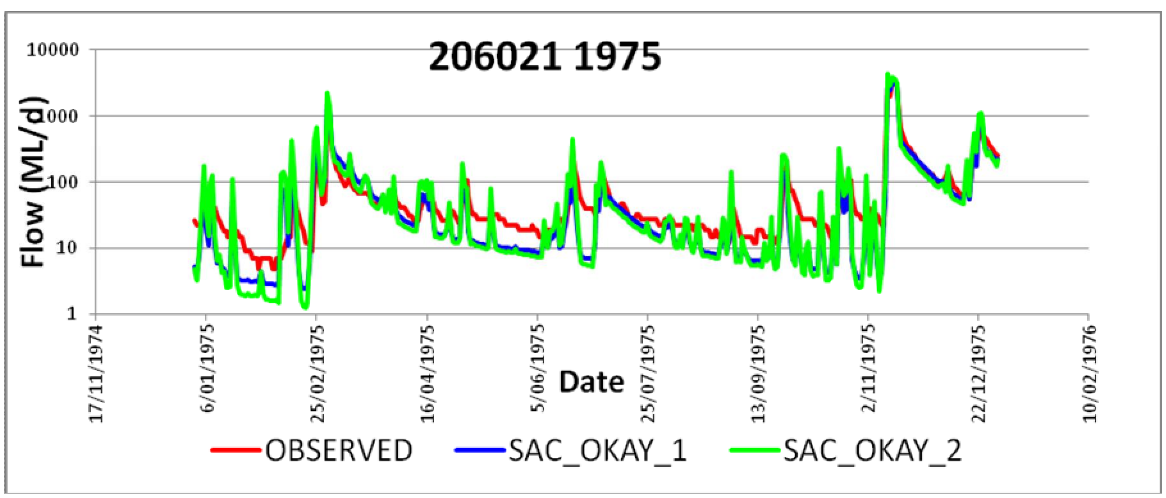
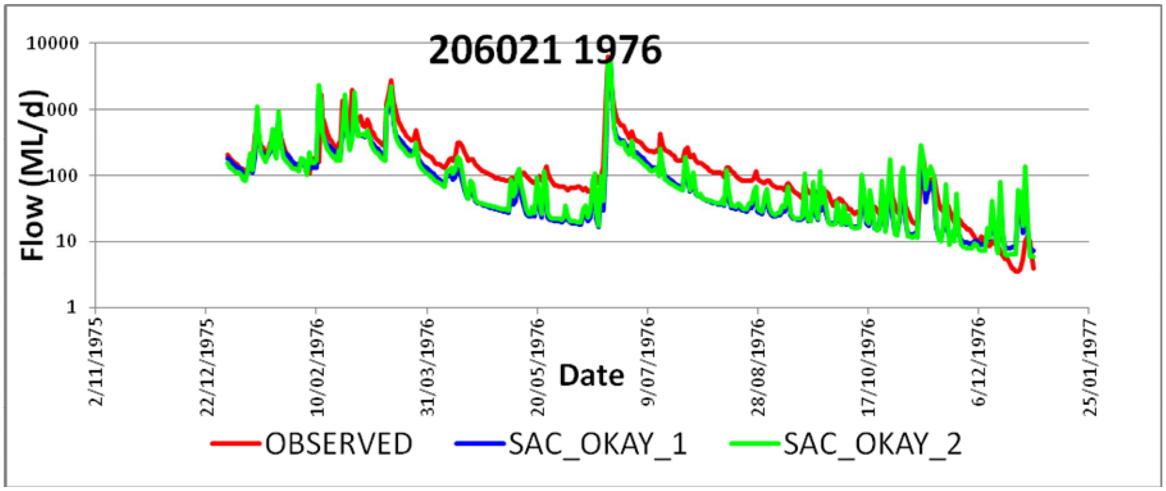
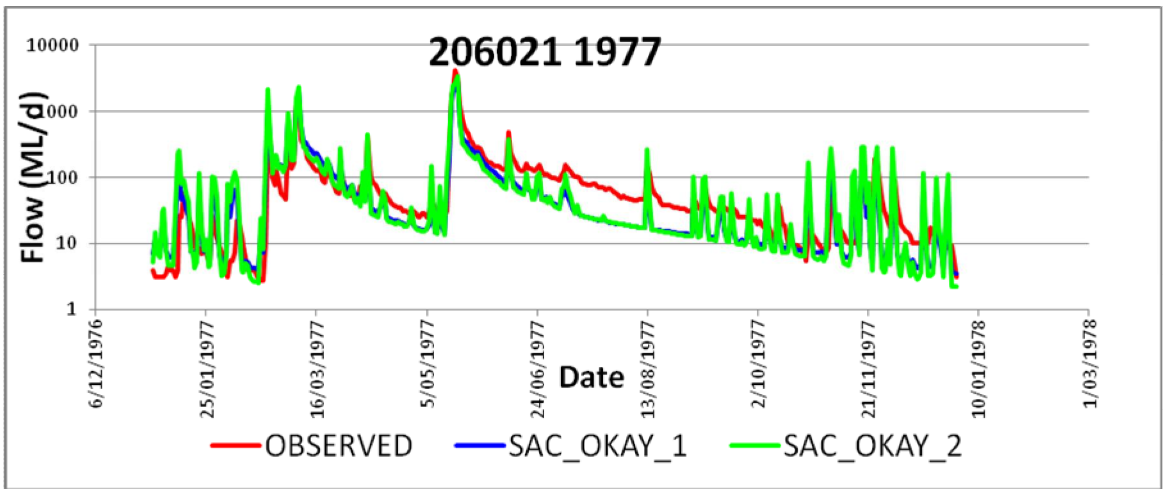


Figure 12 : Comaprison of Daily Flows at Gauging Station (2160210) – 1976-78





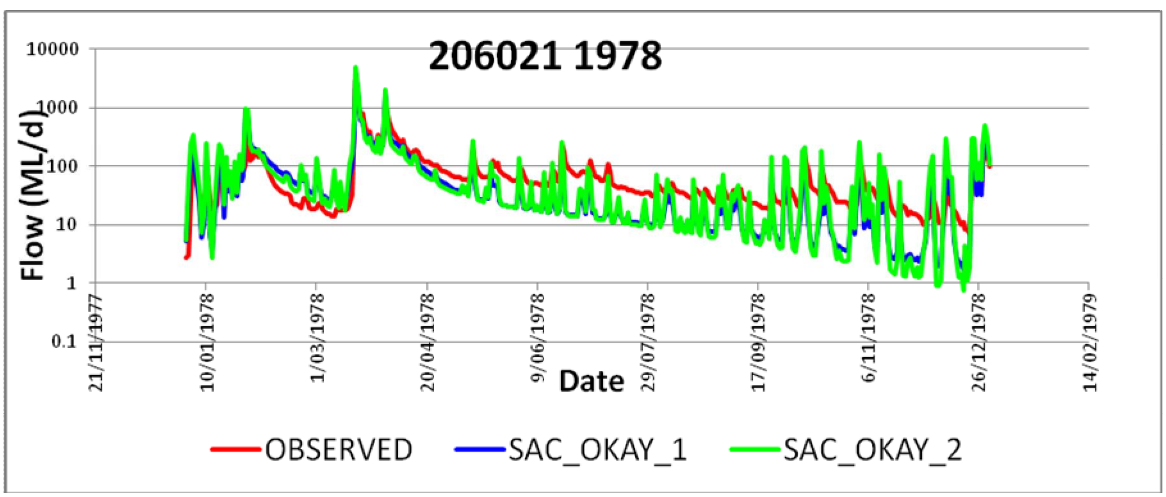
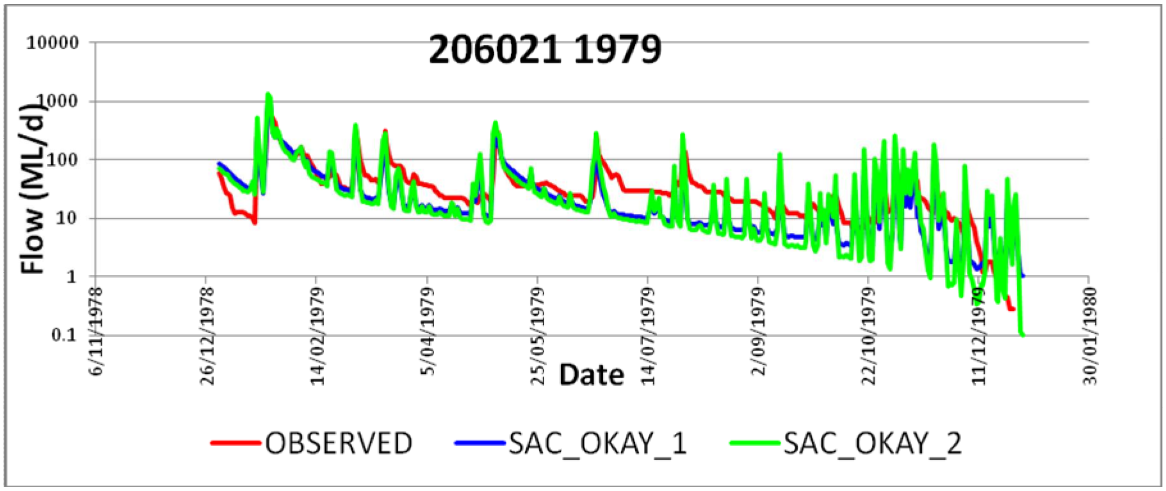
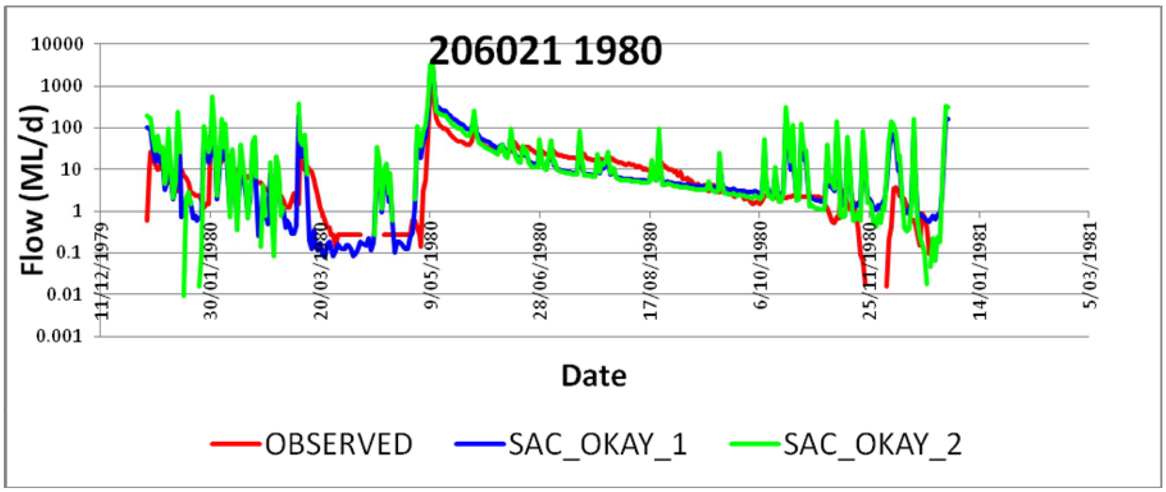


Figure 13 : Comaprison of Daily Flows at Gauging Station (2160210) – 1979-81





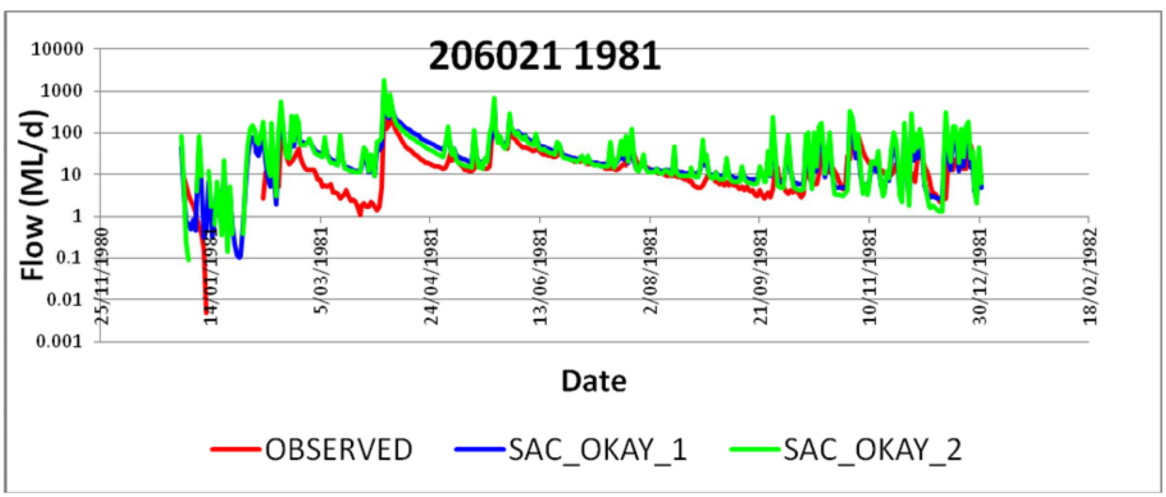
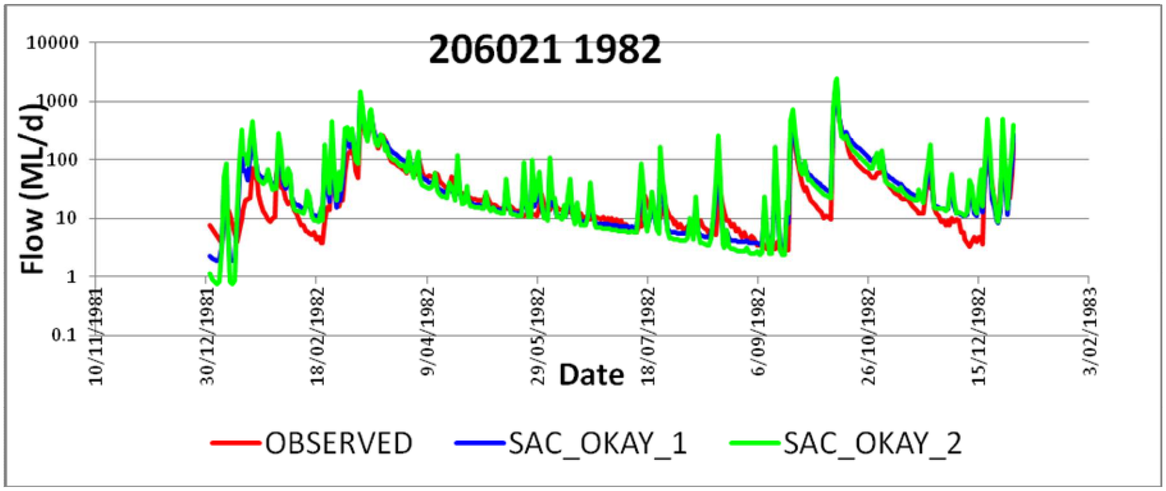
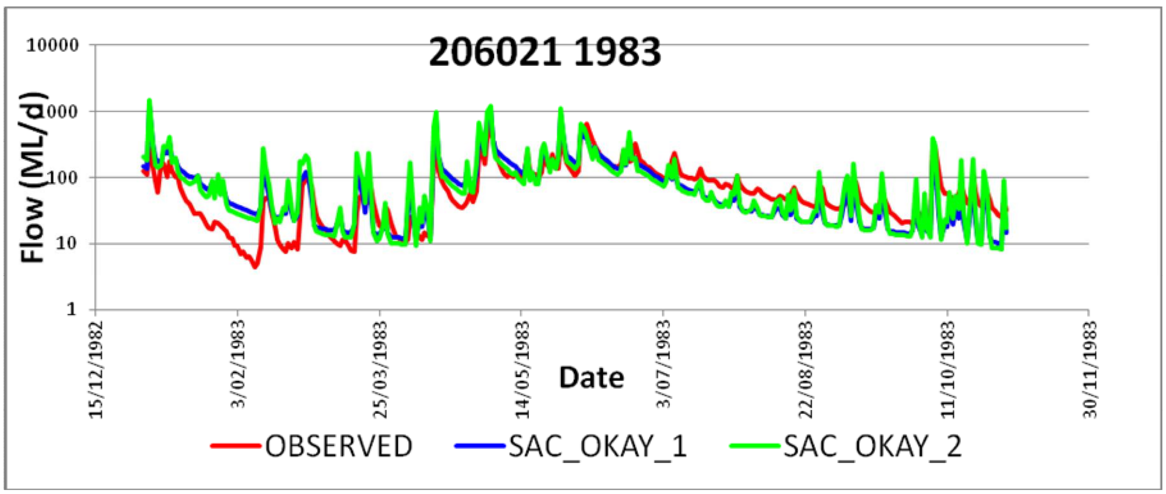


Figure 14 : Comaprison of Daily Flows at Gauging Station (2160210) – 1982-83





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MEMORANDUM

TO	Glenn Fernandes Director, Water Resources Management NSW Public Works
CC	
FROM	Peter Cloke, Principal Hydrologist
DATE	7 June 2023
SUBJECT	Armidale Yield Study: Progress Report (11) ï Oaky Dam 10,000 Year Stochastic Data **DRAFT**

With reference to your email of 6 April 2023 modelling has been undertaken using the 10,000 year stochastic climatic data recently released by DPE Water towards assessing the impact on the previously assessed secure yield of Oak Dam as a standalone scheme. Initial results and findings are reported herein.

Summary

The 10,0000 year stochastic hydroclimatic daily data (rainfall and evapotranspiration) were input into the recalibrated[1] Oaky Dam Sacramento rainfall runoff model to obtain 10,000 years of daily inflows.

The daily inflows were input into the Oaky Dam system model (refer to Progress Report 10 of 15 November 2022) to assess whether the previously determined secure yield could be met.

The 10,000 year daily modelling was then repeated with the hydroclimate data adjusted for climate change using the NARCliM monthly factors that DPE Water used for their North Coast Regional Water Strategy.

The modelling showed that the historic climate secure yield demand could always be satisfied using 10,000 years of stochastic inflows. The modelling also showed that the climate change secure yield could always be satisfied using the 10,000 years of stochastic inflows perturbed for climate change.

It was beyond the scope of this study to assess why the secure yields could be met through the 10,000 years of stochastic data as it would be expected the 10,000 years of stochastic data would result in more extreme droughts than in the 130 years of historic climate. This is understood to be one of the reasons for generating 10,000 years of stochastic data. However it is noted that the 10,000 years is not actually covering the last 10,000 years, it is essentially *rearranging* stochastically the last 130 years of data and *somehow* (*using complex procedures that DPW Water staff who were consulted by NUWS have not been able to fully explain)* taking into account dry periods that have occurred in the last 500 years as informed by paleohydrology.

1. *The Sacramento rainfall runoff was recalibrated using Patch Point rainfall and evapotranspiration data as the 10,000 years of stochastic data was only available at Patch Points. Previously SILO Data Grid point rainfall and evapotranspiration was used.*

Until more case studies are done it will be unknown what the differences in drought security are from using the previous method[2] for determining secure yield and using the *optional* suggested alternative approach[3] utilising the 10,000 years of daily stochastic data. However for Oaky Dam as a standalone system the modelling shows use of the previous 5/10/10 approach provides higher drought security. While it cannot be certain, it is judged that this would also likely be the same for the full headworks system (ie including Malpas, Puddledock, Oaky and the Gara Dams).

The use of the 5/10/10 rules provides a reserve storage or buffer to allow for much worse droughts occurring than have occurred in the last 130 years. It has been argued that it allows for a *1 in 1000 years* drought[4]. Thus it would be expected this buffer would be assisting in still meeting supply albeit with 10% restrictions during more severe droughts that would occur in the 10,000 years of stochastic data.

Another consideration that is noted is that the 5/10/10 critical drought for Oaky Dam was essentially based on observed flows at the upstream gauging station and these inflows were less than the modelled inflows for the critical drought from the modelled stochastic inflows (See Discussion Section).

It is noted the secure yield estimates are dependent on the operating rules, data and assumptions as discussed herein and or in the previous Progress Report No 10 of 15 November 2022.

Rainfall Runoff Modelling

Figure 1 provides a catchment map and location of the patch points (ie where climate data recording stations are or have been in the past) in the vicinity of the dam catchment. However the required 10,000 years of stochastic rainfall and evapotranspiration data was not available for all the sites. Based on data availability and locality appropriateness data from Patch/Seed points 57022, 57011 and 59022 were used to recalibrate the model and to generate the 10,000 years of stochastic inflows.

Figure 2 compares on a flow duration basis the observed flows at the gauging station with the modelled inflows from the recalibrated model and Table 1 provides the calibration statistics. The overall goodness of fit of the modelled flows from the recalibrated model appears similar to that obtained previously.

Table 1: Model Calibration Statistics

Comparative statistics for runoff

Variable	Start	End	Length	Relative diff	Absolute dif	Nash-Sutcli	Correlation
Calibration	6/12/1958	1/11/1983	9097	-0.958%	-68.706	0.712	0.847

Univariate statistics

Variable	Start	End	Length	Missing	Total (mm)	Mean (mm)	Std. Dev. (	Skew (mm)
Calib. Obs	6/12/1958	1/11/1983	9097	0	7173.935	0.789	2.598	16.064
Runoff	6/12/1958	1/11/1983	9097	0	7105.229	0.781	2.384	11.254

1. *NSW Department of Primary Industries, Office of Water (2013), "Assuring future urban water security, Assessment and adaption guidelines for NSW local water utilities", Draft-December 2013.*
2. *NSW Department of Planning and Environment (2022, "Guidance on strategic planning outcome - Understanding water security, December 2022.*
3. *It is noted that '1 in 1000 years drought ' does not mean it only occurs once every thousand years but means it has a 0.1% probability of occurring any year.*

Figure 1: Climate Data Point Locations

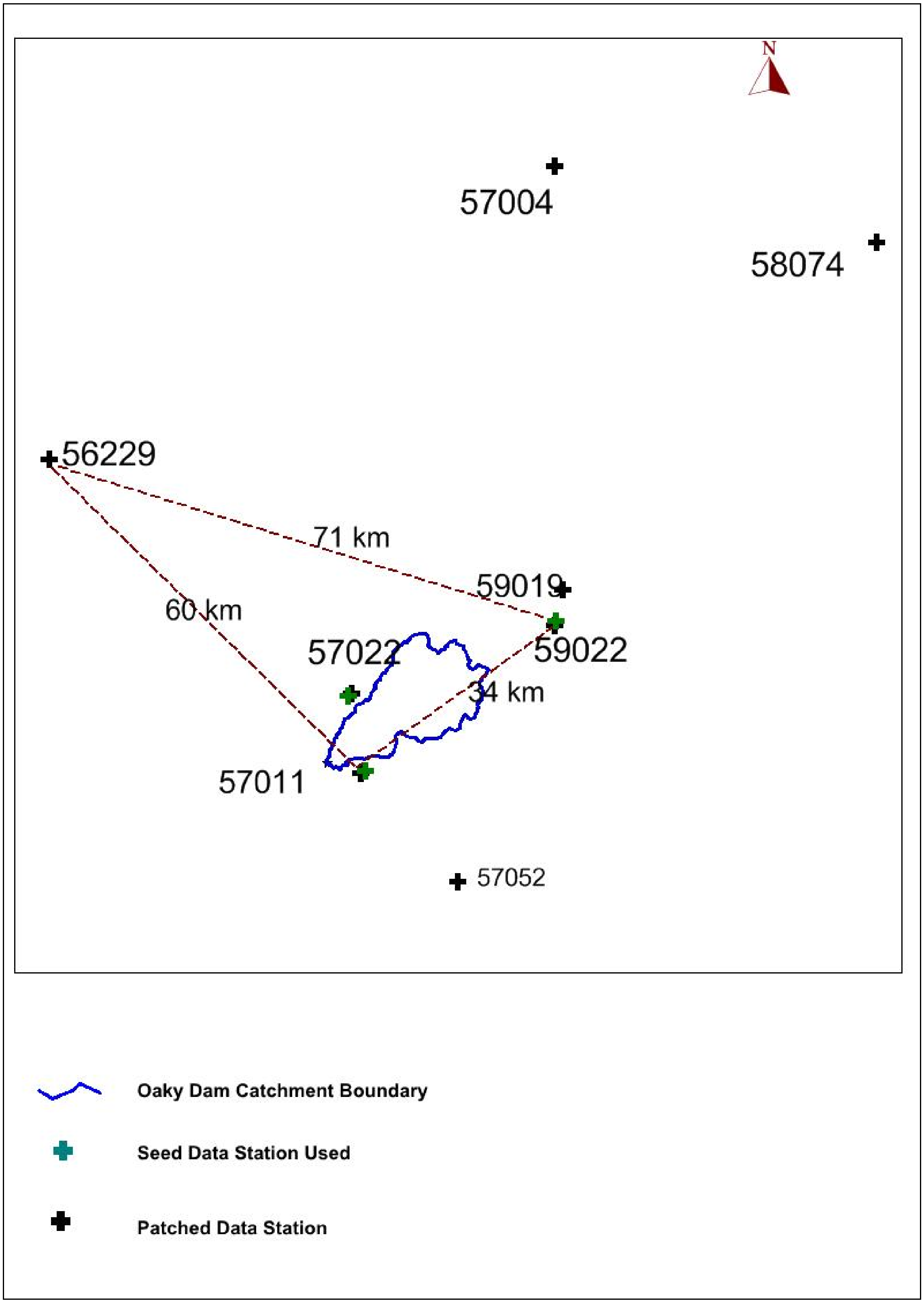
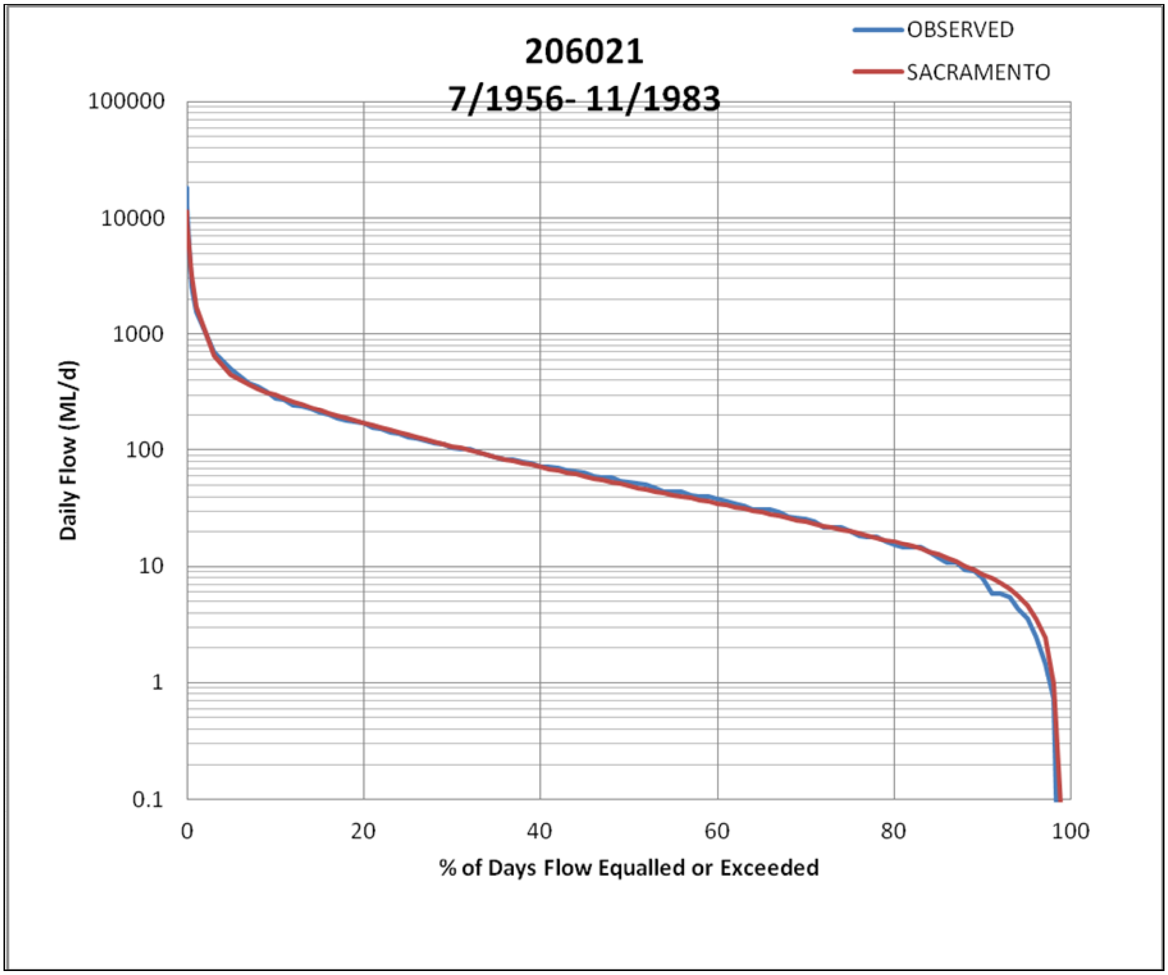


Figure 2: Flow Duration Curve Comparison



The recalibrated model was then used to generate historical inflows and these were merged with the factored upstream inflows as done previously and then used to obtain the historic climate secure yield and the results are provided in Table 2 and compared to the previous result . The recalibrated result was slightly higher (5%) than the previous result.

Table 2: Preliminary Secure Yield Estimates for Oaky Dam Standalone Scheme

Run No	Option	Oaky Flow Series	Oaky Dam Gross** Storage GL	Transfer Rate from New Source ML/d	Historic Climate Secure Yield ML/a	Secure Yield with 1°C Climate Warming ML/a	Historic Climate Critical Drought	
							From	To
Patch Point Data (Model Recalibration):								
257	Oaky Dam	Cat_2	2.78	25	**3613**	*Not Modelled*	24/11/1964	18/07/1965
SILO Grid Data (Previous Progress Report 10):								
251r	Oaky Dam	Oaky1_1	2.78	25	**3425**	**3217**	3/11/1964	18/07/1965
*** Dead storage 0.235 GL*								

EFR rules for Oaky Dam :
1. For January to July can only store when flow above 90% ile
2. For August to December can only store when flow above 80% ile
3. Can only extract 30% of the flow above the % ile flows.
4. If Oaky Dam less than 60% full then above 90% ile is relaxed to 95%ile and 80% ile relaxed to 90% ile

Note : % ile flows based on flows in each month (ie twelve monthly values for the year)

The 10,000 years of stochastic daily rainfall and daily evapotranspiration data were input into the recalibrated Sacramento rainfall runoff model to obtain a corresponding series of 10,000 years of stochastic daily inflows.

Also the 10,000 years of stochastic daily rainfall and daily evapotranspiration data were mulitiplied by the monthly factors for climate change to obtain 10,000 years of stochastic daily inflows perturbed for climate change. The monthly factors were those used for the North Coast Regional Water Strategy study for the period 2060 to 2079 compared the period 1990 to 2009 from NARCliM projections. It is noted the factors for rainfall are different to those for the evapotranspiration.

Modelling Results

The system behaviour model was run with the 10,000 years of stochastic inflows in an operational mode to assess whether the secure yield demand of 3613 ML/a could be met with 10% restrictions occurring whenever the storage was below 75% full (these conditions being taken from the 5/10/10 secure yield determination run 257).

This was also repeated using the 10,000 years of stochastic data perturbed for climate change and using a reduced climate chasnge secure yield demand of 3394 ML/a (*which was estimated by applying the previous reduction factor of 0.9393 to 3613 ML/a*).

It was found that the demand could always be met for both of the above cases and restrictions occurred far less often than implied by the 5/10/10 condition. Table 3 summarises the modelling results. Figures 3 and 4 provide storage volume duration curves for the 10,000 years of data for the two modelling cases showing the storage never got below 50% full.

Table 3: Stochastic Data Modelling Results

Run No	Gross Storage GL	Flow Series	Demand ML/a	Restrictions			Critical Drought	
				Applied at storage (% full)	Duration (%)	% of Years	From	To
10,000 years Stochastic Inflows:								
258	2.78	Oaky_stoch	**3613**	75	0.08	1.26	16/04/8593	6/10/8593
10,000 years Stochastic Inflows Perturbed for Climate Change:								
258CC	2.78	Oaky_stoch _CC	**3394**	75	0.13	1.82	12/04/8593	6/10/8593

Figure 3 : Storage Volume Duration Curve- 10,000 Years Stochastic Data

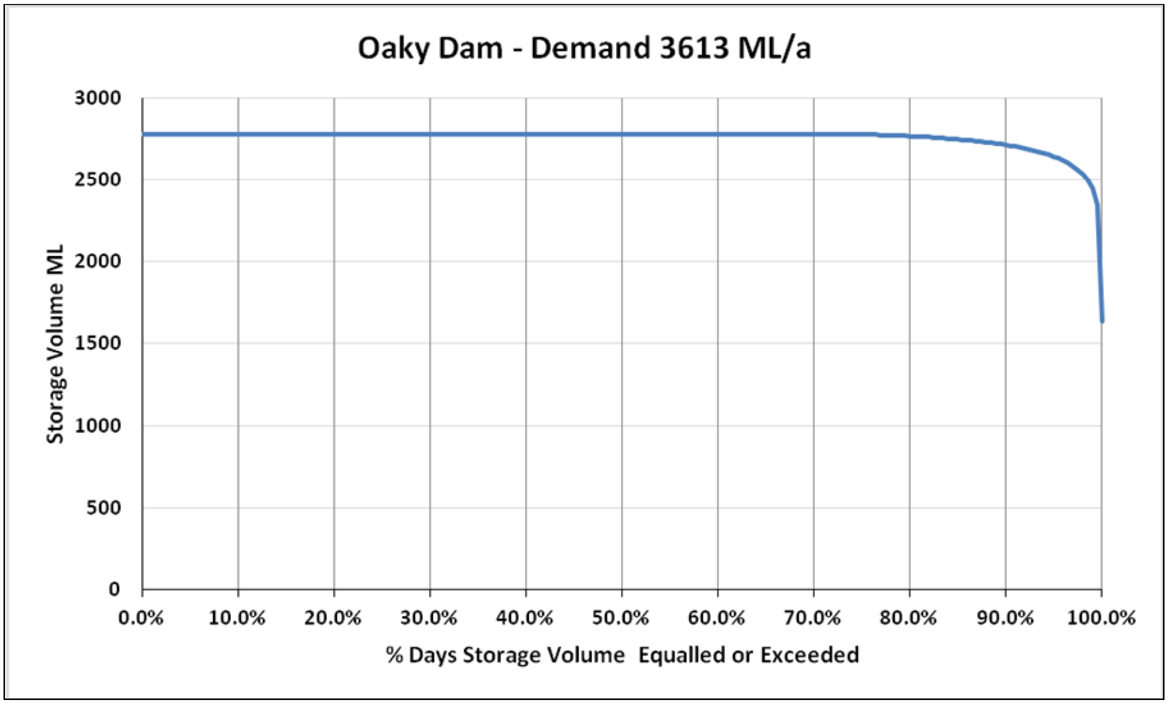
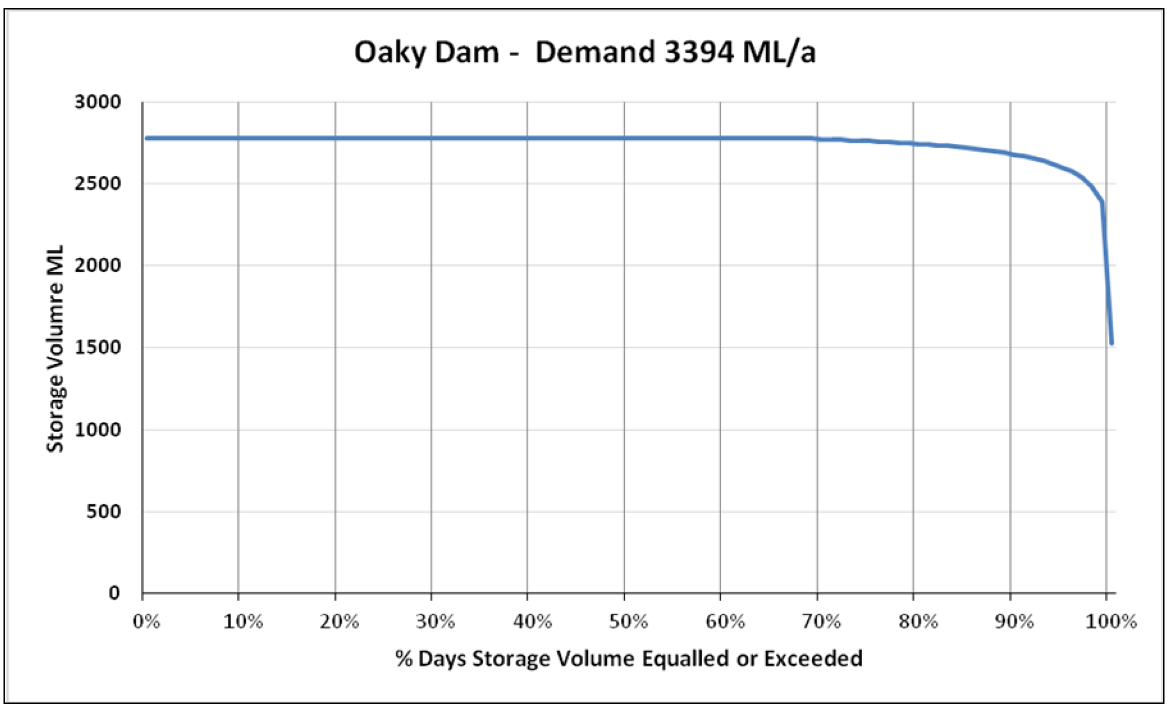


Figure 4 : Storage Volume Duration Curve- 10,000 Years Stochastic Data Perturbed for Climate Change



Climate Change

The alternative approach has a different way of assessing climate change. Thus to see if the alternative approach changed the secure yield significantly different from the previous approach, additional modelling was undertaken.

The historic climate rainfall and evapotranspiration were adjusted by the monthly factors used in the alternative approach for the climate change perturbation and then input into the rainfall runoff model to obtain a series of historic climate inflows perturbed for climate change. These were then input into the system behaviour model. To compare like with like the *unmerged* historic climate modelled flow series was also input into the system behaviour model. Table 4 compares the two secure yield estimates.

Table 3: Stochastic Data Modelling Results

Run No	Gross Storage GL	Flow Series	Secure Yield (5/10/10) ML/a	Restrictions			Critical Drought	
				Applied at storage (% full)	Duration (%)	% of Years	From	To
Historic Climate (unmerged flow series):								
259	2.78	Cat_1	**6535**	65	0.88	7.46	22/01/1902	20/08/1902
Historic Climate Perturbed for Climate Change Using NARCliM Monthly Factors:								
259CC	2.78	DAMCAT-SCALED	**5469**	65	0.67	9.70	21/03/1902	20/08/1902

The reduction in secure yield for climate change was 16 % (6535 to 5469 ML/a) compared to 6% for the previous approach (3425 to 3217 ML/a). It is noted for the previous approach the reductions could be quite variable from case to case and thus without more case studies it cannot be said the alternative approach will result in larger reductions in secure yield for climate change for all cases**.**

It is noted the large difference in the historic climate secure yield from the previous estimate is a consequence of the previous estimate using observed flow data when available (*ie merging*) and this shows the importance of using observed flow data in preference to modelled flow data.

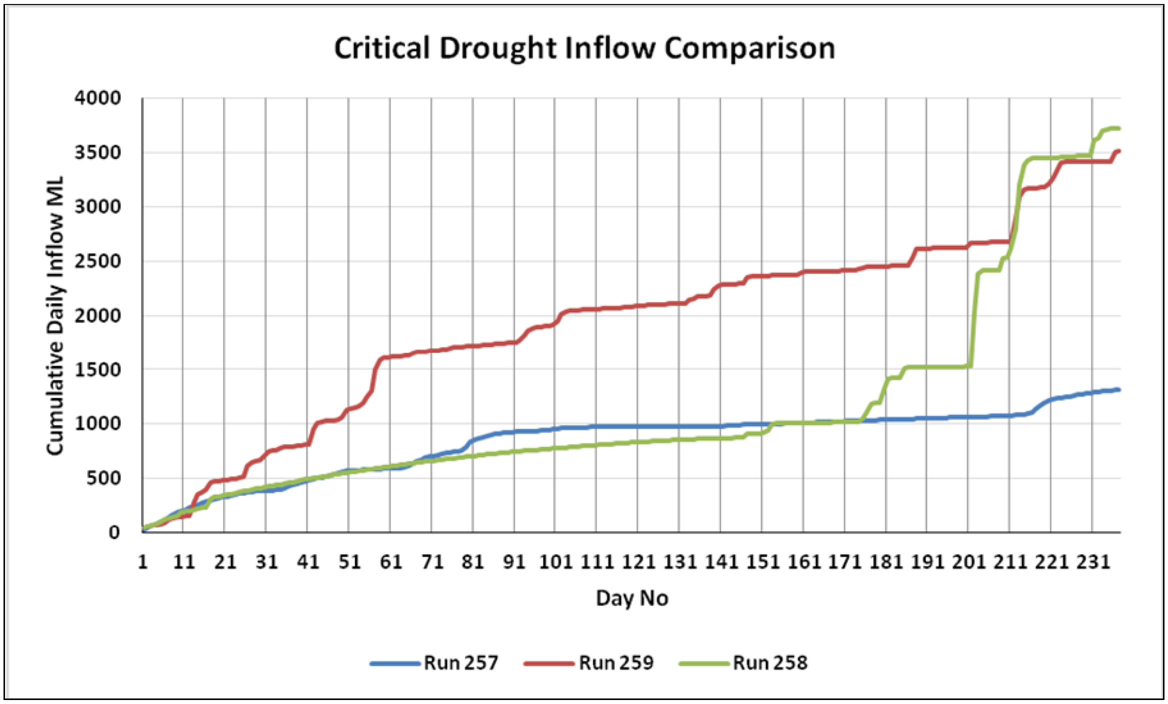
Discussion

Figure 5 provides a cumulative plot of the inflows for the critical drought (*extended from day 1 to the day number of the longest critical drought of the 3*) for three cases:

1. **Run 257**:   24/11/1964-18/7/1965 ï Historic Climate Modelled Flow Series Merged with Observed Data
2. **Run 259**:   22/1/1902-20/8/1902 - Historic Climate Modelled Flow Series
3. **Run 258**:   16/4/8593 - 6/10/8593 ï 10,000 years modelled stochastic data

The differences in the critical inflows would also be a contributing reason to explain why the historic climate secure yield demands could be met in the simulation while using the 10,000 years of stochastic inflows.

Figure 5: Critical Drought Inflow Comparison



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MEMORANDUM

TO	Glenn Fernandes Director ï Water Resources Management NSW Public Works
CC	
FROM	Peter Cloke, Principal Hydrologist
DATE	9 June 2023
SUBJECT	Armidale Yield Study: Progress Report (12) ï Addition of Oaky Dam Optimisation of Transfers **DRAFT**

With reference to your email of 6 April 2023 and subsequent discussions, modelling has been undertaken towards optimising transfer capacities with the system including Oaky Dam. Initial results and findings are reported herein.

Summary

Numerous cases with Oaky Dam with the various nominated transfer rates for the existing Malpas Dam and with Malpas Dam FSL raised by 6.5 m have been modelled. The modelling results are summarised in Tables 1 and 2.

Depending on the case modelled the secure yield was being constrained by the transfer from Malpas Dam to Armidale. Thus towards finding the maximum secure the transfer capacity from Malpas to Armidale was unconstrained in the model. The maximum secure yield achieved was 10138 ML/a for the historic climate and 8322 ML/a with climate change for 1^{o}C warming. To both of these secure yields 755 ML/a needs to be added as in the model Guyra's future demand of 755 ML/a was first satisfied and thus as such not included in the model output.

It is noted for the historic climate secure yield of 10138 ML/a the maximum transfer that occurred from Malpas Dam to Armidale was 37.51 ML/a (*to satisfy peak monthly daily demand*) although the average transfer was only 5.8 ML/d as most of the water (particularly non drought times) on average was coming from Oaky Dam.

It is noted to facilitate the modelling, the transfer from Malpas Dam to Guyra WTP was unconstrained. For the cases modelled, the maximum transfer that occurred was 2.76 ML/d with the average being 1.804 ML/d. This compares to the nominated 2.1 ML/d. It is assumed Guyra's system would able to accommodate Guyraõs peak monthly daily demand or additional water could be taken from the buffer storage resulting from the 5/10/10 rules applied to the Guyra dams.

It is noted the secure yield estimates are dependent on the operating rules, data and assumptions as discussed herein and or in the previous 10 Progress Reports (30/3/2020, 26/5/2020, 18/9/2020, 19/10/2020,16/4/2021,22/04/2021,30/04/2021,8/6/2021,7/9/2021 & 15/11/2022).

It is noted the analysis is very reliant on the observed Oaky River flow data used for the previous rainfall runoff modelling. The provided Oaky River flows were quality coded unknown.

Model System Changes

It is noted in the previous analysis (see Progress Report 10) with the addition of Oaky Dam it was modelled on the basis the water from Oaky Dam was transferred to Malpas Dam. For the current modelling reported herein this was refined so water was transferred directly from Oaky Dam to Armidale WTP and any surplus was transferred to Malpas Dam.

In the previous modelling Guyra's demand was met from the Guyra dams and was fixed at 96 ML/a based on the climate change secure yield of the two Guyra dams as a standalone system.(*It was understood the difference was then allowed for by NSW Public Works in what was needed from the Malpas system*).For the current modelling this was refined to take into account the provided updated future dry year demand pattern for Guyra (*which is different from Armidale which has not changed from the previous modelling*) and also that water can now be transferred from Malpas Dam to Guyra WTP. The demand met from the Guyra dams was still fixed at 96 ML/ a (*this was remodelled as before but with the updated demand pattern 96 ML/a resulted*). The specified future demand for Guyra was 755 ML/a, thus the balance of 659 ML/a was met from Malpas Dam in accordance with the Guyra Demand pattern before meeting Armidale's demand.

The provided demand pattern for Guyra used in the model was:

Monthly % of Annual Demand											
Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
12.98	**8.58**	**10.53**	**7.64**	**6.25**	**4.88**	**5.02**	**6.55**	**8.55**	**8.08**	**8.86**	**12.06**

To facilitate the modelling the transfer from Malpas Dam to Guyra WTP was unconstrained. For the cases modelled, the maximum transfer that occurred was 2.76 ML/d with the average being 1.804 ML/d. This compares to the nominated 2.1 ML/d. It is assumed Guyra's system would able to accommodate Guyra's peak monthly daily demand or additional water could be taken from the buffer storage resulting from the 5/10/10 rules applied to the Guyra dams and the demand taken from the Guyra demands being fixed at 96 ML/a.

Results

Table 1 provides the secure yield results for the nominated transfer rates for the system with Oaky Dam and with the existing Malpas Dam. It was found that the secure yield was constrained by the transfer capacity of 22 ML/d from Malpas Dam to Armidale WTP. Thus trial runs were undertaken using unconstrained transfer (*set in model to 100 ML/d*) from Malpas Dam to Armidale towards finding the maximum secure yield.

Table 2 provides the secure yield results for the nominated transfer rates for the system with Oaky Dam and with the Malpas Dam FSL raised by 6.5 ML. It was found that the secure yield was also still constrained by the transfer capacity of 22 ML/d from Malpas Dam to Armidale WTP. Thus trial runs were undertaken using unconstrained transfer (*set in model to 100 ML/d*) from Malpas Dam to Armidale towards finding maximum yield.

It is noted the secure yield for the unconstrained transfer (in Table 1) was slightly less for Run 264 then Run 265 although the later has a higher transfer capacity from Oaky Dam to Armidale WTP. This relates to using water that is better stored for later use and or water being spilled later. This suggests there may be room to further optimise when to transfer water from which storage but with the raised Malpas Dam this did not occur.

It is noted in the modelling meeting Guyra's specified future demand of 755 ML/a was given priority and thus was always met. The secure yield results in Tables 1 and 2 do not include this 755 ML/a, thus depending how the results are to be considered the 755 ML/a should be added to these results.

Table 1: Secure Yield Results (excludes 755 ML/a provided to Guyra) for Existing Malpas Dam with Proposed Oaky Dam Additional Source

Run No	Transfer ML/d												Historic Climate Secure Yield ML/a	Secure Yield with 1°C Climate Warming ML/a	Historic Climate Critical Drought	
	Oaky Dam to Armidale WTP			Oaky Dam to Malpas Dam via Armidale WTP			Malpas Dam to Armidale WTP			Malpas Dam to Gurya WTP						
	Cap-acity	Max	Ave	Cap-acity	Max	Ave	Cap-acity	Max	Ave	Cap-acity **	Max	Ave			From	To
With Existing Malpas Dam:																
261r	17.8	17.8	14.92	17.3	8.09	0.973	22	22	1.30	5	2.76	1.80	**5945***	**5945*** *See attachment A*	8/08/2017	15/01/2020
262r	23.4	22	15.14	17.3	14.92	2.50	22	22	1.08	5	2.76	1.80	**5945***	*Not modelled as expect to be same as for Run 261r*	4/08/2017	15/01/2020
263r	37.8	22	14.75	17.3	17.3	3.80	22	22	1.46	5	2.76	1.80	**5945***		4/08/2017	15/01/2020
Transfer from Malpas Dam to Armidale WTP Set to 100 ML/d so as to be unconstrained:																
264	17.8	17.8	15.85	17.3	7.17	0.60	**100**	25.26	2.77	5	2.76	1.80	**6828**	*Not modelled*	25/07/2017	15/01/2020
265	37.8	24.26	15.94	17.3	17.3	3.84	**100**	24.26	1.94	5	2.76	1.80	**6557**		25/07/2017	15/01/2020

** The specified 22 Ml/d transfer rate from Malpas Dam to Armidale was constraining the yield*

*** Capacity in model was set to 5 ML/d to so that would not constrain secure yield of system*

Oaky 1-1 Flow Series Used

Oaky Dam Gross Storage 2.78 GL with Dead storage 0.235 GL

Malpas Dam conditions based on Run 202 (*which includes Guyra, Malpas, & Puddledock Dams*) as detailed in Progress Report 4 of 19 October 2020

No Release Required from Malpas Dam when less than 6746 ML (except up to 0.2 Ml/d subject to imflow)

EFR rules for Oaky Dam :

1. For January to July can only store when flow above 90% ile
2. For August to December can only store when flow above 80% ile
3. Can only extract 30% of the flow above the % ile flows.
4. If Malpas Dam less than 60% full then above 90% ile is relaxed to 95%ile and 80% ile relaxed to 90% ile

Note : % ile flows based on flows in each month (ie twelve monthly values for the year)

Table 2: Secure Yield Results (excludes 755 ML/a provided to Guyra) for Raised Malpas Dam with Proposed Oaky Dam Additional Source

Run No	Transfer ML/d												Historic Climate Secure Yield ML/a	Secure Yield with 1°C Climate Warming ML/a	Historic Climate Critical Drought	
	Oaky Dam to Armidale WTP			Oaky Dam to Malpas Dam via Armidale WTP			Malpas Dam to Armidale WTP			Malpas Dam to Gurya WTP						
	Cap-acity	Max	Ave	Cap-acity	Max	Ave	Cap-acity	Max	Ave	Cap-acity **	Max	Ave			From	To
***With Malpas Dam FSL Raised by 6.5 m:**:*																
268	17.8	17.8	14.88	17.3	7.43	1.20	22	22	1.35	5	2.76	1.80	**5945***	*Not modelled as expect to be constrain-ed*	04/08/2017	15/01/2020
269	23.4	22	15.01	17.3	13.03	3.16	22	22	1.22	5	2.76	1.80	**5945***		04/08/2017	15/01/2020
270	37.8	22	14.36	17.3	17.3	5.49	22	22	1.86	5	2.76	1.80	**5945***		04/08/2017	7/01/2020
Transfer from Malpas Dam to Armidale WTP Set to 100 ML/d so as to be unconstrained:																
266	17.8	17.8	17.02	17.3	6.81	0.007	**100**	36.02	9.50	5	2.76	1.80	**9736**	**8083** *See attachment A*	22/07/2017	15/01/2020
267	37.8	37.51	21.82	17.3	17.3	3.485	**100**	37.51	5.80	5	2.76	1.80	**10138**	**8322** *See attachment A*	20/07/2017	15/01/2020

** The specified 22 ML/d transfer rate from Malpas Dam to Armidale was constraining the yield*

*** Capacity in model was set to 5 ML/d to so that would not constrain secure yield of system*

Oaky 1-1 Flow Series Used

Oaky Dam Gross Storage 2.78 GL with Dead storage 0.235 GL

Malpas Dam conditions based on Run 202 (*which includes Guyra, Malpas, & Puddledock Dams*) as detailed in Progress Report 4 of 19 October 2020

No Release Required from Malpas Dam when less than 6746 ML (except up to 0.2 ML/d subject to inflow)

EFR rules for Oaky Dam :

1. For January to July can only store when flow above 90% ile
2. For August to December can only store when flow above 80% ile
3. Can only extract 30% of the flow above the % ile flows.
4. If Malpas Dam less than 60% full then above 90% ile is relaxed to 95%ile and 80% ile relaxed to 90% ile

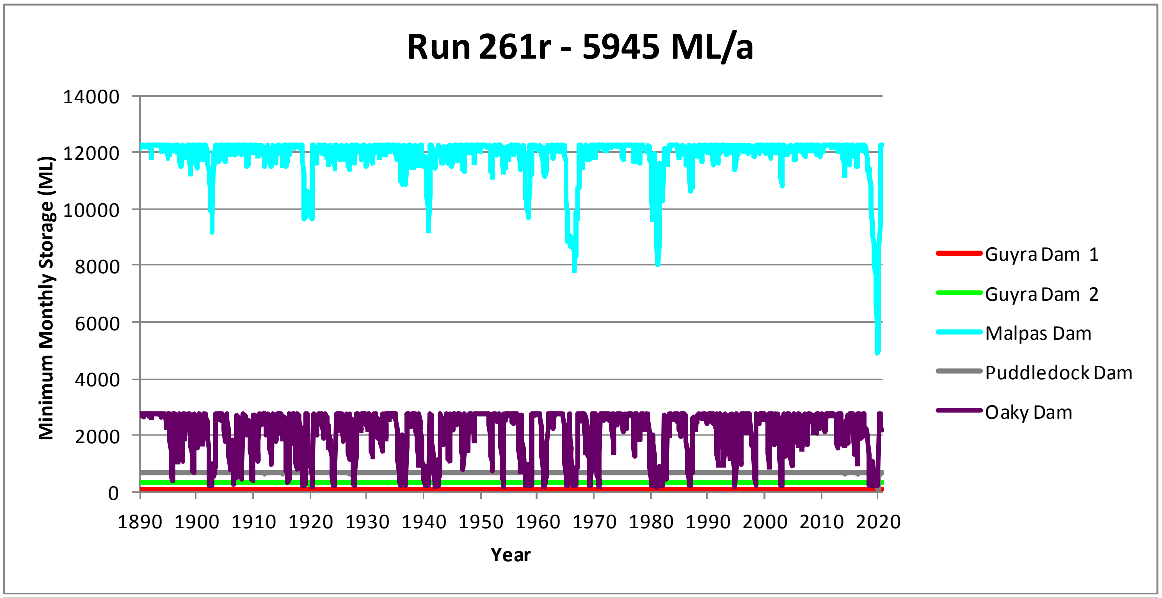
Note : % ile flows based on flows in each month (ie twelve monthly values for the year)

Storage Behaviour

To provide an appreciation of how the storages may perform, Figures 1 to 10 provide the modelled storage behaviour diagrams for the different case meeting their historic secure yields for a repeat of the modelled historic climate. It is noted the apparent reserve storage allows for much worse droughts to occur or is a result of the identified transfer constraints.

For the maximum secure yield case of 10138 ML/a (Run 267) the individual small storages diagrams are provided to provide further details.

Figure 1: Storage Behaviour- Run 261r



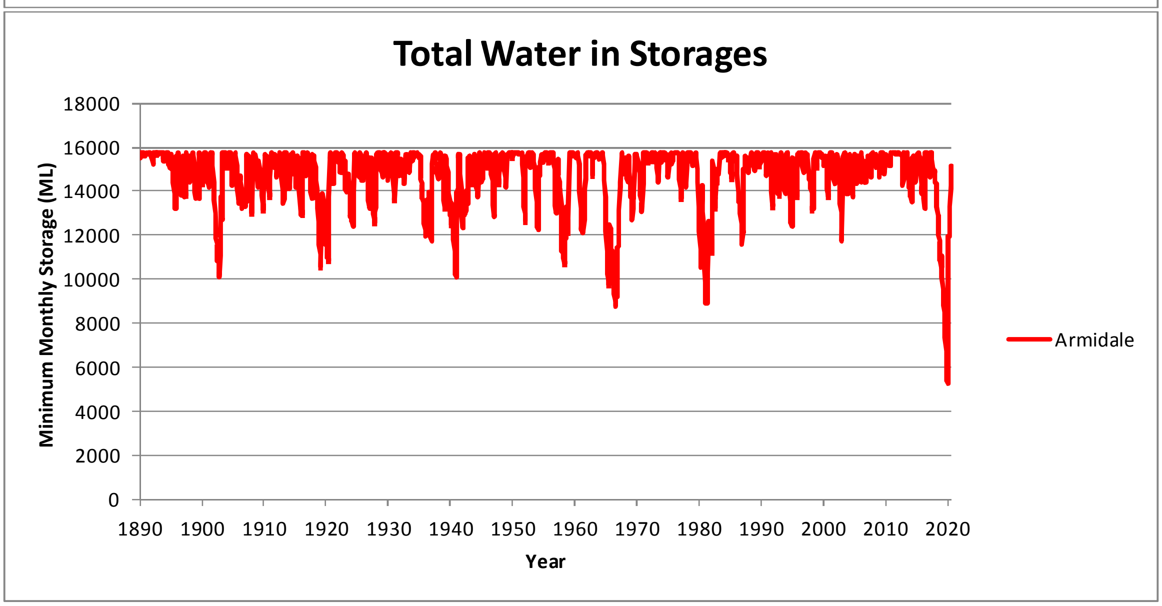
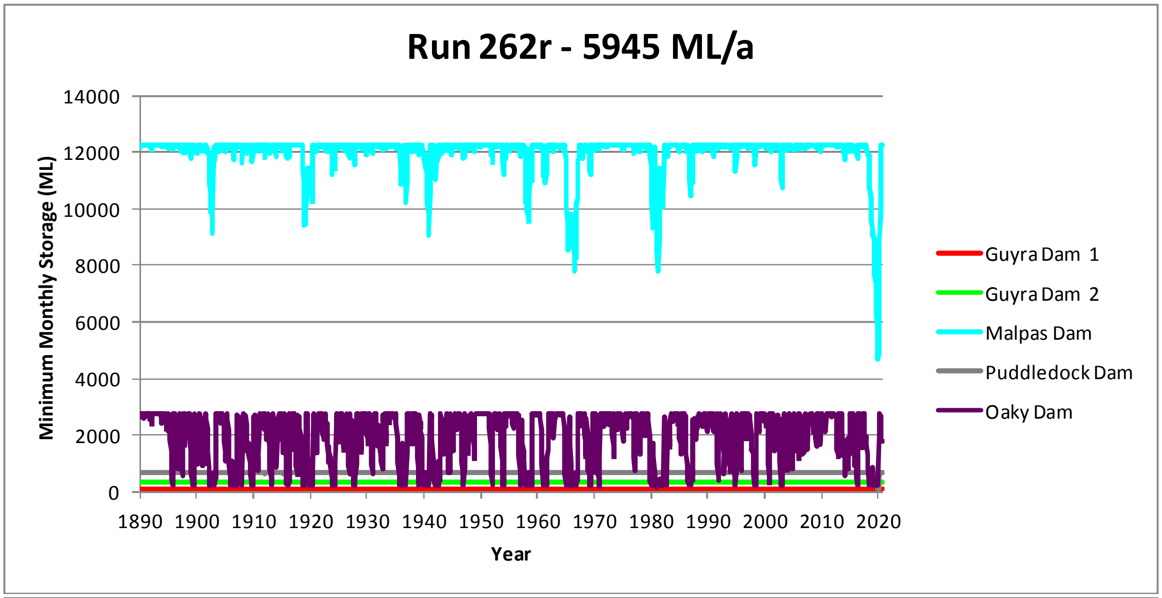


Figure 2: Storage Behaviour- Run 262r



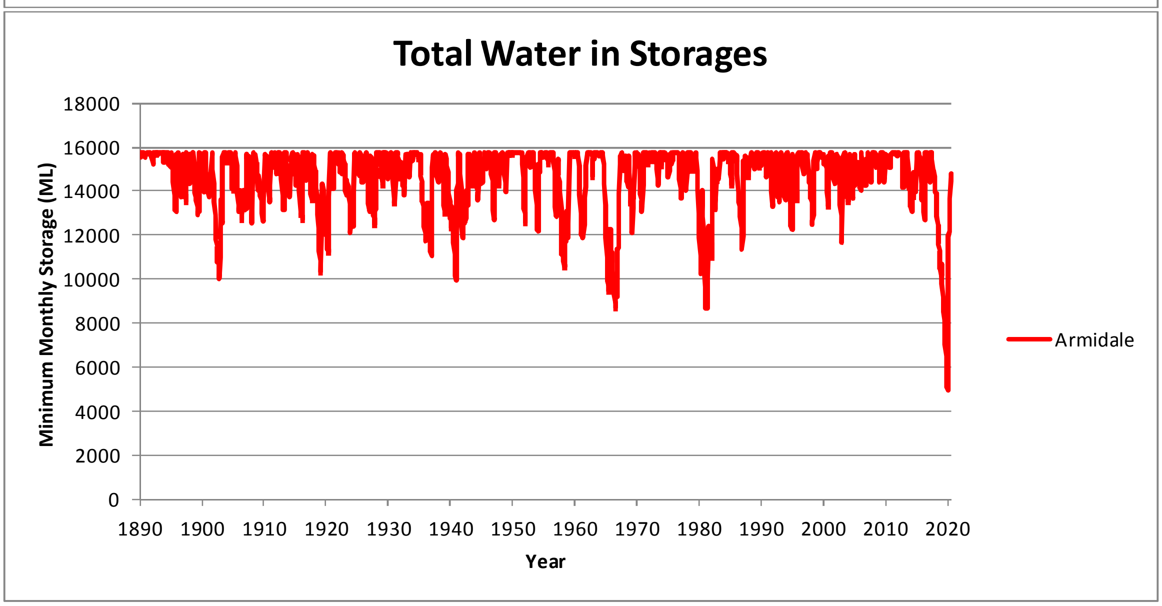
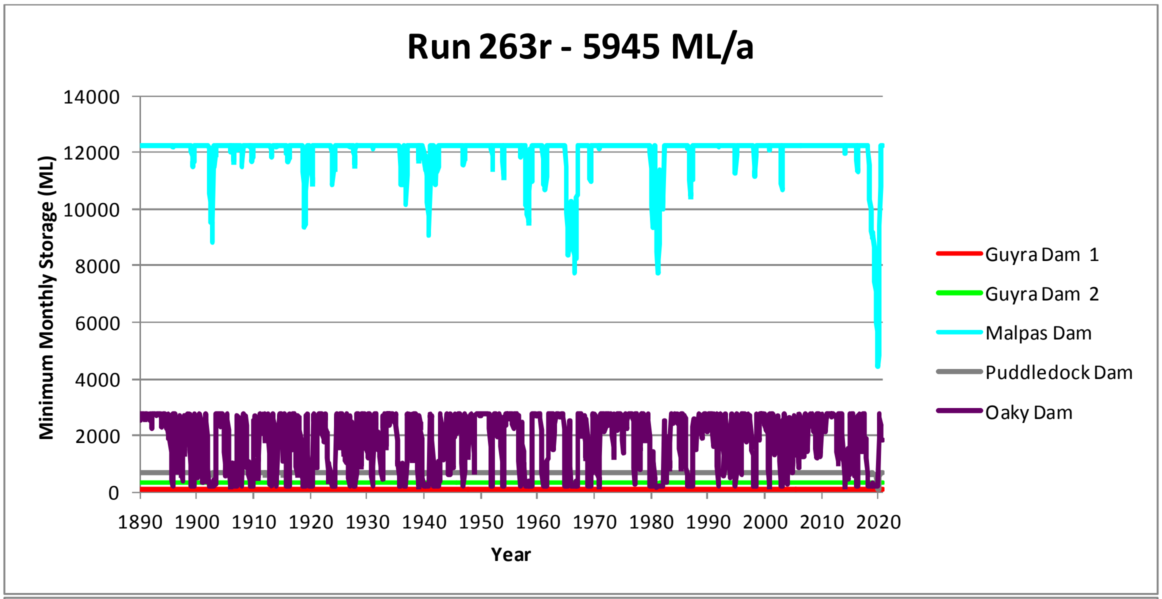


Figure 3: Storage Behaviour- Run 263r



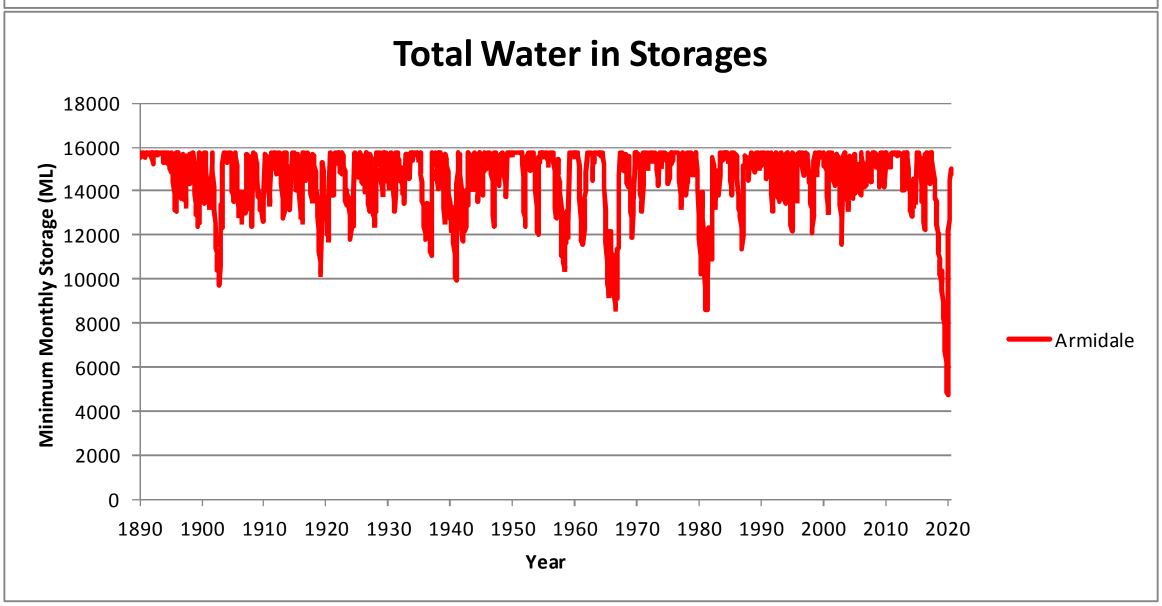
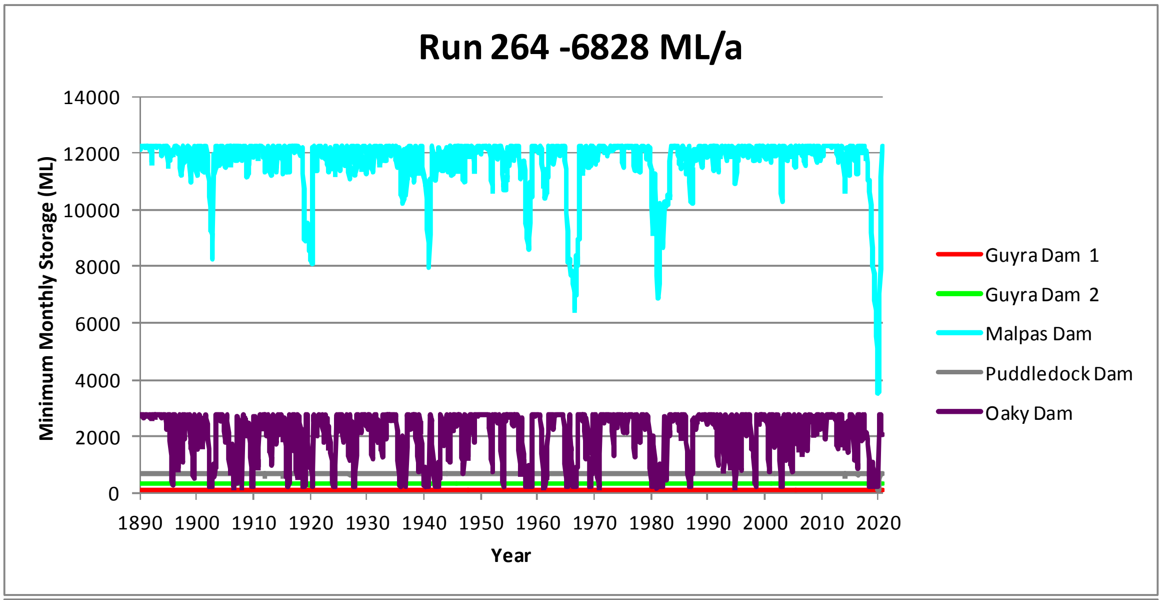


Figure 4: Storage Behaviour- Run 264



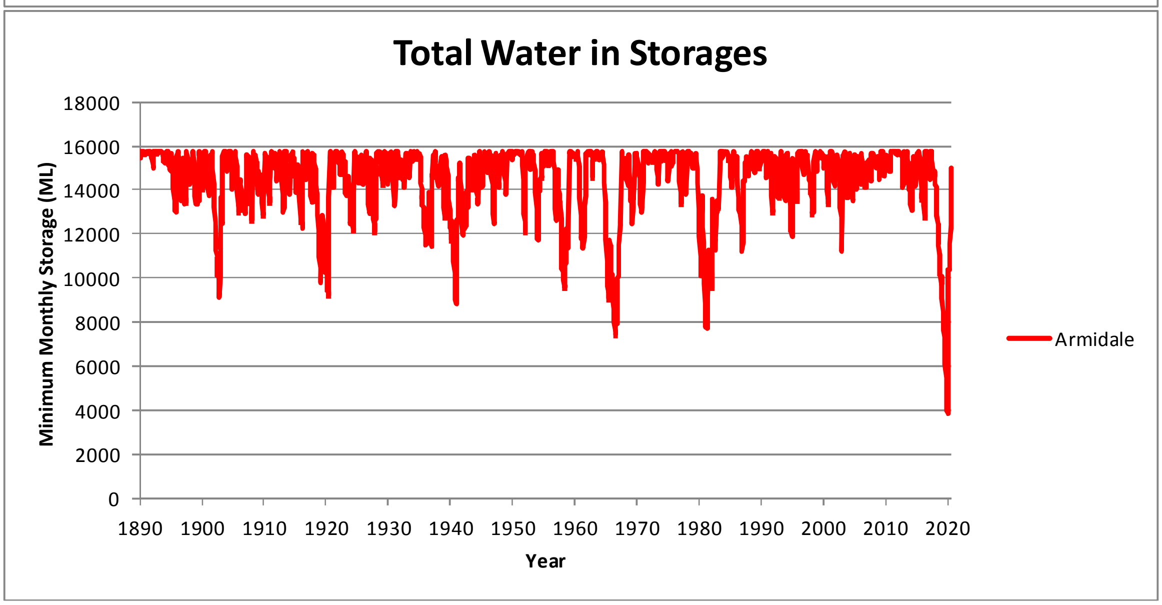


Figure 5: Storage Behaviour- Run 265

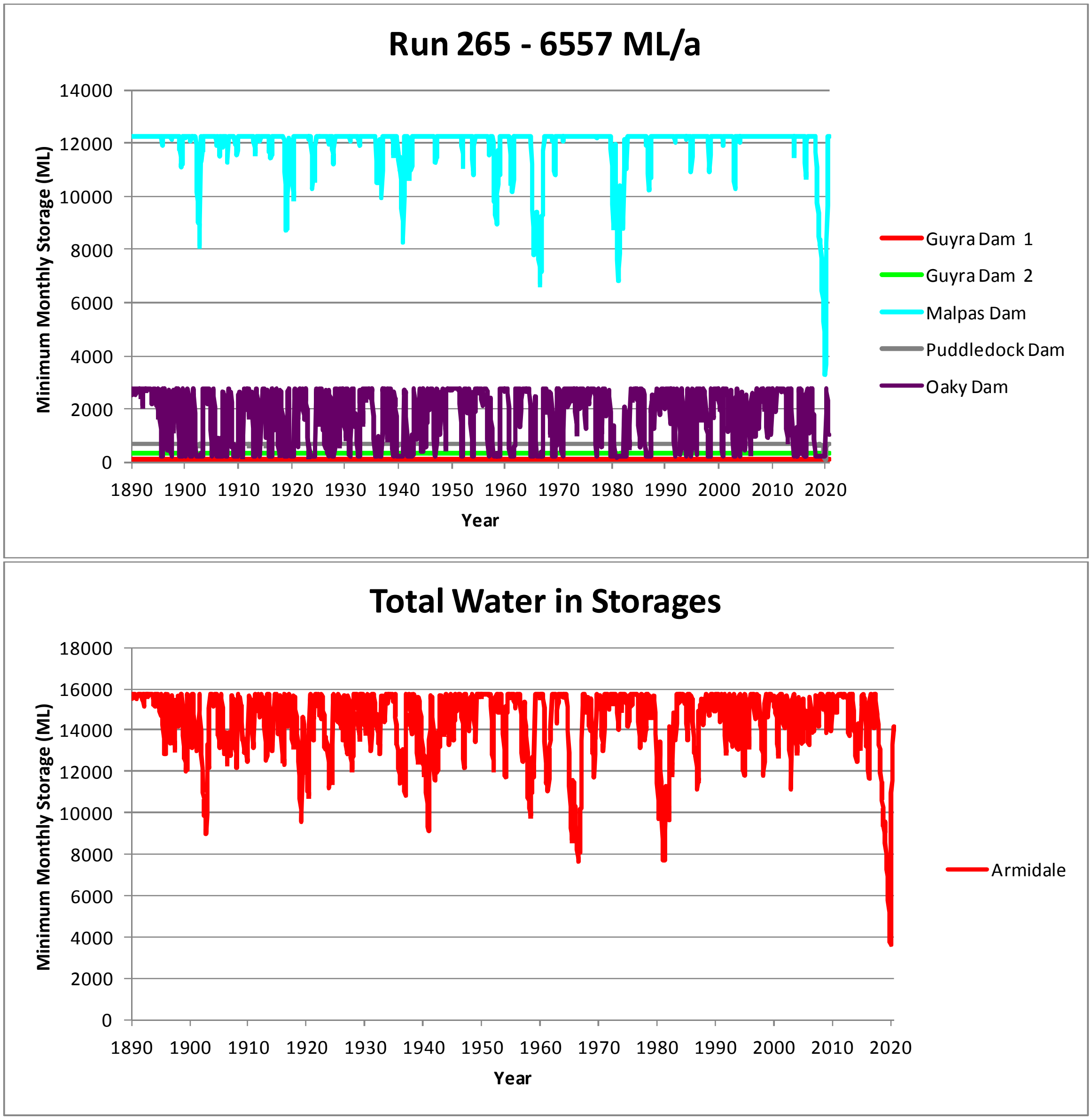
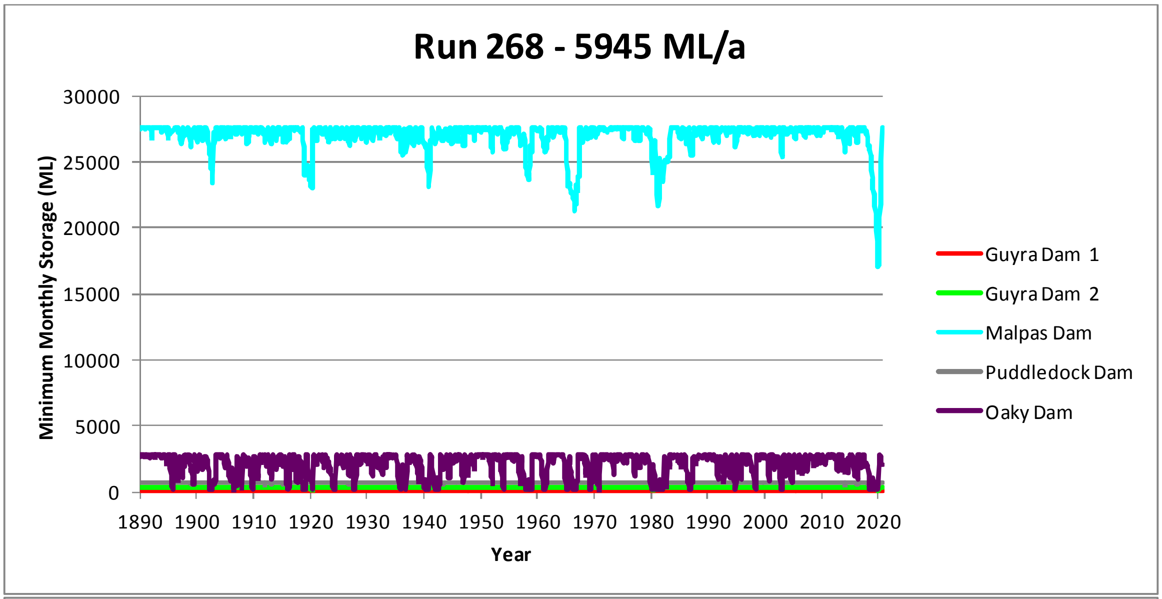


Figure 6: Storage Behaviour- Run 268



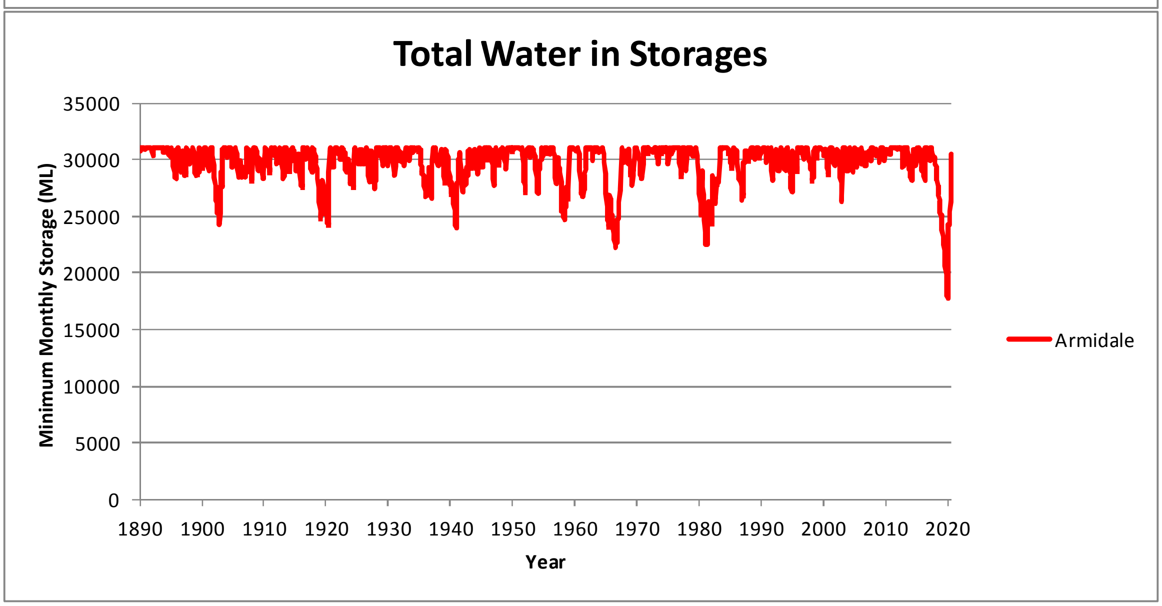
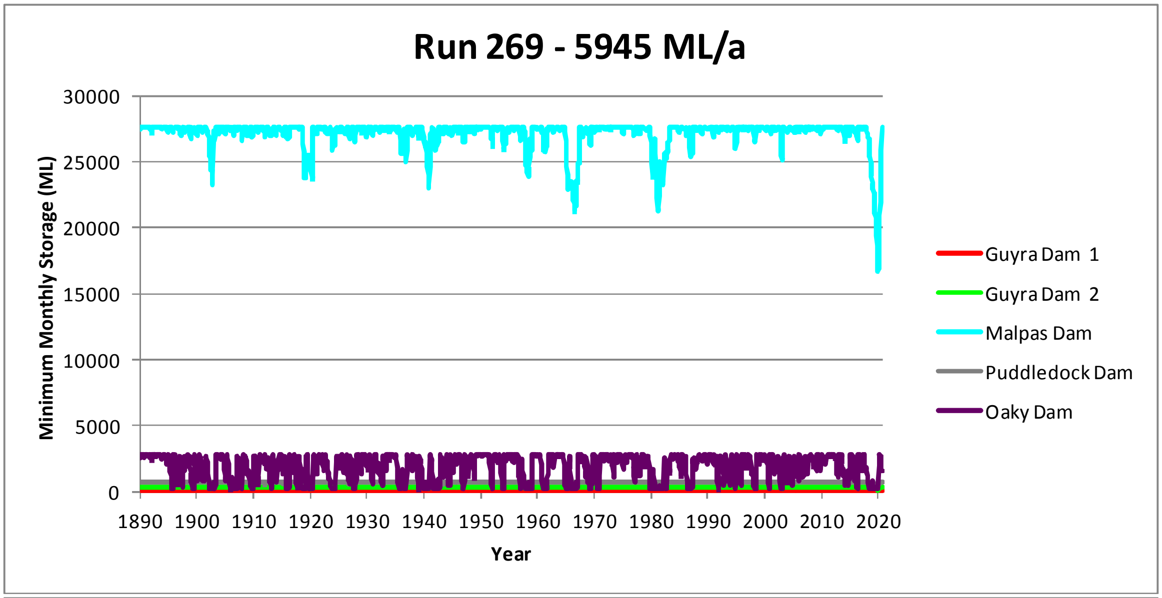


Figure 7: Storage Behaviour- Run 269



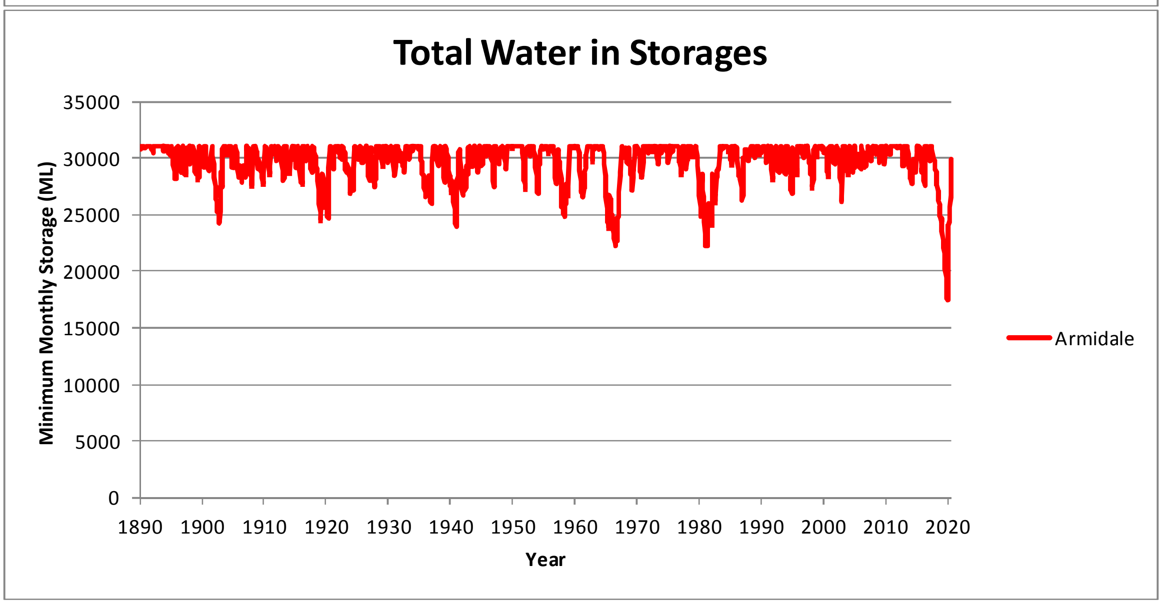
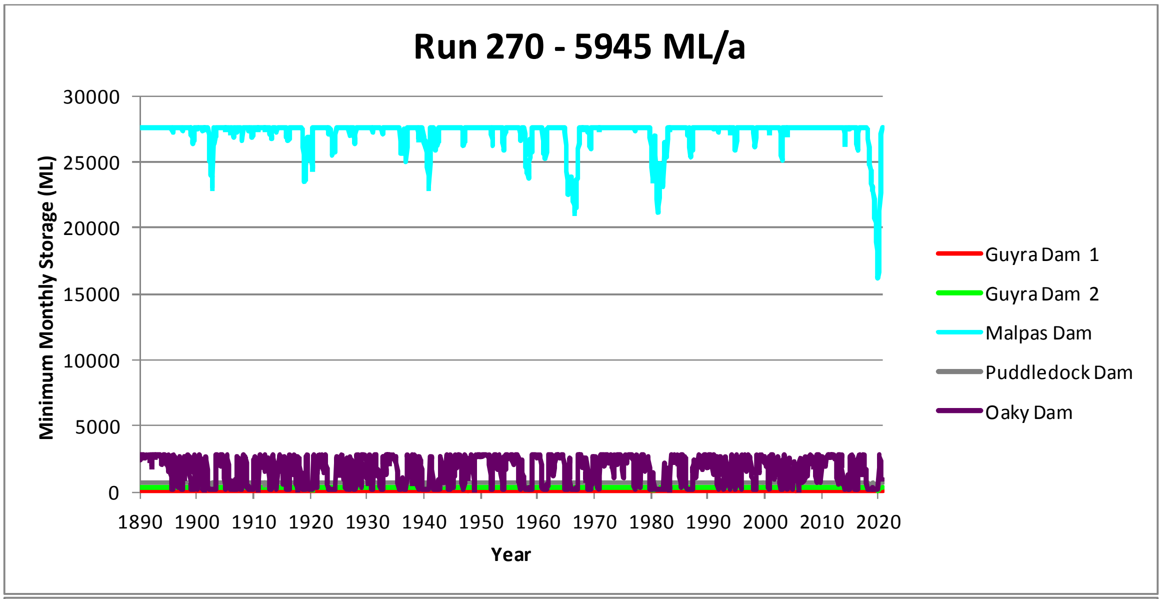


Figure 8: Storage Behaviour- Run 270



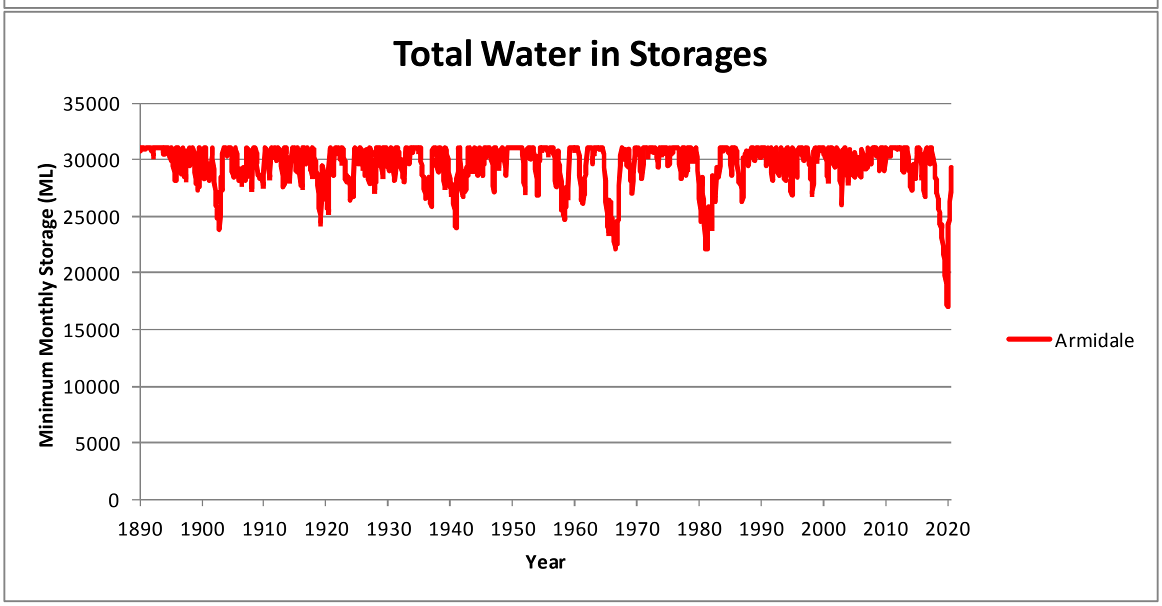
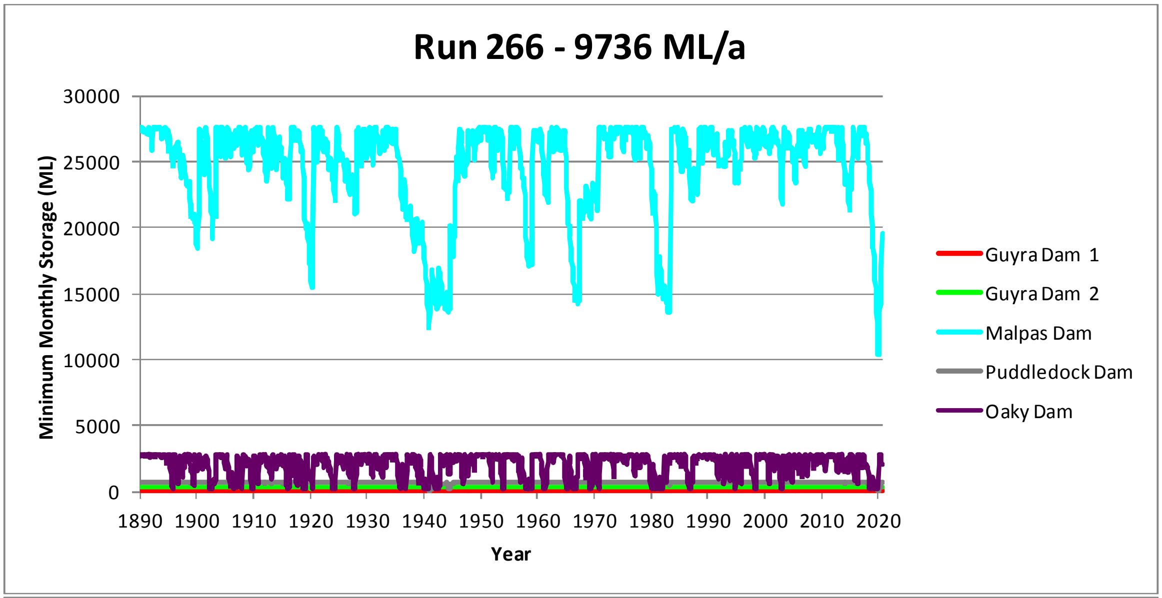


Figure 9: Storage Behaviour- Run 266



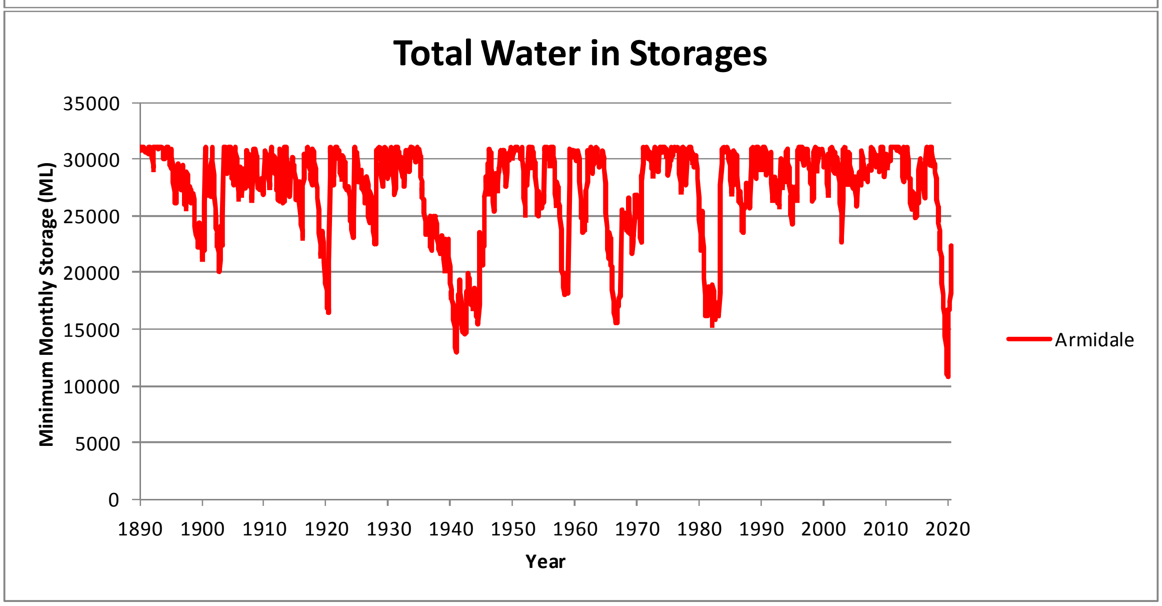
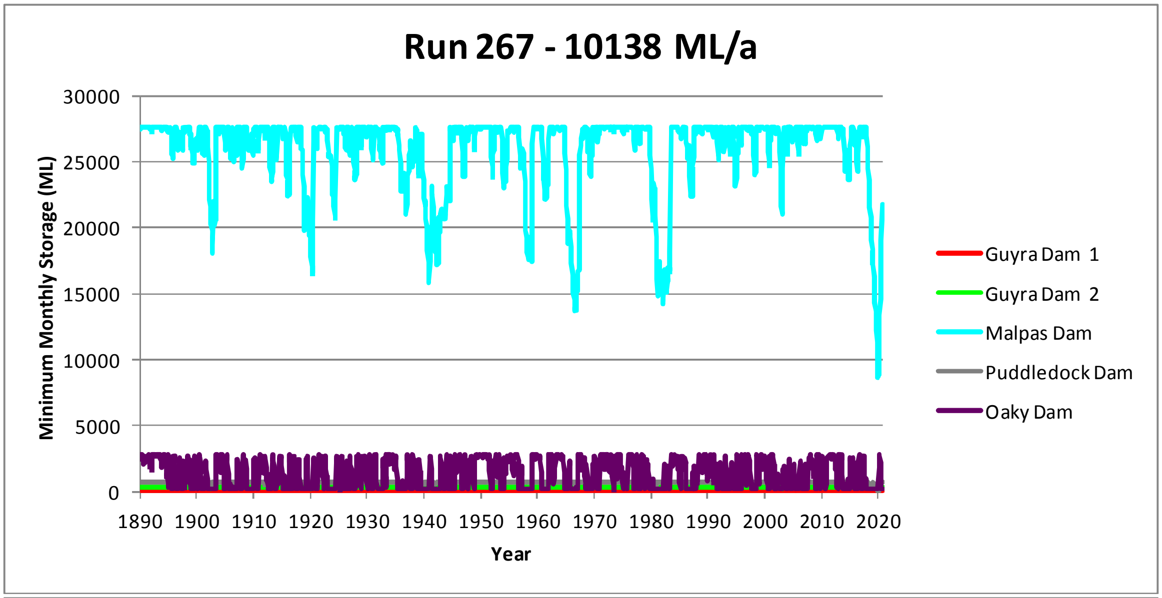


Figure 10a: Storage Behaviour- Run 267



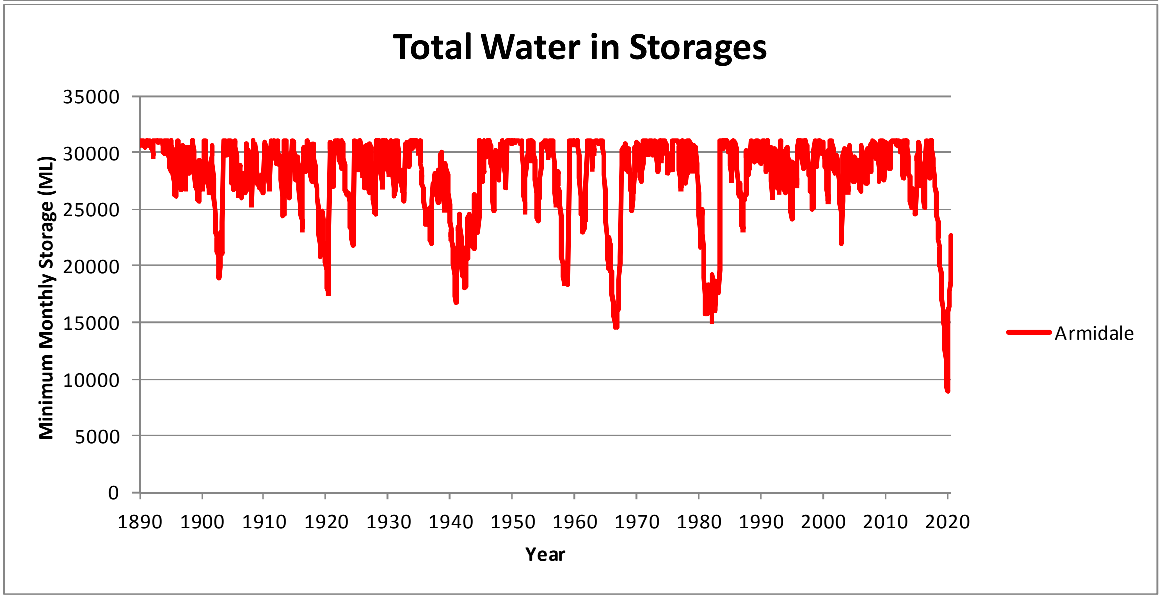
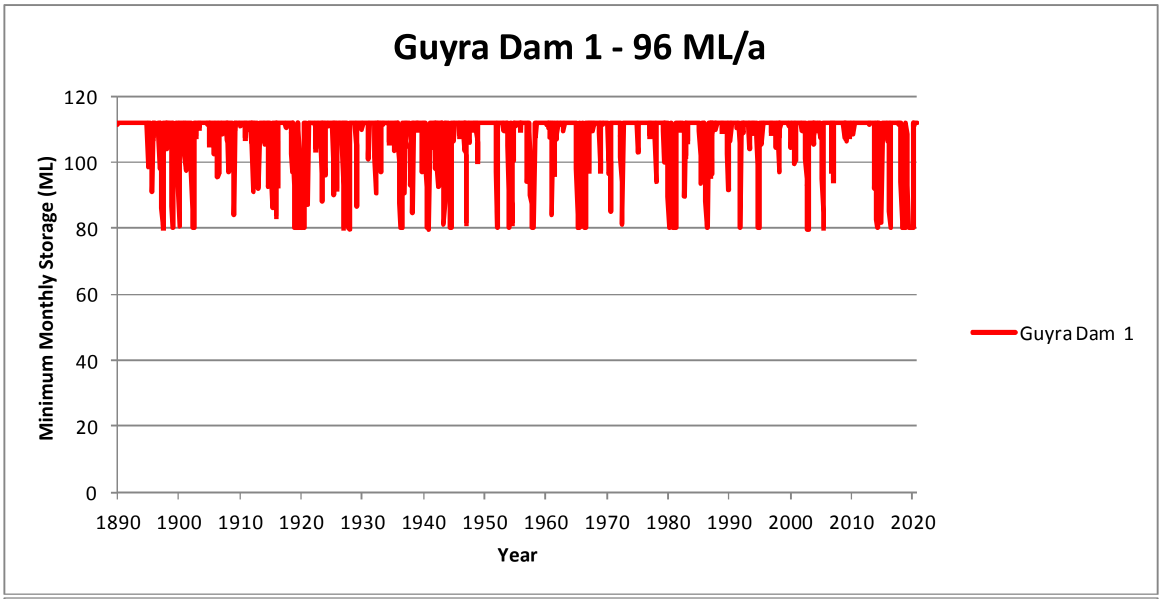


Figure 10b: Storage Behaviour- Run 267



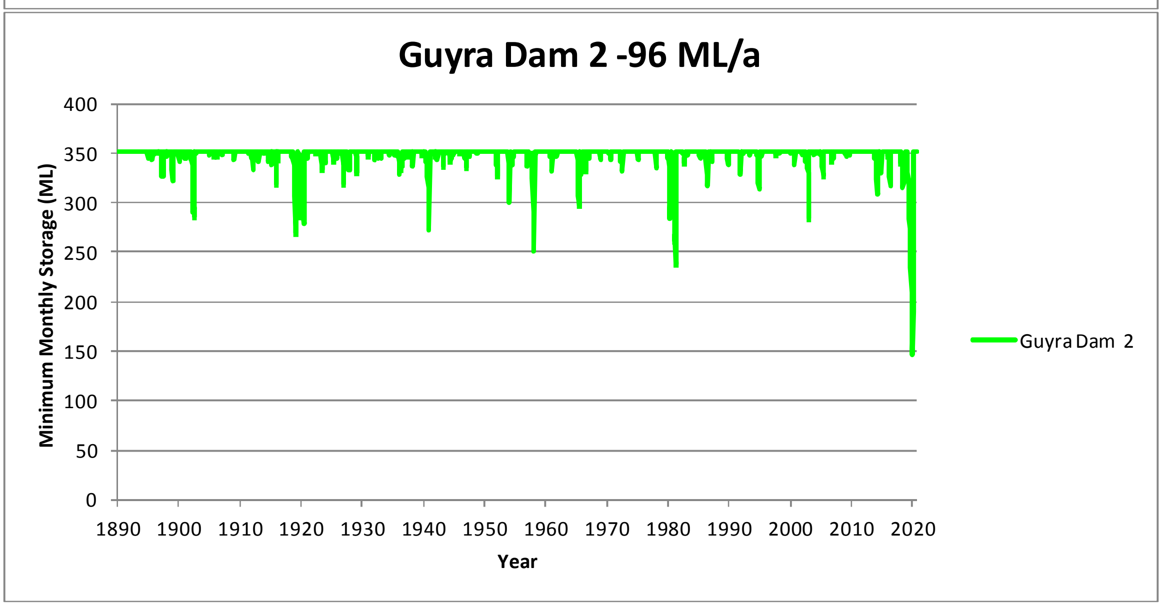
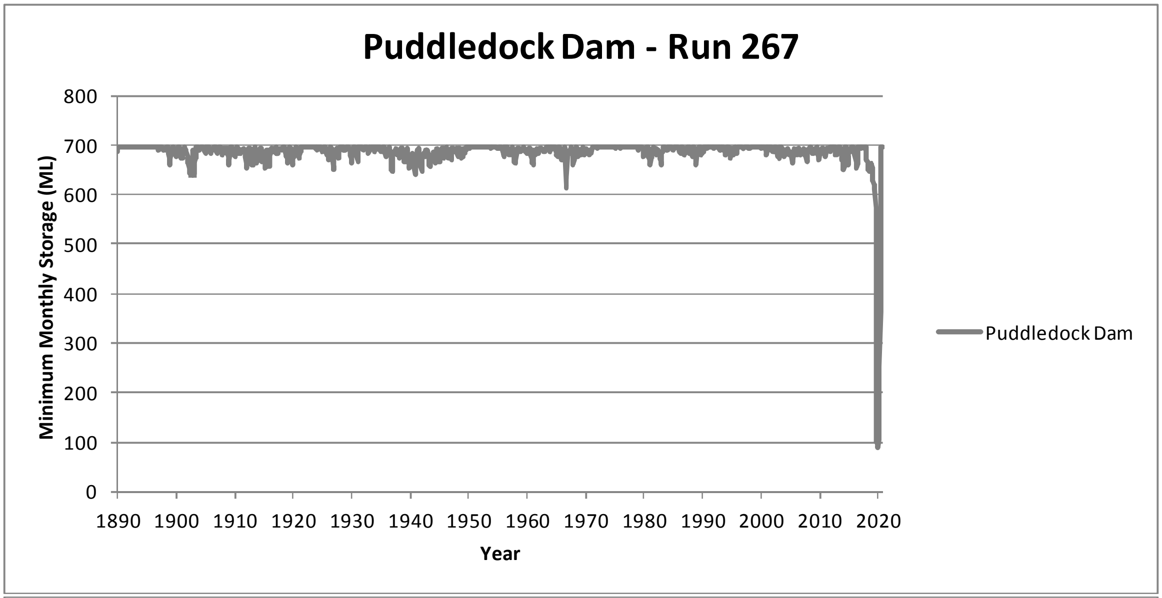
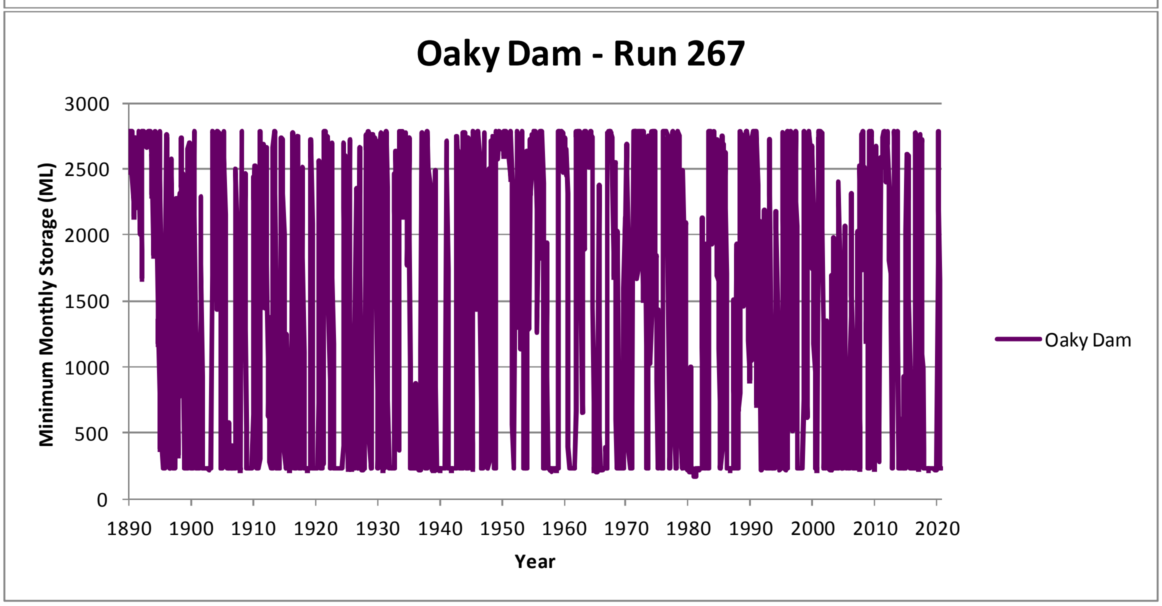


Figure 10c: Storage Behaviour- Run 267





Attachment A – Model Results for 15 GCMs and corresponding Historic Base

Note that in each case shown on the following pages the data is based on modelled flow information (from a data base of daily rainfall and daily evapotranspiration) and not observed flow data. The following data is used to adjust the best estimates of the historic climate secure yields given in Table 1 and 2 in accordance with the DPE Water guidelines.

System with Existing Malpas Dam (Run 261r Conditions):

Armidale, Run 261rCC F:\Results\Armidale\Data\13-11-2022\ClimateChange_Oaky\Armidale_

Time: 02/06/2023 12:29:29 AM

	Run	Storage Capacity	Secure Yield	% Restricted at	Restricted % of duration	Restricted % of years	Critical Drought Start	Critical Drought End
HISTORICAL	1	15742	5945	75	1.76	8.70	28/10/1901	22/11/1902
	2	15742	5945	70	1.02	6.09	16/03/1939	29/12/1940
	3	15742	5945	70	0.98	5.22	30/08/1901	22/11/1902
	4	15742	5945	65	1.29	7.83	02/08/1900	22/11/1902
	5	15742	5945	60	1.59	7.83	01/08/1900	22/11/1902
	6	15742	5945	75	2.11	9.57	30/08/1901	22/11/1902
	7	15742	5945	70	2.14	9.57	30/08/1901	22/11/1902
MEDIAN	8	15742	5945	70	1.46	6.96	27/06/1937	29/12/1940
	9	15742	5945	70	2.98	9.57	03/08/1900	28/11/1902
	10	15742	5945	70	1.60	7.83	06/08/1900	28/11/1902
	11	15742	5945	75	0.75	5.22	28/10/1901	22/11/1902
	12	15742	5945	75	1.45	8.70	01/09/1901	22/11/1902
	13	15742	5945	70	2.06	8.70	30/08/1901	28/11/1902
	14	15742	5945	65	1.82	8.70	05/08/1900	28/11/1902
LOWEST	15	15742	5945	70	1.20	6.09	27/06/1937	29/12/1940
	16	15742	5945	75	1.79	9.57	28/10/1901	22/11/1902
10/15/25	15	15742	5945	75	2.02	10.43	27/06/1937	29/12/1940

System with Raised Malpas Dam (Run 266 Conditions):

Armidale, Run 266CC F:\Results\Armidale\Data\13-11-2022\ClimateChange_Oaky\Armidale_

Time: 06/06/2023 11:13:28 PM

					Restricted		Critical Drought	
	Run	Storage Capacity	Secure Yield	% Restricted at	% of duration	% of years	Start	End
HISTORICAL	1	31106	10713	50	5.00	9.57	20/01/1935	29/12/1940
	2	31106	9956	50	5.00	8.70	20/01/1935	29/12/1940
	3	31106	9928	45	3.41	6.09	19/01/1935	29/12/1940
	4	31106	8430	45	3.94	6.09	19/01/1935	29/12/1940
LOWEST	5	31106	7794	45	4.88	8.70	19/01/1935	29/12/1940
	6	31106	9940	45	3.98	7.83	19/01/1935	29/12/1940
	7	31106	9319	45	4.74	6.96	19/01/1935	29/12/1940
	8	31106	9317	50	4.87	6.96	19/01/1935	29/12/1940
	9	31106	8571	45	4.71	6.09	19/01/1935	29/12/1940
	10	31106	9858	50	4.15	8.70	26/01/1935	29/12/1940
	11	31106	11709	50	4.87	9.57	21/01/1935	29/12/1940
	12	31106	10788	50	5.00	9.57	21/01/1935	29/12/1940
	13	31106	9235	45	4.17	6.09	19/01/1935	29/12/1940
	14	31106	8839	45	4.20	6.09	19/01/1935	29/12/1940
MEDIAN	15	31106	9600	50	4.90	7.83	19/01/1935	29/12/1940
	16	31106	9896	45	3.71	6.09	19/01/1935	29/12/1940
10/15/25	5	31106	8895	35	6.29	13.91	11/02/1895	28/11/1902

System with Raised Malpas Dam (Run 267 Conditions):

Armidale, Run 267CC F:\Results\Armidale\Data\13-11-2022\ClimateChange_Oaky\Armidale_
Time: 06/06/2023 1:09:12 AM

					Restricted		Critical Drought	
		Storage	Secure	% Restricted	% of	% of		
	Run	Capacity	Yield	at	duration	years	Start	End
HISTORICAL	1	31106	12604	50	4.24	9.57	21/01/1935	30/12/1940
	2	31106	11978	50	4.98	9.57	20/01/1935	30/12/1940
	3	31106	11899	50	4.35	9.57	19/01/1935	29/12/1940
	4	31106	9908	50	4.55	8.70	19/01/1935	29/12/1940
LOWEST	5	31106	9059	45	3.93	8.70	25/02/1934	29/12/1940
	6	31106	11833	50	4.95	9.57	19/01/1935	29/12/1940
	7	31106	10557	45	3.03	8.70	19/01/1935	30/12/1940
	8	31106	11135	50	4.72	9.57	19/01/1935	29/12/1940
	9	31106	9909	50	4.91	9.57	19/01/1935	29/12/1940
MEDIAN	10	31106	11188	50	3.60	8.70	21/02/1935	29/12/1940
	11	31106	13864	50	2.35	9.57	26/01/1935	29/12/1940
	12	31106	12587	50	3.66	9.57	21/01/1935	30/12/1940
	13	31106	10790	50	5.00	9.57	19/01/1935	29/12/1940
	14	31106	9946	45	3.24	7.83	19/01/1935	30/12/1940
	15	31106	11442	50	4.33	9.57	19/01/1935	29/12/1940
	16	31106	12015	50	4.67	9.57	19/01/1935	29/12/1940
10/15/25	5	31106	10347	40	6.87	14.78	25/02/1934	29/12/1940

NUWS

NSW Urban Water Services

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MEMORANDUM

TO	Glenn Fernandes Director ï Water Resources Management NSW Public Works
CC	
FROM	Peter Cloke, Principal Hydrologist
DATE	19 June 2023
SUBJECT	Armidale Yield Study: Progress Report (13) ï Addition of Oaky Dam Optimisation of Transfers **DRAFT**

With reference to your email of 13 June 2023 and earlier discussions, additional modelling requested from that reported in Progress Report 12 of 9 June 2023 has been undertaken towards optimising transfer capacities with the system including Oaky Dam. Initial results are reported herein.

Summary

The results for the additional modelling are provided in Table 1 and follow on directly from the results provided in Progress Report 12. It also includes the climate change modelling results for Cases 263r and 265 that were not previously undertaken.

It is noted the secure yield estimates are dependent on the operating rules, data and assumptions as discussed herein and or in the previous 12 Progress Reports (30/3/2020, 26/5/2020, 18/9/2020, 19/10/2020,16/4/2021,22/04/2021,30/04/2021,8/6/2021,7/9/2021,15/11/2022& 9/6/2023).

.

Table 1: Secure Yield Results (excludes 755 ML/a provided to Guyra) Proposed Oaky Dam Additional Source

Run No	Transfer ML/d												Historic Climate Secure Yield ML/a	Secure Yield with 1°C Climate Warming ML/a *(see Attach-ment A for GCM results)*	Historic Climate Critical Drought	
	Oaky Dam to Armidale WTP			Oaky Dam to Malpas Dam via Armidale WTP			Malpas Dam to Armidale WTP			Malpas Dam to Gurya WTP						
	Cap-acity	Max	Ave	Cap-acity	Max	Ave	Cap-acity	Max	Ave	Cap-acity **	Max	Ave			From	To
With Existing Malpas Dam and 2.78 GL Oaky Dam:																
263r	37.8	22	14.75	17.3	17.3	3.80	22	22	1.46	5	2.76	1.80	**5945***	**5945***	4/08/2017	15/01/2020
265	37.8	24.26	15.94	17.3	17.3	3.84	**100*** **	24.26	1.94	5	2.76	1.80	**6557**	**5176**	25/07/2017	15/01/2020
With Existing Malpas Dam and 0.75 GL Oaky Dam:																
271	37.8	22.57	12.62	17.3	17.3	3.56	**100*** **	22.57	4.00	5	2.76	1.80	**6100**	**4946**	4/08/2017	15/01/2020
With Malpas Dam FSL Raised by 6.5 m and 0.75 GL Oaky Dam:																
272	37.8	35.67	17.52	17.3	17.3	3.27	**100*** **	35.67	17.52	5	2.76	1.80	**9640**	**7788**	22/07/2017	15/01/2020

** The specified 22 ML/d transfer rate from Malpas Dam to Armidale was constraining the yield*

*** Capacity in model was set to 5 ML/d to so that would not constrain secure yield of system*

**** Transfer from Malpas Dam to Armidale WTP Set to 100 ML/d so as to be unconstrained*

Oaky 1-1 Flow Series Used

Oaky Dam Gross Storage with Dead storage 0.235 GL

Malpas Dam conditions based on Run 202 (*which includes Guyra, Malpas, & Puddledock Dams*) as detailed in Progress Report 4 of 19 October 2020

No Release Required from Malpas Dam when less than 6746 ML (except up to 0.2 ML/d subject to inflow)

EFR rules for Oaky Dam :

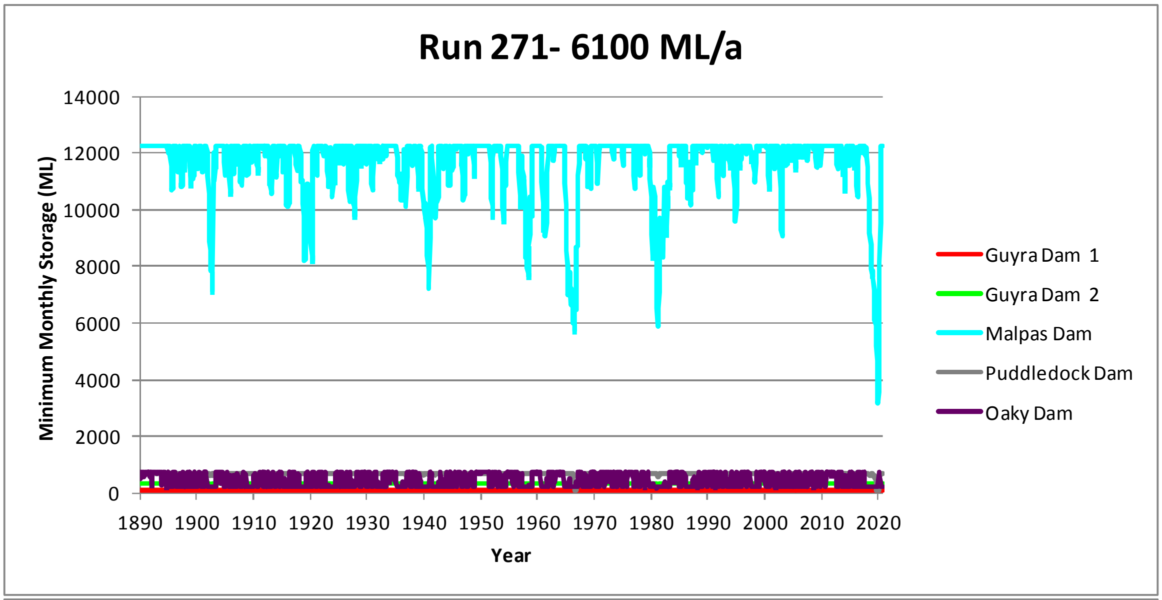
1. For January to July can only store when flow above 90% ile
2. For August to December can only store when flow above 80% ile
3. Can only extract 30% of the flow above the % ile flows.
4. If Malpas Dam less than 60% full then above 90% ile is relaxed to 95%ile and 80% ile relaxed to 90% ile

Note : % ile flows based on flows in each month (ie twelve monthly values for the year)

Storage Behaviour

Figures 1 and 2 provide storage behaviour diagrams for the two new cases (271 & 272)of the modelled storage behaviour for the two cases meeting their historic secure yields for a repeat of the modelled historic climate. It is noted the apparent reserve storage allows for much worse droughts to occur or is a result of the identified transfer constraints.

Figure 1: Storage Behaviour- Run 271



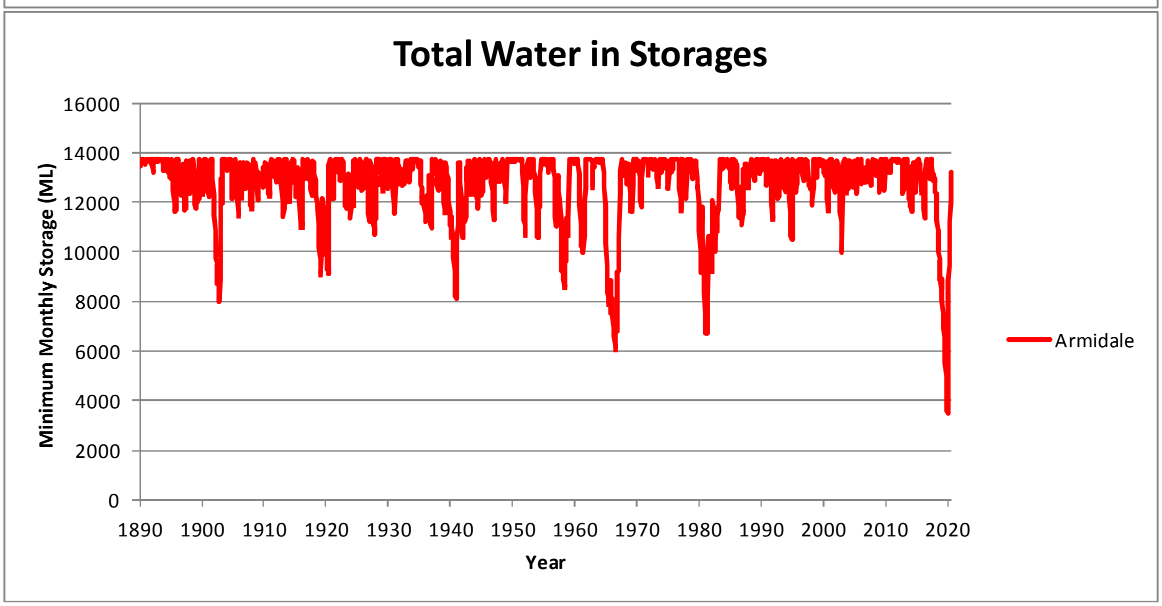
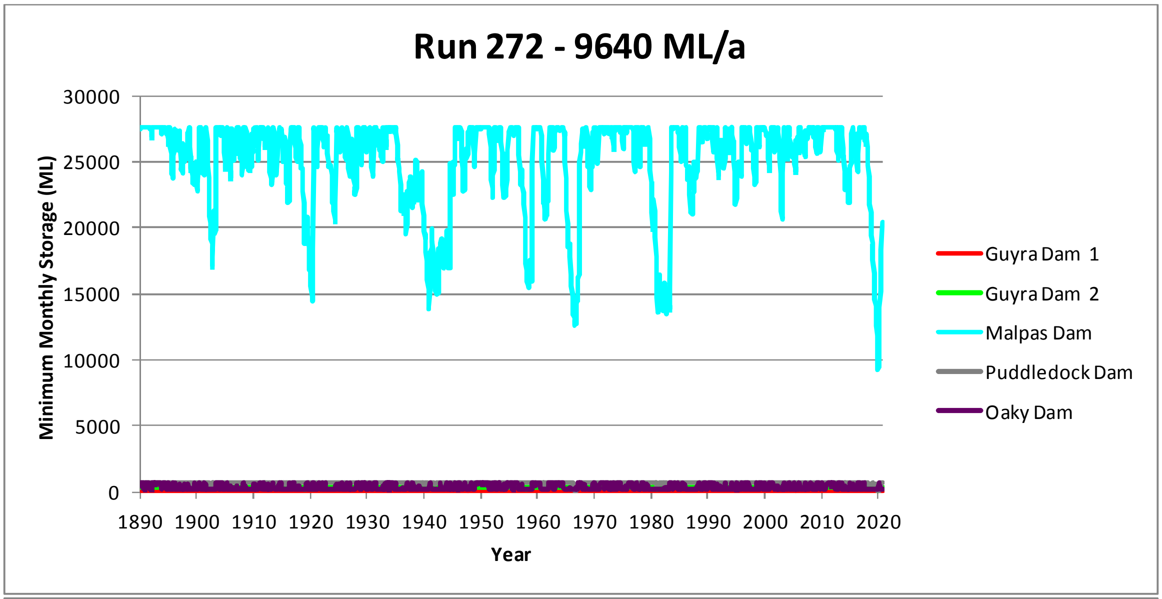
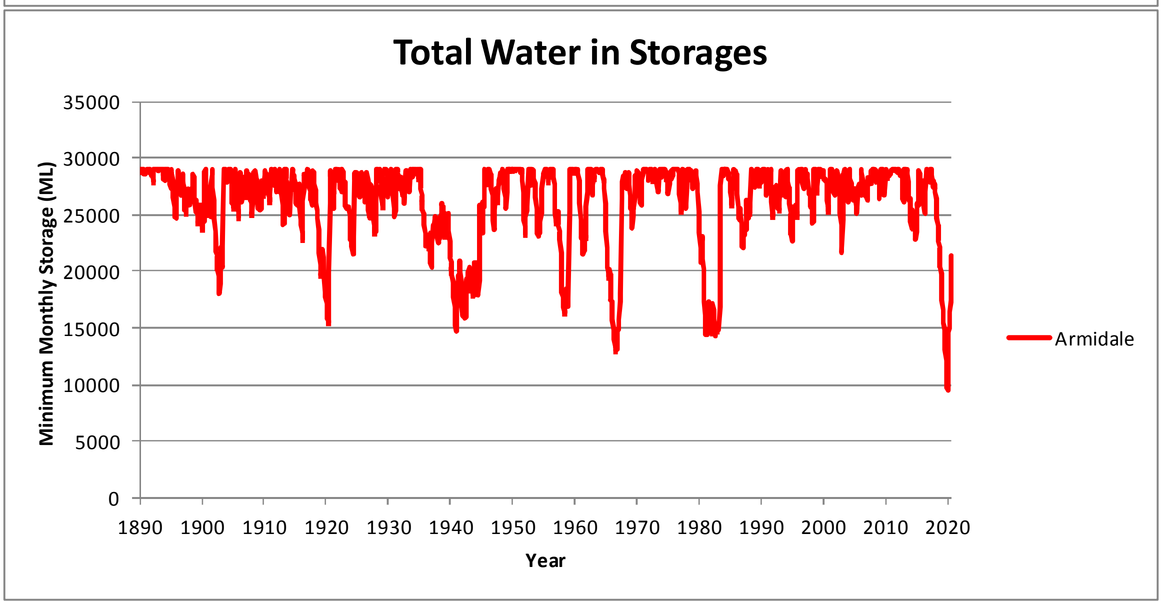


Figure 2: Storage Behaviour- Run 272





Attachment A – Model Results for 15 GCMs and corresponding Historic Base

Note that in each case shown on the following pages the data is based on modelled flow information (from a data base of daily rainfall and daily evapotranspiration) and not observed flow data. The following data is used to adjust the best estimates of the historic climate secure yields given in Table 1 and 2 in accordance with the DPE Water guidelines.

System with Existing Malpas Dam with 2.78 GL Oaky Dam (Run 263r Conditions):

Armidale, Run 263rCC F:\Results\Armidale\Data\13-11-2022\ClimateChange_Oaky\Armidale_

Time: 14/06/2023 3:07:31 AM					Restricted		Critical Drought	
	Run	Storage Capacity	Secure Yield	% Restricted at	% of duration	% of years	Start	End
HISTORICAL	1	15742	5945	75	1.84	8.70	01/09/1901	22/11/1902
	2	15742	5945	70	1.31	6.96	30/08/1901	22/11/1902
	3	15742	5945	70	1.22	7.83	30/08/1901	22/11/1902
	4	15742	5945	70	2.65	9.57	02/08/1900	22/11/1902
	5	15742	5945	60	1.77	7.83	01/08/1900	22/11/1902
	6	15742	5945	70	1.06	6.96	30/08/1901	22/11/1902
	7	15742	5945	65	1.35	6.96	05/08/1900	22/11/1902
MEDIAN	8	15742	5945	70	1.69	7.83	02/08/1900	22/11/1902
	9	15742	5945	65	1.83	6.96	03/08/1900	22/11/1902
	10	15742	5945	70	1.93	8.70	06/08/1900	22/11/1902
	11	15742	5945	75	1.21	7.83	02/09/1901	22/11/1902
	12	15742	5945	70	0.90	6.09	01/09/1901	22/11/1902
	13	15742	5945	70	1.95	9.57	05/08/1900	28/11/1902
	14	15742	5945	65	2.03	7.83	05/08/1900	22/11/1902
LOWEST	15	15742	5945	70	1.60	7.83	04/08/1900	22/11/1902
	16	15742	5945	75	2.11	9.57	04/08/1900	22/11/1902
10/15/25	15	15742	5945	75	2.39	10.43	04/08/1900	22/11/1902

System with Existing Malpas Dam with 2.78 GL Oaky Dam and unconstrained transfer Malpas to Armidale (Run 265 Conditions):

Armidale, Run 265CC F:\Results\Armidale\Data\13-11-2022\ClimateChange_Oaky\Armidale_

Time: 14/06/2023 11:53:14 AM

					Restricted		Critical Drought	
	Run	Storage Capacity	Secure Yield	% Restricted at	% of duration	% of years	Start	End
HISTORICAL	1	15742	9861	55	2.71	9.57	26/06/1938	29/12/1940
	2	15742	9194	55	2.88	9.57	26/06/1938	29/12/1940
	3	15742	9394	55	2.89	9.57	26/06/1938	29/12/1940
	4	15742	7605	55	2.46	9.57	02/08/1900	28/11/1902
LOWEST	5	15742	6682	50	1.18	5.22	01/08/1900	28/11/1902
	6	15742	9244	55	2.80	9.57	05/08/1900	28/11/1902
	7	15742	8026	55	2.64	9.57	05/08/1900	28/11/1902
MEDIAN	8	15742	8563	55	2.48	9.57	26/06/1938	29/12/1940
	9	15742	7645	50	1.66	7.83	03/08/1900	28/11/1902
	10	15742	8458	55	2.78	9.57	06/08/1900	28/11/1902
	11	15742	10428	55	1.93	8.70	02/09/1901	28/11/1902
	12	15742	9784	55	2.30	8.70	26/06/1938	29/12/1940
	13	15742	8275	55	2.76	9.57	05/08/1900	28/11/1902
	14	15742	7538	50	1.88	9.57	05/08/1900	28/11/1902
	15	15742	8878	55	2.61	9.57	21/02/1935	29/12/1940
	16	15742	9221	55	2.34	9.57	23/02/1938	29/12/1940
10/15/25	5	15742	7784	50	3.47	14.78	01/08/1900	28/11/1902

System with Existing Malpas Dam with 0.75 GL Oaky Dam and unconstrained transfer Malpas to Armidale (Run 271 Conditions):

Armidale, Run 271CC F:\Results\Armidale\Data\13-11-2022\ClimateChange_Oaky\Armidale_

Time: 15/06/2023 3:55:26 AM

					Restricted		Critical Drought	
	Run	Storage Capacity	Secure Yield	% Restricted at	% of duration	% of years	Start	End
HISTORICAL	1	13712	8969	55	2.96	9.57	23/05/1979	01/04/1981
	2	13712	8117	55	2.53	9.57	21/06/1978	01/04/1981
	3	13712	8368	55	2.84	9.57	24/05/1979	01/04/1981
	4	13712	7114	55	3.19	9.57	15/01/1935	29/12/1940
LOWEST	5	13712	6594	50	2.28	8.70	19/01/1935	29/12/1940
	6	13712	8460	55	2.97	9.57	24/05/1979	01/04/1981
	7	13712	7513	55	2.78	9.57	21/06/1978	01/04/1981
MEDIAN	8	13712	8045	55	3.05	9.57	21/05/1978	01/04/1981
	9	13712	7039	55	3.25	9.57	21/06/1978	01/04/1981
	10	13712	7774	55	2.87	9.57	05/03/1979	31/01/1981
	11	13712	9577	55	2.45	7.83	23/06/1979	31/01/1981
	12	13712	8874	55	2.71	9.57	29/05/1979	01/04/1981
	13	13712	7699	55	3.51	9.57	21/05/1978	01/04/1981
	14	13712	7155	55	3.61	9.57	21/05/1978	01/04/1981
	15	13712	8317	55	3.10	9.57	22/05/1978	01/04/1981
	16	13712	8571	55	3.09	9.57	08/02/1979	01/04/1981
10/15/25	5	13712	7272	45	3.38	14.78	19/01/1935	29/12/1940

System with Raised Malpas Dam with 0.75 GL Oaky Dam and unconstrained transfer Malpas to Armidale (Run 272 Conditions):

Armidale, Run 272CC F:\Results\Armidale\Data\13-11-2022\ClimateChange_Oaky\Armidale_

Time: 15/06/2023 9:13:10 PM

					Restricted		Critical Drought	
	Run	Storage Capacity	Secure Yield	% Restricted at	% of duration	% of years	Start	End
HISTORICAL	1	29076	11142	50	4.99	8.70	21/01/1935	29/12/1940
	2	29076	10404	45	3.94	7.83	21/02/1935	29/12/1940
	3	29076	10321	50	4.99	9.57	19/01/1935	29/12/1940
	4	29076	8549	45	3.93	7.83	19/01/1935	29/12/1940
LOWEST	5	29076	7710	45	5.00	7.83	19/01/1935	29/12/1940
	6	29076	10190	45	3.68	6.96	19/01/1935	29/12/1940
	7	29076	9372	45	4.67	8.70	19/01/1935	29/12/1940
	8	29076	9672	50	5.00	7.83	19/01/1935	29/12/1940
	9	29076	8602	45	4.88	8.70	19/01/1935	29/12/1940
MEDIAN	10	29076	9982	50	4.91	7.83	21/02/1935	29/12/1940
	11	29076	12549	50	5.00	9.57	26/01/1935	29/12/1940
	12	29076	11162	50	5.00	9.57	21/01/1935	29/12/1940
	13	29076	9405	45	4.49	7.83	19/01/1935	29/12/1940
	14	29076	8751	45	4.99	7.83	19/01/1935	29/12/1940
	15	29076	10008	50	5.00	8.70	21/02/1935	29/12/1940
	16	29076	10444	50	5.00	8.70	19/01/1935	29/12/1940
10/15/25	5	29076	9002	40	8.35	14.78	19/01/1935	29/12/1940

NUWS

NSW Urban Water Services

377 Sussex Street SYDNEY NSW 2000
PO Box 20078 WORLD SQUARE NSW 2002
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ABN 86 163 223 667

MEMORANDUM

TO	Glenn Fernandes Director ï Water Resources Management NSW Public Works
CC	
FROM	Peter Cloke, Principal Hydrologist
DATE	26 March 2024
SUBJECT	Armidale Yield Study: Progress Report (14) ï Addition of Oaky Dam Optimisation of Transfers **DRAFT**

With reference to your email of 22 March 2024 the previous model Run 265 was rerun but with no transfers from Oaky Dam to Malpas Dam via Armidale WTP. The results are reported herein.

Summary

The results for the additional modelling are provided in Table 1 and follow on directly from the results provided in Progress Report 13 and compares them with the results from Run 265.

Without the transfer from Oaky Dam to Malpas via Armidale WTP, the secure yield increased slightly (about 3%). The reason for this unexpected result was explored. It was found water was transferred[1] from Oaky Dam around the start of the critical drought and then Malpas Dam spilled so the water was lost and would have been better kept in Oaky Dam. An additional run was undertaken to only transfer water if Malpas Dam was less than 70% full. This resulted in the same secure yield as without the transfer from Oaky Dam to Malpas Dam occurring. Table 1 also includes the climate change modelling results for the requested new case Run 300.

It is noted the secure yield estimates are dependent on the operating rules, data and assumptions as discussed herein and or in the previous 13 Progress Reports (30/3/2020, 26/5/2020, 18/9/2020, 19/10/2020,16/4/2021,22/04/2021,30/04/2021,8/6/2021,7/9/2021,15/11/2022, 9/6/2023 & 19/6/2023).

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1. *The non optimised rule was to transfer water to Malpas Dam from Oaky Dam via Armidale WTP whenever Malpas Dam not full.*

Table 1: Secure Yield Results (excludes 755 ML/a provided to Guyra) Proposed Oaky Dam Additional Source

Run No	Transfer ML/d												Historic Climate Secure Yield ML/a	Secure Yield with 1°C Climate Warming ML/a *(see Attach-ment A for GCM results)*	Historic Climate Critical Drought	
	Oaky Dam to Armidale WTP			Oaky Dam to Malpas Dam via Armidale WTP			Malpas Dam to Armidale WTP			Malpas Dam to Gurya WTP						
	Cap-acity	Max	Ave	Cap-acity	Max	Ave	Cap-acity	Max	Ave	Cap-acity **	Max	Ave			From	To
With Existing Malpas Dam and 2.78 GL Oaky Dam:																
265	37.8	24.26	15.94	17.3	17.3	3.84	**100*** **	24.26	1.94	5	2.76	1.80	**6557**	**5176**	25/07/2017	15/01/2020
With Existing Malpas Dam and 2.78 GL Oaky Dam and No transfer From Oaky Dam to Malpas Dam Armidale WTP :																
300	37.8	25.03	17.55	0	0	0	**100*** **	25.03	0.87	5	2.76	1.80	**6766**	**5493**	28/07/2017	15/01/2020
With Existing Malpas Dam and 2.78 GL Oaky Dam and transfer from Oaky Dam to Malpas Dam Armidale WTP when Malpas Dam less than 70%full:																
301	37.8	25.03	17.49	17.3	17.3	0.10	**100*** **	25.03	0.93	5	2.76	1.80	**6766**	*Not Modelled*	28/07/2017	15/01/2020

*** Capacity in model was set to 5 ML/d to so that would not constrain secure yield of system*

**** Transfer from Malpas Dam to Armidale WTP Set to 100 ML/d so as to be unconstrained*

Oaky 1-1 Flow Series Used

Oaky Dam Gross Storage 2.78 GL with Dead storage 0.235 GL

Malpas Dam conditions based on Run 202 (*which includes Guyra, Malpas, & Puddledock Dams*) as detailed in Progress Report 4 of 19 October 2020

No Release Required from Malpas Dam when less than 6746 ML (except up to 0.2 ML/d subject to inflow)

EFR rules for Oaky Dam :

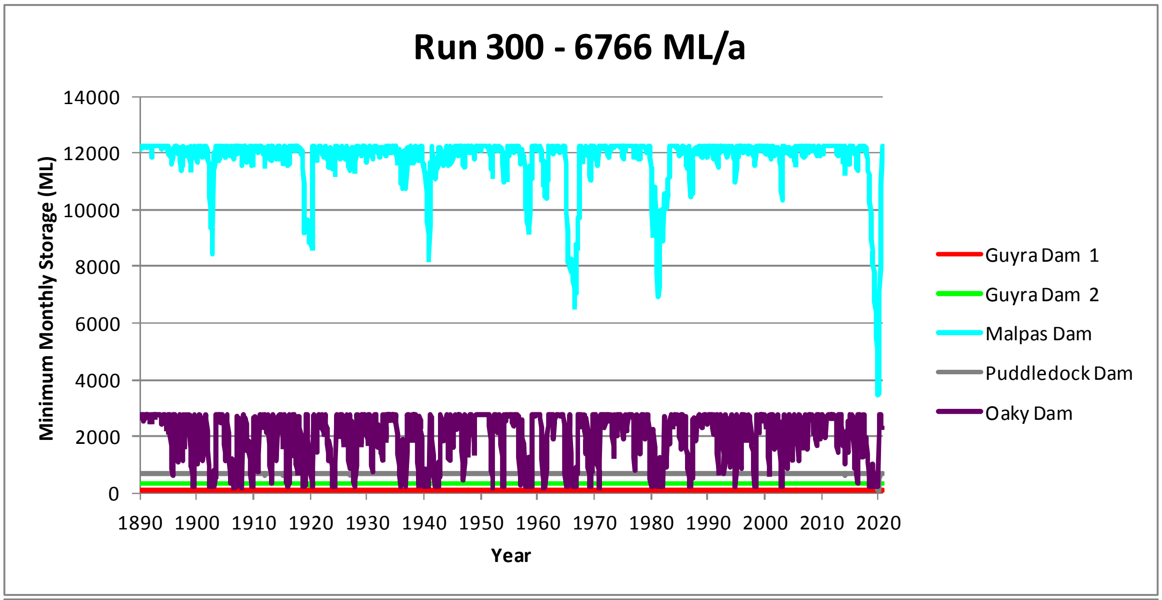
1. For January to July can only store when flow above 90% ile
2. For August to December can only store when flow above 80% ile
3. Can only extract 30% of the flow above the % ile flows.
4. If Malpas Dam less than 60% full then above 90% ile is relaxed to 95%ile and 80% ile relaxed to 90% ile

Note : % ile flows based on flows in each month (ie twelve monthly values for the year)

Storage Behaviour

Figures 1 and 2 provide storage behaviour diagrams for the two new cases (300 & 301)of the modelled storage behaviour for the two cases meeting their historic secure yields for a repeat of the modelled historic climate. It is noted the apparent reserve storage allows for much worse droughts to occur or is a result of the identified transfer constraints.

Figure 1: Storage Behaviour- Run 300



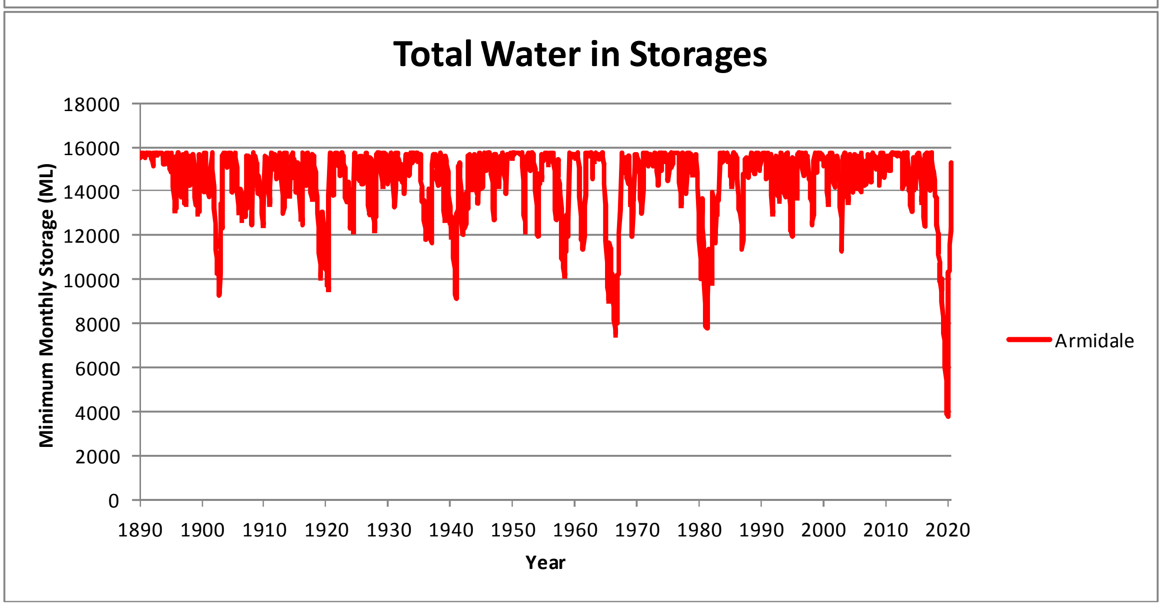
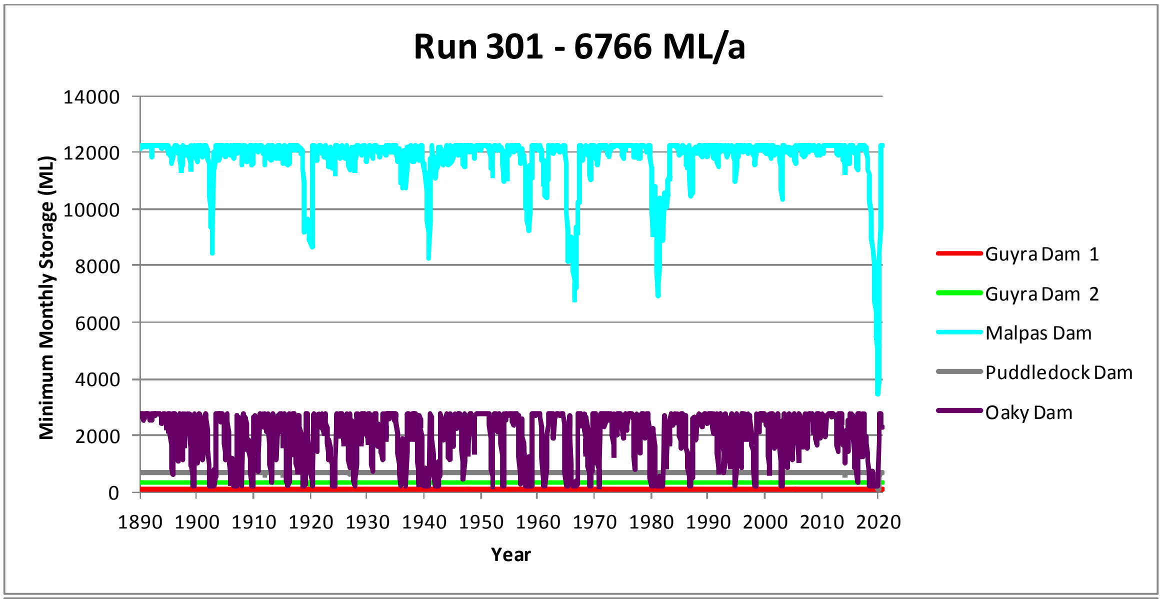
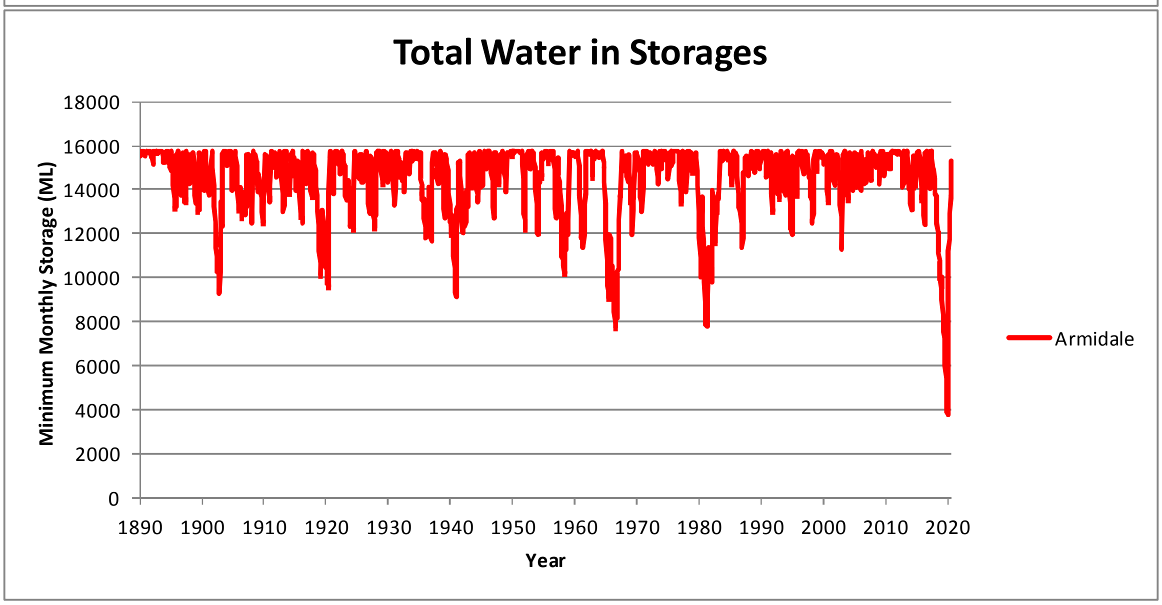


Figure 2: Storage Behaviour- Run 301





Attachment A – Model Results for 15 GCMs and corresponding Historic Base

Note that in each case shown on the following pages the data is based on modelled flow information (from a data base of daily rainfall and daily evapotranspiration) and not observed flow data. The following data is used to adjust the best estimates of the historic climate secure yields given in Table 1 in accordance with the DPE Water guidelines.

System with Existing Malpas Dam with 2.78 GL Oaky Dam (Run 300 Conditions – No transfer from Oaky Dam To Malpas Dam via Armidale WTP):

Armidale, Run 300CC			F:\Results\Armidale\Data\13-11-2022\ClimateChange_Oaky\Armidale_					
Time: 24/03/2024 11:52:35 PM					Restricted		Critical Drought	
	Run	Storage Capacity	Secure Yield	% Restricted at	% of duration	% of years	Start	End
HISTORICAL	1	15742	9608	55	2.56	7.83	22/05/1978	01/04/1981
	2	15742	9202	55	3.02	9.57	20/01/1935	29/12/1940
	3	15742	9232	55	2.75	9.57	19/01/1935	29/12/1940
	4	15742	7600	50	1.71	6.96	19/01/1935	29/12/1940
LOWEST	5	15742	6966	50	2.28	9.57	19/01/1935	29/12/1940
	6	15742	9160	55	2.61	9.57	22/05/1978	01/04/1981
	7	15742	8126	50	1.69	6.96	05/08/1900	28/11/1902
MEDIAN	8	15742	8383	50	1.26	4.35	02/08/1900	22/11/1902
	9	15742	7633	50	1.95	6.96	19/01/1935	29/12/1940
	10	15742	8271	55	2.59	9.57	06/08/1900	28/11/1902
	11	15742	10593	55	2.64	8.70	02/09/1901	28/11/1902
	12	15742	9993	55	2.98	9.57	21/01/1935	29/12/1940
	13	15742	8107	55	2.45	9.57	05/08/1900	28/11/1902
	14	15742	7550	50	1.72	5.22	05/08/1900	28/11/1902
	15	15742	8893	55	2.85	9.57	19/01/1935	29/12/1940
	16	15742	9147	55	2.47	9.57	19/01/1935	29/12/1940
10/15/25	5	15742	7801	45	3.09	14.78	19/01/1935	29/12/1940

working together to ensure water supply security

NUWS

NSW Urban Water Services

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PO Box 20078 WORLD SQUARE NSW 2002

ABN 86 163 223 667

MEMORANDUM

TO	Glenn Fernandes Director ï Water Resources Management NSW Public Works
CC	
FROM	Peter Cloke, Principal Hydrologist
DATE	27 August 2024
SUBJECT	Armidale Yield Study: Progress Report (14) ï Varying Levels of Service **DRAFT**

With reference to your email of 7 and 21 August 2024 the requested runs with different ‘*Levels of Service’* (10/20/20 instead of 5/10/10) have been undertaken for the nominated cases and the results are reported herein.

Results

The results for the additional modelling are provided in Table 1 and are compared with the previous results for the same conditions but with the 5/10/10 rule.

Table 2 provide the results of the duration and frequency of restrictions that occurred for modelling the cases for a repeat of the historic climate which show that while the 10/20/20 rule is applied the frequency and duration of restrictions are not as severe as a consequence of having to satisfy all three conditions.

It is noted when applying the adjustment for climate change with use of the 5/10/10 rule in the *Guidelines* consideration is given to the result from the lowest GCM with a 10/15/25 rule. Thus with use of the 10/10/20 rule it can be argued that this adjustment should be based on 10/20/25 or a 15/25/35 rule. For sensitivity purposes both rules were tested.

It is noted the secure yield estimates are dependent on the operating rules, data and assumptions as discussed herein and or in the previous 14 Progress Reports (30/3/2020, 26/5/2020, 18/9/2020, 19/10/2020,16/4/2021,22/04/2021,30/04/2021,8/6/2021,7/9/2021,15/11/2022, 9/6/2023, 19/6/2023 & 26/3/2024).

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Table 1: Secure Yield Results

Run No	Transfer ML/d *(From Historic Climate Modelled Cases)* Oaky Dam to Armidale WTP			Oaky Dam to Malpas Dam via Armidale WTP			Malpas Dam to Armidale WTP			Malpas Dam to Gurya WTP			Historic Climate Secure Yield ML/a	Secure Yield with 1°C Climate Warming ML/a *(see Attach-ment A for new GCM results)*	Historic Climate Critical Drought	
	Cap-acity	Max	Ave	Cap-acity	Max	Ave	Cap-acity	Max	Ave	Cap-acity **	Max	Ave			From	To
Guyra Dams Only:																
200	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	**175 *(5/10/10)***	**96**	15/01/2018	15/01/2020
302	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	**222 *(10/20/20)***	**102 – 118******	15/01/2018	15/01/2020
Malpas Dam FSL Raised by 6.5 m (plus Guyra, Puddledock and Gara Dams, No Oaky Dam):																
207	n/a	n/a	n/a	n/a	n/a	n/a	**26**	20.88	14.96	n/a	n/a	n/a	**5593* *(10/10/10)***	**3956**	20/01/1935	30/12/1940
303	n/a	n/a	n/a	n/a	n/a	n/a	**26**	24.33	17.09	n/a	n/a	n/a	**6517* *(10/20/20)***	**4107 – 4538******	20/01/1935	30/12/1940
With Existing Malpas Dam and 2.78 GL Oaky Dam and No transfer from Oaky Dam to Malpas Dam Armidale WTP (Secure Yield Excludes 755 ML/a Demand Supplied to Guyra):																
300	37.8	25.03	17.55	0	0	0	**100*****	25.03	0.87	5	2.76	1.80	**6766**	**5493**	28/07/2017	15/01/2020
304	37.8	29.68	20.03	0	0	0	**100*****	29.68	1.60	5	2.24	1.46	**8021**	**5790 – 6405******	24/07/2017	15/01/2020
Malpas Dam FSL Raised by 6.5 m plus Oaky Dam (plus Guyra, Puddledock and Gara Dams) (Secure Yield Excludes 755 ML/a Demand Supplied to Guyra) :																
266	17.8	17.8	17.02	17.3	6.81	0.007	**100*****	36.02	9.50	5	2.76	1.80	**9736**	**8083**	22/07/2017	15/01/2020
305	16.5	16.5	16.0	16.5	5.02	0.018	**100*****	41.71	14.09	5	2.24	1.46	**11272**	**8408 – 9000******	20/01/1935	29/12/1940

** Excludes Guyra Dams secure yield. The demand on the Guyra Dams Fixed at corresponding equivalent Guyra Dam Secure Yield ..*
*** Capacity in model was set to 5 ML/d to so that would not constrain secure yield of system*
**** Transfer from Malpas Dam to Armidale WTP Set to 100 ML/d so as to be unconstrained*
*****Depends on if use 10/20/25 or 15/25/35 for lowest GCM (Higher result occurs with 15/25/35)*
Oaky 1-1 Flow Series Used
Oaky Dam Gross Storage 2.78 GL with Dead storage 0.235 GL
Malpas Dam conditions based on Run 207 (*which includes Guyra, Malpas, & Puddledock Dams*) as detailed in Progress Report 4 of 19 October 2020
No Release Required from Malpas Dam when less than 6746 ML (except up to 0.2 ML/d subject to inflow)
EFR rules for Oaky Dam : 1. For January to July can only store when flow above 90% ile 2. For August to December can only store when flow above 80% ile 3. Can only extract 30% of the flow above the % ile flows. 4. If Malpas Dam less than 60% full then above 90% ile is relaxed to 95%ile and 80% ile relaxed to 90% ile **Note : % ile flows based on flows in each month (ie twelve monthly values for the year)**

Table 2: Historic Climate Secure Yield Restriction Results

Run No	Case	Service Level Rule	Historic Climate Secure Yield ML/a	Restrictions			Critical Drought	
				Applied at storage (% full)	Duration (%)	% of Years	From	To
200	Guyra Dams Only	**5/10/10**	**175**	70	1.38	7.58	15/01/2018	15/01/2020
302		**10/20/20**	**222**	75	3.40	17.42	15/01/2018	15/01/2020
207	Malpas Dam FSL Raised by 6.5m (No Oaky Dam)	**5/10/10**	**5593**[1]	50	5.00	7.58	20/01/1935	30/12/1940
303		**10/20/20**	**6517**[2]	50	8.62	13.64	20/01/1935	30/12/1940
300	Existing Malpas Dam With Oaky Dam	**5/10/10**	**6766**[3]	70	4.65	9.85	28/07/2017	15/01/2020
304		**10/20/20**	**8021**[3]	70	6.91	18.94	28/07/2017	15/01/2020
266	Malpas Dam FSL Raised by 6.5m plus Oaky Dam	**5/10/10**	**9736**[3]	55	3.20	9.85	22/07/2017	15/01/2020
305		**10/20/20**	**11272**[3]	55	10.00	17.42	20/01/1935	29/12/1940

Refer to Table 1 for Details of Conditions

1. Excludes 175 ML/a met from Guyra Dams
2. Excludes 222 ML/a met from Guyra Dams
3. Excludes 755 ML/a supplied to Guyra

Storage Behaviour

Figures 1 to 3 provide storage behaviour diagrams for the three main new cases (303, 304 & 305) of the modelled storage behaviour for the three cases meeting their historic secure yields for a repeat of the modelled historic climate. It is noted the apparent reserve storage allows for much worse droughts to occur.

Figure 1: Storage Behaviour- Run 303

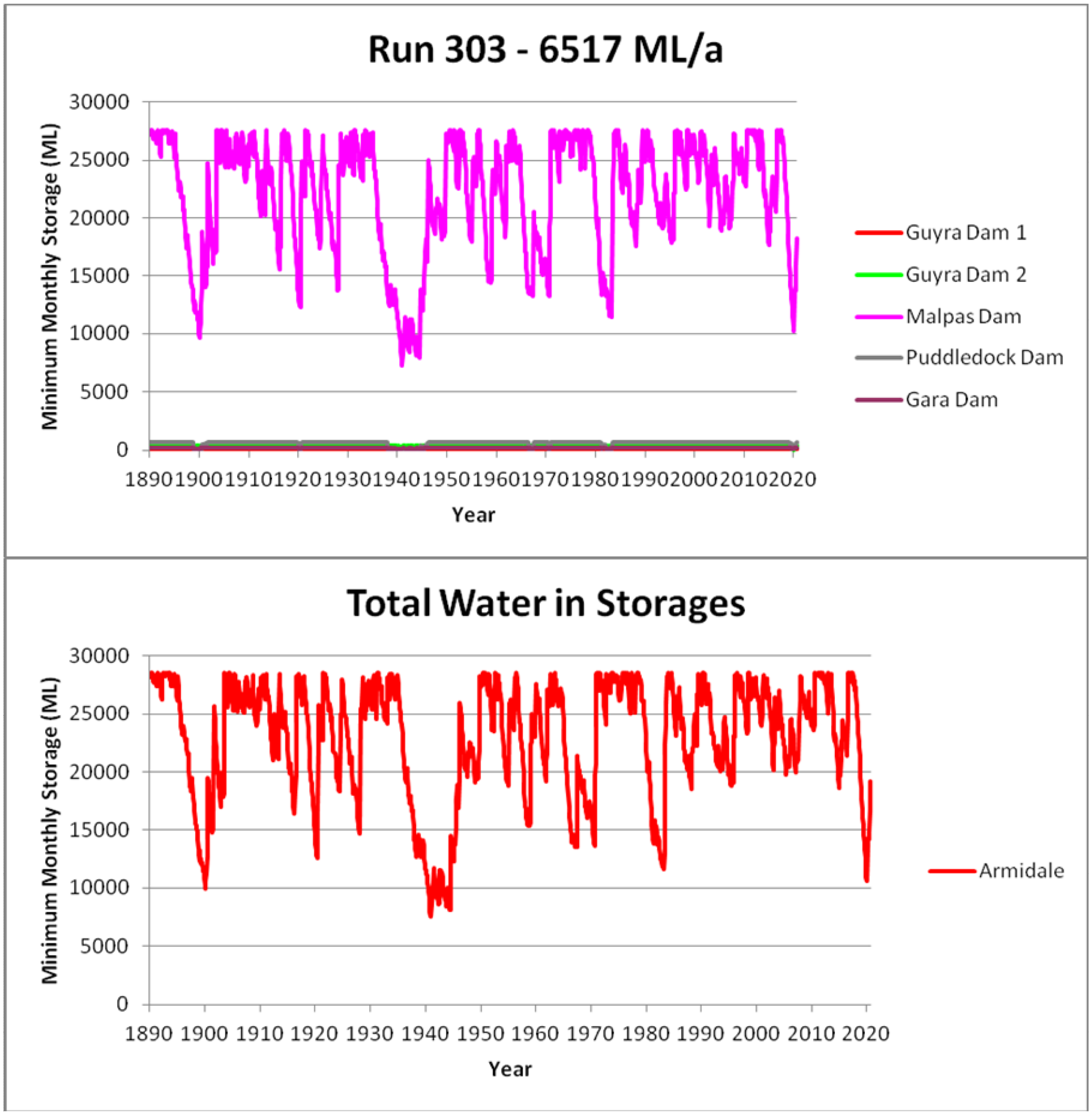


Figure 2: Storage Behaviour- Run 304

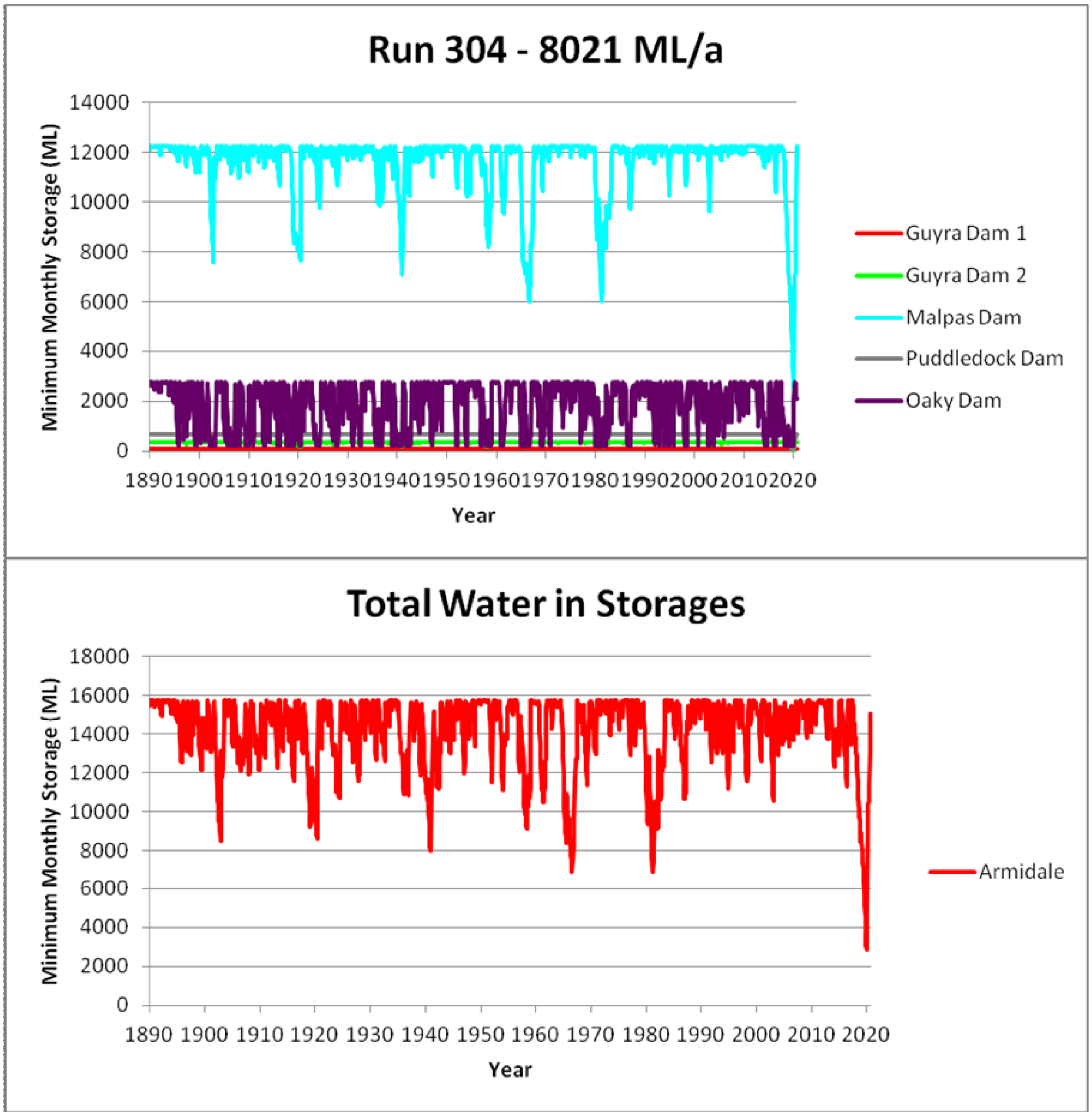
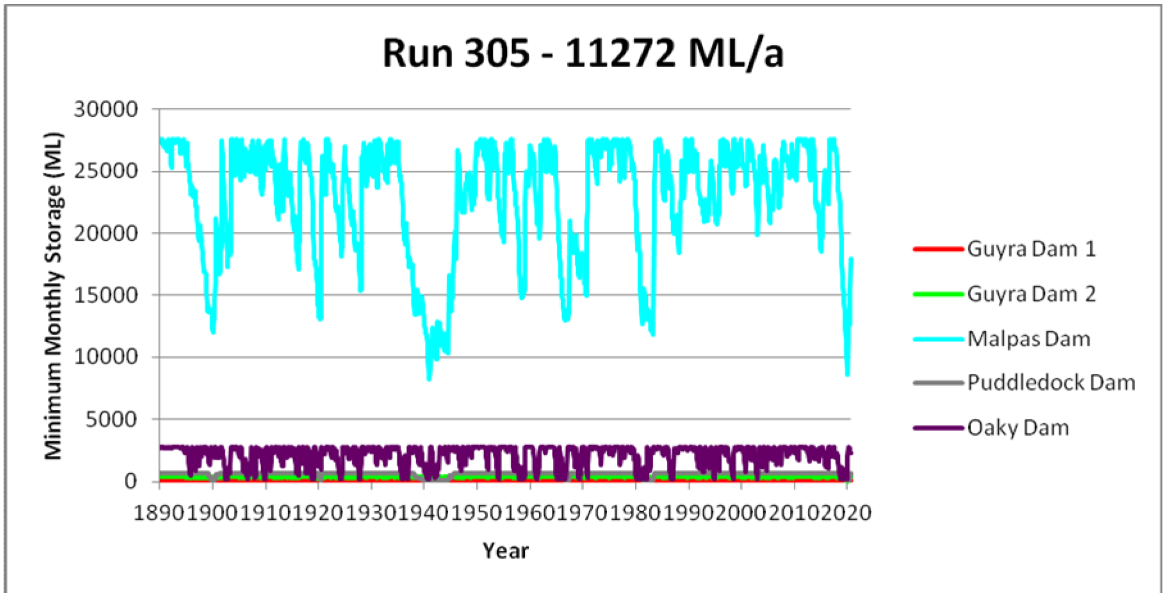
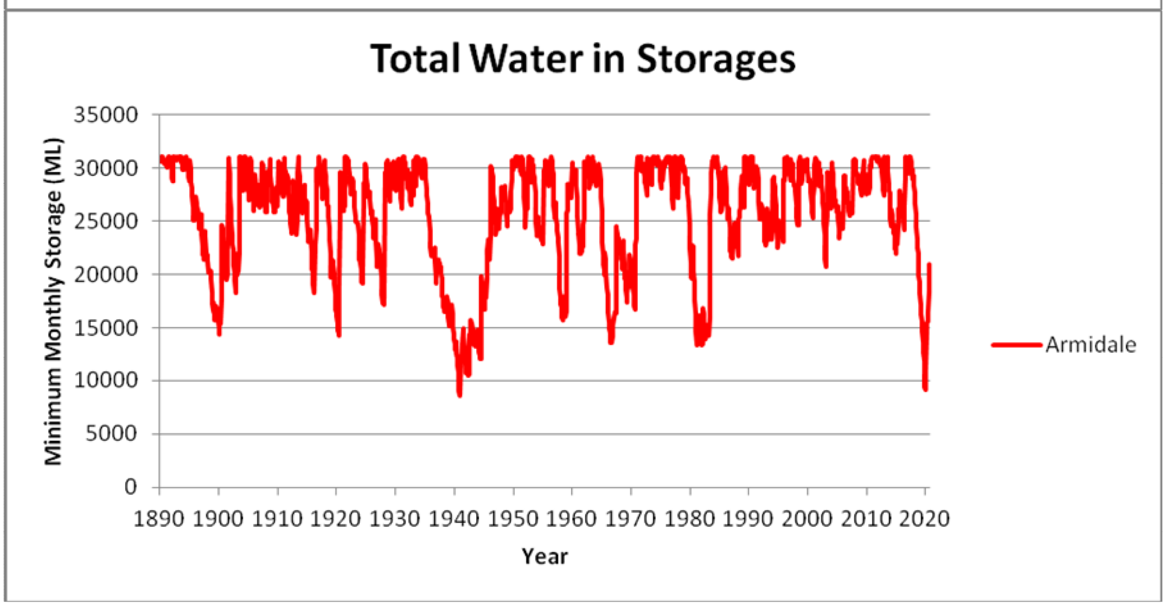


Figure 3: Storage Behaviour- Run 305





Attachment A – Model Results for 15 GCMs and corresponding Historic Base

Note that in each case shown on the following pages the data is based on modelled flow information (from a data base of daily rainfall and daily evapotranspiration) and not observed flow data. The following data is used to adjust the best estimates of the historic climate secure yields given in Table 1 in accordance with the DPE Water guidelines.

Case 303: Malpas Dam with FSL Raised by 6.5 ML (No Oaky Dam)

Armidale, Run 303CC F:\Results\Armidale\Mar2020\Data\ClimateChange\Armidale_

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					Restricted		Critical Drought	
	Run	Storage Capacity	Secure Yield	% Restricted at	% of duration	% of years	Start	End
HISTORICAL	1	28544.97	6052	50	10.00	17.24	21/01/1935	30/12/1940
	2	28544.97	5489	45	7.68	13.79	20/01/1935	30/12/1940
	3	28544.97	5391	45	8.22	13.79	19/01/1935	30/12/1940
	4	28544.97	4192	40	6.72	10.34	19/01/1935	30/12/1940
LOWEST	5	28544.97	3630	40	9.93	15.52	09/11/1933	22/08/1944
	6	28544.97	5302	45	9.99	18.97	19/01/1935	30/12/1940
	7	28544.97	4699	45	9.89	15.52	01/01/1894	14/02/1900
	8	28544.97	4972	45	8.99	16.38	19/01/1935	30/12/1940
	9	28544.97	4235	40	8.09	15.52	09/11/1933	02/07/1944
	10	28544.97	5672	50	9.83	19.83	26/01/1935	29/12/1940
	11	28544.97	6964	50	9.17	16.38	21/01/1935	30/12/1940
	12	28544.97	6192	50	9.99	16.38	21/01/1935	30/12/1940
	13	28544.97	4761	45	9.99	18.97	19/01/1935	30/12/1940
	14	28544.97	4652	45	10.00	18.97	19/01/1935	30/12/1940
MEDIAN	15	28544.97	5169	45	8.20	12.93	19/01/1935	30/12/1940
	16	28544.97	5228	45	7.90	12.93	19/01/1935	30/12/1940
10/20/25	5	28544.97	3815	35	8.24	14.66	09/11/1933	22/08/1944
15/25/35	5	28544.97	4180	30	8.64	17.24	20/02/1894	28/11/1902

Case 304: Existing Malpas Dam with Oaky Dam

Armidale, Run 304CC F:\Results\Armidale\Data\13-11-2022\ClimateChange_Oaky\Armidale_

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					Restricted		Critical Drought	
	Run	Storage Capacity	Secure Yield	% Restricted at	% of duration	% of years	Start	End
HISTORICAL	1	15742	10814	55	4.80	17.39	15/02/1935	29/12/1940
	2	15742	10355	55	5.79	17.39	20/01/1935	29/12/1940
	3	15742	10588	55	6.18	19.13	19/01/1935	29/12/1940
	4	15742	8640	55	6.64	19.13	19/01/1935	29/12/1940
LOWEST	5	15742	7648	50	4.59	19.13	19/01/1935	29/12/1940
	6	15742	10213	55	5.53	19.13	19/01/1935	29/12/1940
	7	15742	9144	50	4.82	17.39	19/01/1935	29/12/1940
MEDIAN	8	15742	9851	55	6.51	19.13	19/01/1935	29/12/1940
	9	15742	8539	50	4.76	19.13	19/01/1935	29/12/1940
	10	15742	9674	55	5.24	13.04	21/02/1935	29/12/1940
	11	15742	11919	55	4.05	14.78	15/02/1935	29/12/1940
	12	15742	11243	55	5.47	18.26	21/01/1935	29/12/1940
	13	15742	9137	55	5.74	19.13	19/01/1935	29/12/1940
	14	15742	8479	50	4.65	19.13	19/01/1935	29/12/1940
	15	15742	10230	55	6.72	19.13	19/01/1935	29/12/1940
	16	15742	10726	55	6.65	19.13	19/01/1935	29/12/1940
10/20/25	5	15742	7806	45	3.10	14.78	19/01/1935	29/12/1940
15/25/35	5	15742	8636	45	6.52	24.35	11/02/1895	22/11/1902

Case 305: Raised Malpas Dam with Oaky Dam

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					Restricted		Critical Drought	
	Run	Storage Capacity	Secure Yield	% Restricted at	% of duration	% of years	Start	End
HISTORICAL	1	31106	11579	45	8.70	16.52	21/01/1935	29/12/1940
	2	31106	10737	40	6.16	8.70	20/01/1935	29/12/1940
	3	31106	10683	40	6.40	10.43	19/01/1935	29/12/1940
	4	31106	9113	40	6.12	11.30	19/01/1935	29/12/1940
LOWEST	5	31106	8417	40	7.60	15.65	11/02/1895	28/11/1902
	6	31106	10573	40	6.68	14.78	19/01/1935	29/12/1940
	7	31106	10048	40	7.67	18.26	19/01/1935	29/12/1940
	8	31106	10042	40	5.56	9.57	19/01/1935	29/12/1940
	9	31106	9269	40	7.52	17.39	09/11/1933	29/12/1940
	10	31106	10777	50	9.84	18.26	26/01/1935	29/12/1940
	11	31106	12682	45	8.82	16.52	21/01/1935	29/12/1940
	12	31106	11747	45	9.02	17.39	20/01/1935	29/12/1940
	13	31106	9951	40	6.72	14.78	19/01/1935	29/12/1940
	14	31106	9559	40	6.23	11.30	19/01/1935	29/12/1940
MEDIAN	15	31106	10360	40	5.76	9.57	19/01/1935	29/12/1940
	16	31106	10693	40	6.81	11.30	19/01/1935	29/12/1940
10/20/25	5	31106	8638	35	6.61	13.91	11/02/1895	28/11/1902
15/25/35	5	31106	9246	25	6.25	17.39	11/02/1895	28/11/1902

working together to ensure water supply security

NUWS

NSW Urban Water Services

377 Sussex Street SYDNEY NSW 2000
PO Box 20078 WORLD SQUARE NSW 2002

ABN 86 163 223 667

MEMORANDUM

TO	Glenn Fernandes Director ï Water Resources Management NSW Public Works
CC	Jennifer Blaikie Project Engineer, Water Resources Management NSW Public Works
FROM	Peter Cloke, Principal Hydrologist
DATE	20 January 2025
SUBJECT	Armidale Yield Study: Progress Report (16) ï Sensitivity to NARCLiM1.5 and 10,000 Years Daily Stochastic Hydroclimate Data **DRAFT**

With reference to your email of 6 August 2024 to undertake the proposed modelling to assess the sensitivity of using NARCLiM1.5 data and also the 10,000 years of daily stochastic hydroclimate data to estimate *Secure Yield*, details of the modelling undertaken and results obtained so far are reported herein.

SUMMARY

For the cases modelled with the NARCLIM1.5 data and 10,000 Years of daily stochastic hydroclimate data, it is judged the previous secure yield results based on the 5/10/10 rule can still be adopted.

The previous results are comparable for case 267 (*Malpas Dam FSL raised by 6.5m with Oaky Dam, Puddledock and Guyra Dams*) (within the range to those obtained using the NARCLiM1.5 data and also (slightly lower) to those using the 10,000 years of daily stochastic hydroclimate data.

The previous results are preferred as the historic climate critical drought was generally (for most previous cases) was 2017/2020 and which were essentially based on observed flow data for this period. For the other two approached the critical drought necessarily relied on modelled data for their critical droughts.

RESULTS

It is noted the secure yield results estimates are dependent on the operating rules, data and assumptions as discussed herein and or in the previous 15 Progress Reports (30/3/2020, 26/5/2020, 18/9/2020, 19/10/2020,16/4/2021,22/04/2021,30/04/2021,8/6/2021,7/9/2021,15/11/2022, 9/6/2023, 19/6/2023, 26/3/2024 & 27/8/2024).

10,000 YEARS STOCHASTIC DATA
Raised Malpas Dam, Oaky, Guyra and Puddledock Dams

Table 1 provides the results from using the 10,000 years of daily stochastic hydroclimate data for the previous case **Run 267** (Malpas Dam FSL raised by 6.5 m, Oaky Dam (2.78 GL), Guyra Dams and Puddledock Dam) as reported in Progress Report 12 of 6/6/2023.

It is noted he 10,000 years of daily flows developed from the 10,000 years of daily stochastic hydroclimate data can be used to model yield in various ways. For example it can be broken into 76 replicates of 130 years of data (ie comparable to the length of the historic climate instrumental record) data however this then leads to 76 Yield estimates. They can also be modelled using the 5/10/10 rule or using Councils actual restriction policy. For this study for sensitivity purposes and comparison with the previous results it was considered appropriate initially to using the 10,000 years of data as one continuous time series and determine the 5/10/10 Secure Yield. *(However based on the results obtained it may now not be necessary to trial the other approaches*).

Table 3: Modelling Results (Raised Malpas Dam with Oaky, Puddledock and Guyra Dams)

Run No	Gross Storage GL	Secure Yield (5/10/10) ML/a	Restrictions			Critical Drought	
			Applied at storage (% full)	Duration (%)	% of Years	From	To
10,000 years Stochastic Inflows:							
388	31106	**12513***	70	2.88	7.31	27/02/0043	21/06/0047
10,000 years Stochastic Inflows Perturbed for Climate Change:							
391	31106	**10485***	70	3.80	8.61	05/09/5102	07/03/5110
Historic Climate Inflows (modelled merged with observed flows):							
267	31106	**10138***	60	3.70	9.85	20/07/2017	15/01/2020
Based on Adjusting Historic Climate through 15 GCMs in accordance with 2013 Guidelines:							
267CC	31106	**8322***	*Values varied with GCM data which covered 1895 to 2005*				
			~50	*~4.5*	*~9.5*	*~1/1935*	*~12/1940*
* Excludes 755 ML/a provided to Guyra							

It is noted the perturbation for climate change of the 10,000 years of daily stochastic hydroclimate data was based on the monthly factors (one set for rainfall and one set for evapotranspiration) as used for the DPEs Regional Water Strategy Studies. Currently this is the only basis readily available for such perturbation and it is understood the factors were based on NARCLiM1.0.

It is understood one of the reasons DPE generated 10,000 years of daily stochastic hydroclimate data was to synthesise worse but plausible droughts than available in the historic climate (instrumental record). The comparison of the results for the two sets of results without climate change (ie Run 388 and Run 267) suggests this has not occurred in this case. Based on the readily available details of how the 10,000 years of daily stochastic hydroclimate data were developed and within the scope of this study, it is not known why this has not occurred. However it is judged that contributing factors were the spatial limitation of the available daily stochastic hydroclimate data (*there was only one SEED point considered* *relevant to cover the Malpas/Guyra and Puddledock dams catchments*). Furthermore Run 267 benefitted from using essentially observed flow data for the critical drought whereas Run 388 was necessarily based on modelled flow data.

Interestingly the two approaches resulted in similar reductions for climate change. The 10,000 years of daily stochastic hydroclimate data perturbed for climate change resulted in a 16.2% reduction in *Secure Yield* whereas the previous method using the 2013 Guidelines (ie 15GCMs and SEAC data) resulted in a 17.9 % reduction in *Secure Yield*.

NARCLiM1.5 DATA

Raised Malpas Dam, Oaky, Guyra and Puddledock Dams

Tables 2 to 7 provide the secure yields obtained from using the flow data obtained from using the data from the six NARCLiM1.5 model data sets for the previous case **Run 267** (Malpas Dam FSL raised by 6.5 m, Oaky Dam (2.78 GL), Guyra Dams and Puddledock Dam) as reported in Progress Report 12 of 6/6/2023. Two periods were modelled, the full period 1951-2099 and 1951 to 2020 so that it could be compared on a consistent time basis to the observed historic data case.

It is noted run numbers ending in b indicate where original run had to be rerun unconstraining the transfer capacity of 100 ML/d from Malpas Dam to Armidale WTP as this was the constraining yield

Table 8 summarises the results from Tables 2 to 7. Table 9 provides the *observed* historic climate secure yield results. Table 10 summarises the results after the correction for bias.

The six NARCliM1.5 data series used are given below:

Case 1 (CCCMA-J): CCCma-CanESM2_historical_UNSW-WRF360J CCCma-CanESM2_RCP85_UNSW-WRF360J	**Case 4 (CSIRO-ACCESS1.0-K):** CSIRO-BOM-ACCESS1-0_historical_UNSW-WRF360K CSIRO-BOM-ACCESS1-0_RCP85_UNSW-WRF360K
Case 2 (CCCMA-K): CCCma-CanESM2_historical_UNSW-WRF360K CCCma-CanESM2_RCP85_UNSW-WRF360K	**Case 5 (CSIRO-ACCESS1.3-J):** CSIRO-BOM-ACCESS1-3_historical_UNSW-WRF360J CSIRO-BOM-ACCESS1-3_RCP85_UNSW-WRF360J
Case 3 (CSIRO-ACCESS1.0-J): CSIRO-BOM-ACCESS1-0_historical_UNSW-WRF360J CSIRO-BOM-ACCESS1-0_RCP85_UNSW-WRF360J	**Case 6 (CSIRO-ACCESS1.3-K):** CSIRO-BOM-ACCESS1-3_historical_UNSW-WRF360K CSIRO-BOM-ACCESS1-3_RCP85_UNSW-WRF360K

The historical data was from 1/1/1951- 31/12/2005, the RCP8.5 was from 1/1/2006 to 31/12/2099

Table 2: Case 1 (CCCMA-J) Results (Raised Malpas with Oaky, Puddledock and Guyra Dams)

Run No	Gross Storage ML	Secure Yield* (5/10/10) ML/a	Restrictions			Critical Drought	
			Applied at storage (% full)	Duration (%)	% of Years	From	To
Modelling period 1/1/1951 -31/12/2099							
375	**31106**	**23457**	55	1.29	4.67	24/05/2094	11/11/2095
Modelling period: 1/1 1951 to 1/9/2020							
376b	**31106**	**28146**	50	1.22	7.04	15/11/2004	12/12/2006
* Excludes 755 ML/a provided to Guyra							

Table 3: Case 2 (CCCMA-K) Results (Raised Malpas with Oaky, Puddledock and Guyra Dams)

Run No	Gross Storage ML	Secure Yield* (5/10/10) ML/a	Restrictions			Critical Drought	
			Applied at storage (% full)	Duration (%)	% of Years	From	To
Modelling period 1/1/1951 -31/12/2099							
377	**31106**	**23450**	55	1.92	9.33	3/11/2092	24/12/2094
Modelling period: 1/1 1951 to 1/9/2020							
378	**31106**	**25297**	50	0.84	7.04	3/01/2005	28/01/2006
* Excludes 755 ML/a provided to Guyra							

Table 4: Case 3 (CSIRO-ACCESS1.0-J) Results (Raised Malpas with Oaky, Puddledock and Guyra Dams)

Run No	Gross Storage ML	Secure Yield* (5/10/10) ML/a	Restrictions			Critical Drought	
			Applied at storage (% full)	Duration (%)	% of Years	From	To
Modelling period 1/1/1951 -31/12/2099							
379b	**31106**	**35204**	55	1.15	8.00	1/06/2080	24/11/2081
Modelling period: 1/1 1951 to 1/9/2020							
380b	**31106**	**36358**	60	1.65	9.86	12/04/1956	17/05/1957
* Excludes 755 ML/a provided to Guyra							

Table 5: Case 4 (CSIRO-ACCESS1.0-K) Results (Raised Malpas with Oaky, Puddledock and Guyra Dams)

Run No	Gross Storage ML	Secure Yield* (5/10/10) ML/a	Restrictions			Critical Drought	
			Applied at storage (% full)	Duration (%)	% of Years	From	To
Modelling period 1/1/1951 -31/12/2099							
381b	**31106**	**29734**	60	1.71	6.67	11/12/2080	24/09//2082
Modelling period: 1/1 1951 to 1/9/2020							
382b	**31106**	**31792**	60	2.01	9.86	15/11/1964	2/04/1966
* Excludes 755 ML/a provided to Guyra							

Table 6: Case 5 (CSIRO-ACCESS1.3-J) Results (Raised Malpas with Oaky, Puddledock and Guyra Dams)

Run No	Gross Storage ML	Secure Yield* (5/10/10) ML/a	Restrictions			Critical Drought	
			Applied at storage (% full)	Duration (%)	% of Years	From	To
Modelling period 1/1/1951 -31/12/2099							
383b	**31106**	**27588**	55	0.91	6.67	6/04/2096	5/11/2097
Modelling period: 1/1 1951 to 1/9/2020							
384b	**31106**	**30364**	50	1.47	7.04	11/02/1986	27/12/1988
* Excludes 755 ML/a provided to Guyra							

Table 7: Case 6 (CSIRO-ACCESS1.3-K) Results (Raised Malpas with Oaky, Puddledock and Guyra Dams)

Run No	Gross Storage ML	Secure Yield* (5/10/10) ML/a	Restrictions			Critical Drought	
			Applied at storage (% full)	Duration (%)	% of Years	From	To
Modelling period 1/1/1951 -31/12/2099							
385	**31106**	**23987**	60	2.43	9.33	18/02/2093	22/12/2094
Modelling period: 1/1 1951 to 22/11/2023							
386	**31106**	**24683**	60	4.28	9.86	20/03/1997	12/04/1999
* Excludes 755 ML/a provided to Guyra							

Table 8: NARCLiM1.5 Secure Yield Results Summary (Raised Malpas with Oaky, Puddledock and Guyra Dams)

NARCLiM	Secure Yield ML/a 1951-2020	Secure Yield ML/a 1951-2099	Reduction Factor (Full Period/Short Period)
Case 1	**28146**	**23457**	**0.8334**
Case 2	**25297**	**23450**	**0.9270**
Case 3	**36358**	**35204**	**0.9683**
Case 4	**31792**	**29734**	**0.9353**
Case 5	**30364**	**27588**	**0.9086**
Case 6	**24683**	**23987**	**0.9718**
Excludes 755 ML/a provided to Guyra			

The reduction factors can be considered proxies for expected reduction in secure yield for climate change. The factors suggest expected reduction in secure yield varying from 16.7% to 2.8%. The 16.7% is consistent with that obtained using the 10,000 years of daily stochastic hydroclimate data and also using the 2013 *Guidelines* approach.

Table 9: Secure Yield Estimates (Historic Climate) Raised Malpas with Oaky, Puddledock and Guyra Dams)

Run No	Gross Storage ML	Secure Yield* (5/10/10) ML/a	Restrictions			Critical Drought	
			Applied at storage (% full)	Duration (%)	% of Years	From	To
Previous Flow Series: (modelling period 1/1/1890-1/9/2020):							
267	**31106**	**10138**	60	3.70	9.85	20/07/2017	15/01/2020
Previous Flow Series: (modelling period 1/1/1951-1/9/2020) (for comparison with NARCLiM1.5 Data):							
391	**31106**	9698	60	4.99	9.86	21/07/2017	15/01/2020
* Excludes 755 ML/a provided to Guyra							

Table 10: Bias Correction of NARCLiM1.5 Secure Yield Results (Raised Malpas with Oaky, Puddledock and Guyra Dams)

Item	Flow Basis	Modelled Period	SECURE YIELD* ML/a *(Run No given in brackets)*					
			CASE 1 CanESM2_J	**CASE 2 CanESM2_K**	**CASE 3 ACCESS 1.0_J**	**CASE 4 ACCESS 1.0_K**	**CASE 5 ACCESS 1.3_J**	**CASE 6 ACCESS 1.3_K**
1	NARCLiM1.5	1951-2099	*(375)* **23457**	*(377)* **23450**	*(379b)* **35204**	*(381b)* **29734**	*(383b)* **27588**	*(385)* **23987**
2	NARCLiM1.5	1951-1/9/2020	*(376b)* **28146**	*(378)* **25297**	*(380b)* **36358**	*(382b)* **31792**	*(384b)* **30364**	*(386)* **24683**
3	***Modelled/ Merged Flow Data Used for Run 267***	1951-1/9/2020	*(391)* **9698**					
4	Bias Factor (Item3/Item2) result		**0.3446**	**0.3741**	**0.2667**	**0.3050**	**0.3194**	**0.3929**
Item 1 results adjusted for bias *(bias factor in Item 4 x Item 1)*			**8082**	**8990**	**9390**	**9070**	**8811**	**9424**

Run numbers ending in b indicate where original run had to be rerun unconstraining the transfer capacity of 100 ML/d from Malpas Dam to Armidale WTP as this was constraining yield

* Excludes 755 ML/a provided to Guyra

The bias adjusted NARCLiM1.5 Secure Yield results in Table 10 vary from 8082 ML/a to 9424 ML/a (with mean 8961 ML/a and median 9030 ML/a).This compares with the 8322 ML/a obtained previously using the 2013 *Guidelines* Approach.

Raised Malpas Dam, Guyra and Puddledock Dams

Tables 11 to 16 provide the secure yields obtained from using the flow data obtained from using the data from the six NARCLiM1.5 model data sets for a new case similar to the previous case **Run 207** (*Malpas Dam FSL raised by 6.5 m, Guyra Dams and Puddledock Dam but without Gara Dam and with the transfer from Malpas Dam to Armidale WTP unconstrained*) as reported in Progress Report 4 of 19/10/2020. Two periods were modelled, the full period 1951-2099 and 1951 to 2020 so that it could be compared on a consistent time basis to the observed historic data case.

Table 17 summarises the results from Tables 11 to 16. Table 17 provides the *observed* historic climate secure yield results and also them adjusted for climate change. Table 18 summarises the NARCLiM1.5 results after the correction for bias.

Table 11: Case 1 (CCCMA-J) Results (Raised Malpas with Puddledock and Guyra Dams)

Run No	Gross Storage ML	Secure Yield* (5/10/10) ML/a	Restrictions			Critical Drought	
			Applied at storage (% full)	Duration (%)	% of Years	From	To
Modelling period 1/1/1951 -31/12/2099							
352	**28326**	**13725**	55	3.97	8.67	5/01/2083	22/01/2086
Modelling period: 1/1 1951 to 1/9/2020							
354	**28326**	**15914**	50	0.69	4.23	15/11/2004	13/12/2006
* Excludes 755 ML/a provided to Guyra							

Table 12: Case 2 (CCCMA-K) Results (Raised Malpas with Puddledock and Guyra Dams)

Run No	Gross Storage ML	Secure Yield* (5/10/10) ML/a	Restrictions			Critical Drought	
			Applied at storage (% full)	Duration (%)	% of Years	From	To
Modelling period 1/1/1951 -31/12/2099							
356	**28326**	**11968**	65	2.90	9.33	4/11/2092	19/01/2095
Modelling period: 1/1 1951 to 1/9/2020							
358	**28326**	**16073**	55	1.85	9.86	7/07/2017	8/11/2018
* Excludes 755 ML/a provided to Guyra							

Table 13: Case 3 (CSIRO-ACCESS1.0-J) Results (Raised Malpas with Puddledock and Guyra Dams)

Run No	Gross Storage ML	Secure Yield* (5/10/10) ML/a	Restrictions			Critical Drought	
			Applied at storage (% full)	Duration (%)	% of Years	From	To
Modelling period 1/1/1951 -31/12/2099							
360	**28326**	**21766**	55	1.25	9.33	25/04/2080	24/11/2081
Modelling period: 1/1 1951 to 1/9/2020							
362	**28326**	**22883**	55	1.62	9.86	12/04/1956	18/05/1957
* Excludes 755 ML/a provided to Guyra							

Table 14: Case 4 (CSIRO-ACCESS1.0-K) Results (Raised Malpas with Puddledock and Guyra Dams)

Run No	Gross Storage ML	Secure Yield* (5/10/10) ML/a	Restrictions			Critical Drought	
			Applied at storage (% full)	Duration (%)	% of Years	From	To
Modelling period 1/1/1951 -31/12/2099							
364	**28326**	**15456**	60	1.13	2.67	11/12/2080	2/11//2082
Modelling period: 1/1 1951 to 1/9/2020							
366	**28326**	**17537**	60	1.85	9.86	16/11/1964	11/04/1966
* Excludes 755 ML/a provided to Guyra							

Table 15: Case 5 (CSIRO-ACCESS1.3-J) Results (Raised Malpas with Puddledock and Guyra Dams)

Run No	Gross Storage ML	Secure Yield* (5/10/10) ML/a	Restrictions			Critical Drought	
			Applied at storage (% full)	Duration (%)	% of Years	From	To
Modelling period 1/1/1951 -31/12/2099							
368	**28326**	**15132**	55	1.35	7.33	6/04/2096	28/11/2097
Modelling period: 1/1 1951 to 1/9/2020							
370	**28326**	**16499**	55	1.96	5.63	11/02/1986	24/10/1987
* Excludes 755 ML/a provided to Guyra							

Table 16: Case 6 (CSIRO-ACCESS1.3-K) Results (Raised Malpas with Puddledock and Guyra Dams)

Run No	Gross Storage ML	Secure Yield* (5/10/10) ML/a	Restrictions			Critical Drought	
			Applied at storage (% full)	Duration (%)	% of Years	From	To
Modelling period 1/1/1951 -31/12/2099							
372	**28326**	**12507**	65	3.18	9.33	18/02/2093	27/12/2094
Modelling period: 1/1 1951 to 22/11/2023							
374	**28326**	**13671**	60	4.39	9.86	1/09/1997	2/08/1999
* Excludes 755 ML/a provided to Guyra							

Table 17: NARCLiM1.5 Secure Yield Results Summary (Raised Malpas with Puddledock and Guyra Dams)

NARCLiM	Secure Yield ML/a 1951-2020	Secure Yield ML/a 1951-2099	Reduction Factor (Full Period/Short Period)
Case 1	**15914**	**13725**	**0.8624**
Case 2	**16073**	**11968**	**0.7446**
Case 3	**22883**	**21766**	**0.9512**
Case 4	**17537**	**15456**	**0.8813**
Case 5	**16499**	**15132**	**0.9171**
Case 6	**13671**	**12507**	**0.9149**
Excludes 755 ML/a provided to Guyra			

The reduction factors can be considered proxies for expected reduction in secure yield for climate change. The factors suggest expected reduction in secure yield varying from 25.5% to 4.9% (*mean 12.1%).* The values do not appear so similar to that obtained using the 10,000 years of daily stochastic hydroclimate data and also using the 2013 *Guidelines* approach however this may relate to that it was for a different headworks system.

Table 18: Secure Yield Estimates (Raised Malpas with Puddledock and Guyra Dams)

Run No	Gross Storage ML	Case	Secure Yield* (5/10/10) ML/a	Restrictions			Critical Drought	
				Applied at storage (% full)	Duration (%)	% of Years	From	To
Previous Flow Series: (modelling period 1/1/1890-1/9/2020):								
392	**28326**	**Historic Climate**	**4686**	50	5.00	7.58	20/01/1935	2/07/1944
Previous Flow Series: (modelling period 1/1/1951-1/9/2020) (for comparison with NARCLiM1.5 Data):								
393	**28326**	**Historic Climate**	**5453**	55	4.72	9.86	27/10/2017	6/02/2020
Climate Change (15 GCMs Flows 1894 -2008) Using 2013 Guidelines:								
392CC	**28326**	**Climate Change**	**2895****	*See Attachment A for the 15 GCM results*				
* Excludes 755 ML/a provided to Guyra ** Based on ratio of lowest GCM with 10/15/25 to Historic Base								

Table 19: Bias Correction of Secure Yield Results (Raised Malpas with Puddledock and Guyra Dams)

Item	Flow Basis	Modelled Period	SECURE YIELD* ML/a *(Run No given in brackets)*					
			CASE 1 CanESM2_J	**CASE 2 CanESM 2_K**	**CASE 3 ACCESS 1.0_J**	**CASE 4 ACCESS 1.0_K**	**CASE 5 ACCESS 1.3_J**	**CASE 6 ACCESS 1.3_K**
1	NARCLiM1.5	1951-2099	*(352)* **13725**	*(356)* **11968**	*(360)* **21766**	*(364)* **15456**	*(368)* **15132**	*(372)* **12507**
2	NARCLiM1.5	1951-1/9/2020	*(354)* **15914**	*(358)* **16073**	*(362)* **22883**	*(366)* **17537**	*(370)* **16499**	*(374)* **13671**
3	***Modelled/ Merged Flow Data Used for Run 267***	1951-1/9/2020	*(393)* **5453**					
4	Bias Factor (Item3/Item2) result		**0.3427**	**0.3393**	**0.2383**	**0.3109**	**0.3305**	**0.3989**
Item 1 results adjusted for bias *(bias factor in Item 4 x Item 1)*			**4702**	**4060**	**5187**	**4806**	**5001**	**4988**
* Excludes 755 ML/a provided to Guyra								

The bias adjusted NARCLiM1.5 Secure Yield results in Table 19 vary from 4060 ML/a to 4897 ML/a (*with mean 4790 ML/a and median 5027 ML/a).*This compares with the 2895 ML/a obtained (see Table 18 & Appendix A) using the 2013 *Guidelines* Approach.

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Attachment A – Model Results for 15 GCMs and corresponding Historic Base

Note that in each case shown on the following pages the data is based on modelled flow information (from a data base of daily rainfall and daily evapotranspiration) and not observed flow data. The following data is used to adjust the best estimates of the historic climate secure yields given in Table 18 in accordance with the DPIE Water 2013 guidelines

Armidale, Run 392CC F:\Results\Armidale\Mar2020\Data\ClimateChange\Armidale_

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	Run	Storage Capacity	Secure Yield	% Restricted at	Restricted % of duration	Restricted % of years	Critical Drought Start	Critical Drought End
HISTORICAL	1	28326	4492	40	3.78	6.03	21/01/1935	30/12/1940
	2	28326	4062	40	4.71	6.90	20/01/1935	02/07/1944
	3	28326	3925	40	4.99	7.76	19/01/1935	02/07/1944
	4	28326	2862	35	5.00	8.62	19/01/1935	22/08/1944
LOWEST	5	28326	2312	30	3.76	7.76	25/02/1934	22/08/1944
	6	28326	3735	35	3.21	6.90	19/01/1935	22/08/1944
	7	28326	3218	40	4.99	8.62	19/01/1935	02/07/1944
	8	28326	3437	40	5.00	8.62	19/01/1935	04/11/1943
	9	28326	2811	35	5.00	9.48	19/01/1935	22/08/1944
	10	28326	4172	45	5.00	6.90	26/01/1935	29/12/1940
	11	28326	5263	45	4.99	6.90	21/01/1935	30/12/1940
	12	28326	4585	40	4.29	6.03	21/01/1935	02/07/1944
	13	28326	3253	40	5.00	6.90	19/01/1935	22/08/1944
	14	28326	3155	40	4.99	6.90	19/01/1935	22/08/1944
MEDIAN	15	28326	3709	40	5.00	6.90	19/01/1935	22/08/1944
	16	28326	3798	40	5.00	6.90	19/01/1935	22/08/1944
10/15/25	5	28326	2775	30	8.77	13.79	09/11/1933	22/08/1944