Application of the Bureau of Meteorology's National Hydrologic Projections dataset – Harding Dam Supply Reliability

Assessing climate change risk and the National Hydrological Projections

The Pilbara Region's warming climate combined with increasing uncertainty in projected future rainfall presents a challenge to planning long-term water availability.

Climate projections for the Pilbara, located in the Rangelands Natural Resource Management region, indicate a broad range of potential risks to water availability. The acute risk of extreme rainfall and associated weather events beyond our current experience will potentially damage infrastructure. Meanwhile, the longer-term chronic impacts of higher temperatures, potential declines in average annual rainfall and significantly longer drought periods will influence the future sustainability of essential water resources (CSIRO, 2018; DWER, 2021).

Water service providers and resource managers need fit-for-purpose information representing localised climate change conditions to assess the impacts on essential water supplies.

Water Corporation, working closely with the Western Australian Department of Water and Environmental Regulation (the department) and the Bureau of Meteorology (the Bureau), is investigating the potential future risk climate change presents to the reliability of Water Corporation's water supply schemes.

The project team has been working with a range of climate change projections as represented by the Bureau's National Hydrological Projections (NHP). These are available through the Australian Water Outlook service.

The National Hydrological Projections are based on four global climate models (GCM) chosen to represent the key climate drivers around Australia (Srikanthan et al. 2022). State-of-the-art techniques refine the climate data to a finer geographic scale and correct for biases, which adjust for discrepancies between local observations and climate model outputs. Using the bias-corrected climate datasets of rainfall, temperature, wind, and solar radiation, for two Representative Concentration Pathways (RCPs), the Australian Landscape Water Balance Model (AWRA-L) produced daily model outputs of soil moisture, runoff, and potential evapotranspiration[1] across Australia (Oke et al, 2022). Future greenhouse gas emission scenarios were based on two representative concentration pathways, RCP 4.5, and RCP 8.5 (BoM, 2022).

The resulting hydro-climate model outputs provide water resource planners with 32 equally plausible projections of future hydrological changes and extreme climate conditions (Figure 1). The 32 projections are collectively known as the National Hydrologic Projections.

[1] The amount of evaporation and transpiration that would occur at a particular location when water available for this process is non-limited.

Australian Government Bureau of Meteorology
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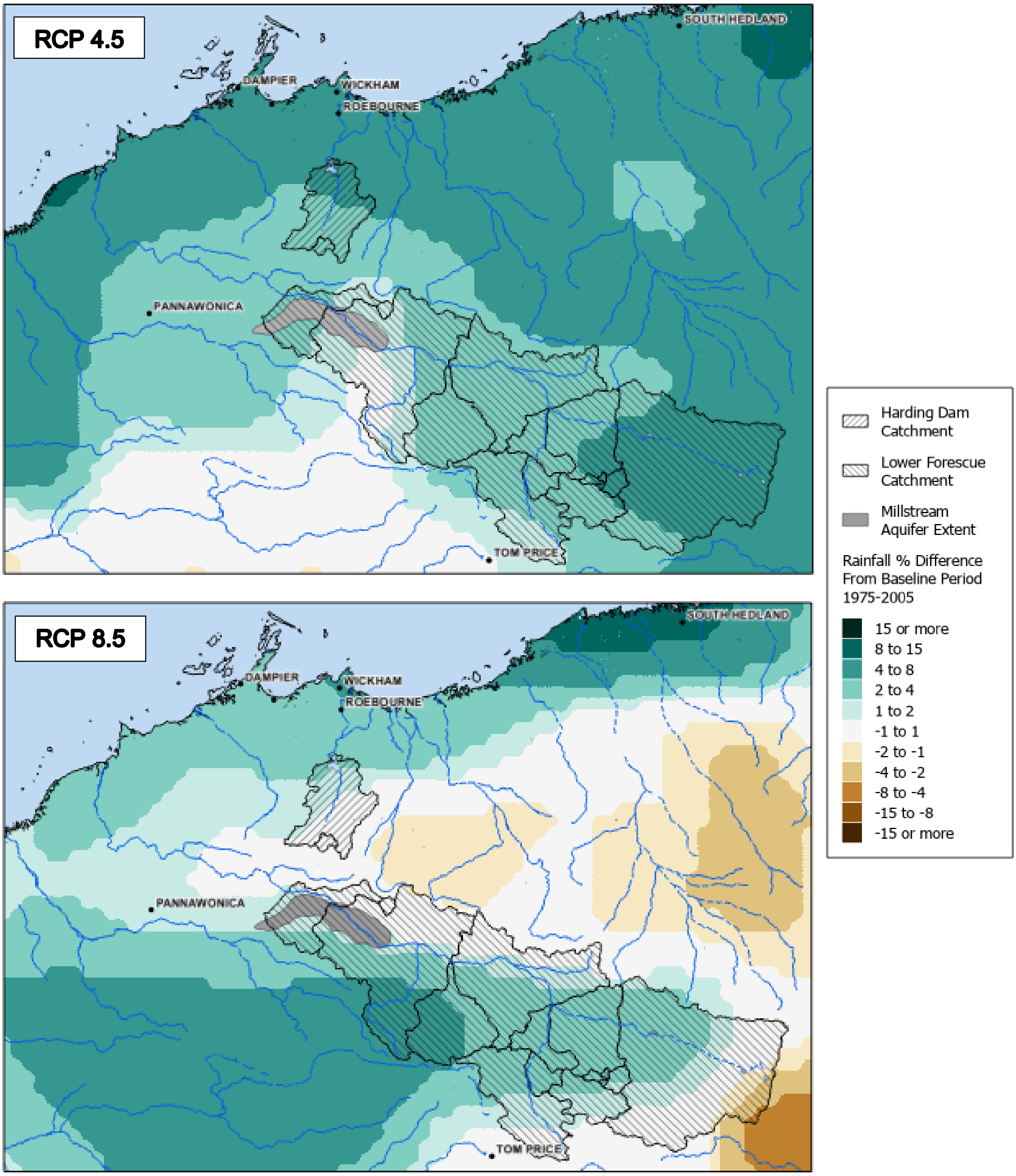


Figure 1: West Pilbara Water Supply Scheme Relative change to Annual Rainfall centred on 2050 (2036-2065 rainfall percentage mean change from 1976-2005 reference period) for two representative concentration pathways (Australian Water Outlook, the Bureau 2023)

Supporting water utilities

Water Corporation has been working closely with DWER and the Bureau to understand how the Australian Water Outlook service, specifically its National Hydrological Projections for the Rangelands Region, can be applied to assessing the risk climate change presents to the future reliability of Karratha's Harding Dam.

This case study expands on previous water resource modelling to investigate how sensitive the reliability of the Harding Dam is to varying patterns of rainfall and evaporation under a range of plausible future climate projections.

West Pilbara Water Supply Scheme

The West Pilbara Water Supply Scheme (the scheme) supplies drinking water to the towns of Karratha, Wickham, Dampier, Roebourne, and Point Samson. Water is also supplied to major iron ore exporting ports operated by Rio Tinto Iron Ore at Cape Lambert and Dampier as well as numerous smaller, but significant, industrial customers, mostly located on the Burrup Peninsular.

The public water supply scheme supplies water from two sources owned and operated by Water Corporation: Harding Dam; and Millstream Borefield. Since 2013 the scheme has been supplemented by the Bungaroo Borefield which is owned and operated by Rio Tinto.

Harding Dam is the scheme's primary water source. This is due to stringent regulatory requirements on the Millstream Borefield designed to protect the significant environmental, social, and cultural values of the aquifer and wetland systems. These include a requirement that abstraction from the Millstream Borefield only occur when water from Harding Dam is unavailable.

The Millstream aquifer sustains a large wetland complex which includes four major permanent river pools (Deep Reach, Crossing, Livistona and Palm pools) interconnected by permanent flowing channels, spring-fed pools on tributaries (e.g., Chinderwarriner Pool) and large areas of riparian and wetland vegetation (Braimbridge et al, 2010). It is a significant area of isolated habitat for wetland flora and fauna and supports a range of regionally under-represented species (Braimbridge et al, 2010). The bicarbonate-rich aquifer also hosts a species rich community of stygofauna (Eberhard et al. 2005).

The area is partly within the Millstream-Chichester National Park and is listed on the Register of the National Estate and in the Directory of Important Wetlands in Australia (Environment Australia 2001). The system has also been nominated for listing under the Ramsar Convention on Wetlands (DEC. 2007). It is an outstanding example of a system of permanent river pools and springs in the semi-arid tropics and the best known in north Western Australia (Braimbridge, 2010).

The Millstream Chichester area is also one of the most significant indigenous cultural and mythological sites of importance in northern Western Australia (Rijavec et al. 2005, DEC. 2011). The area not only contains numerous cultural heritage sites but is also the home of the mythological serpent or *warlu,* meaning snake. Today the warlu rests at Deep Reach Pool (*Nhankangunha*) which is an important place for Law and culture for the Yindjibarndi people (Juluwarlu Aboriginal Corporation, 2007). Both the Yindjibarndi and Ngarluma people come to the area to spend time on country and to carry out customary activities (DEC. 2011).

The Bungaroo Borefield supplies bulk water via the scheme, to support Rio Tinto operations, in accordance with a Deed of Agreement between Rio Tinto and the State of Western Australia (DoW, 2012). Rio Tinto puts into the scheme what it uses at the ports largely for dust suppression.

All three sources are highly dependent on recharge through largely cyclone driven rainfall and rainfall-generated runoff. Due to their proximity, all sources are often recharged by the same event or may concurrently experience a 'failed' wet season or drought. Harding Dam also experiences high losses due to evaporation from Lake Poongkaliyarra (Pung-Kalli-ar-raa).

Climate

The West Pilbara scheme is located within the Pilbara ranges of the Rangelands region (Oke et al. 2022). Historical rainfall observations show an increasing trend in summer rainfall with intermittent periods of wetter and drier conditions. Temperatures have also increased over the past century, with the rate of warming higher since 1960.

The climate and hydrological systems within the Rangelands region display high year-to-year and interdecadal variability as influenced by the seasonal monsoon in the north (Oke et al. 2022, DWER, 2021). Due to the vastness of the region, which covers the Pilbara, Mid-West Gascoyne and much of inland Australia, changes in rainfall are not consistent in space or in time (Oke et al, 2022). This natural variability in rainfall will continue to dominate over trends due to greenhouse gas emissions by 2030 (CSIRO, 2015).

Summary of climate trends for Western Australia's Rangelands Region (Adapted from Oke et al., 2022):

- Annual rainfall changes projected over the Rangelands range between a 36% decrease (94 mm) to a 45% increase (115 mm) (Figure 2a). Many of the ensembles indicate an increase (Figure 5) out until the end of the century.
- Due to the large spread of the projected rainfall, and the remaining uncertainty around the behaviour of the monsoon under a warming climate, significant rainfall decreases are plausible so should not be discounted.
- The projected median changes in annual rainfall differ under the two emissions scenarios RCP4.5 shows a consistent small increase in rainfall for all future time periods. RCP8.5 shows an initial increase in rainfall followed a gradual decrease to the end of the century.
- Rainfall events are projected to be more intense.
- Time spent in drought is projected, with a moderate level of confidence, to increase.
- There is a high level of confidence in the continued projected rise in temperatures and potential evapotranspiration across all seasons.

Impact assessments within this region should consider the risk of both a drier and wetter climate (CSIRO, 2015).

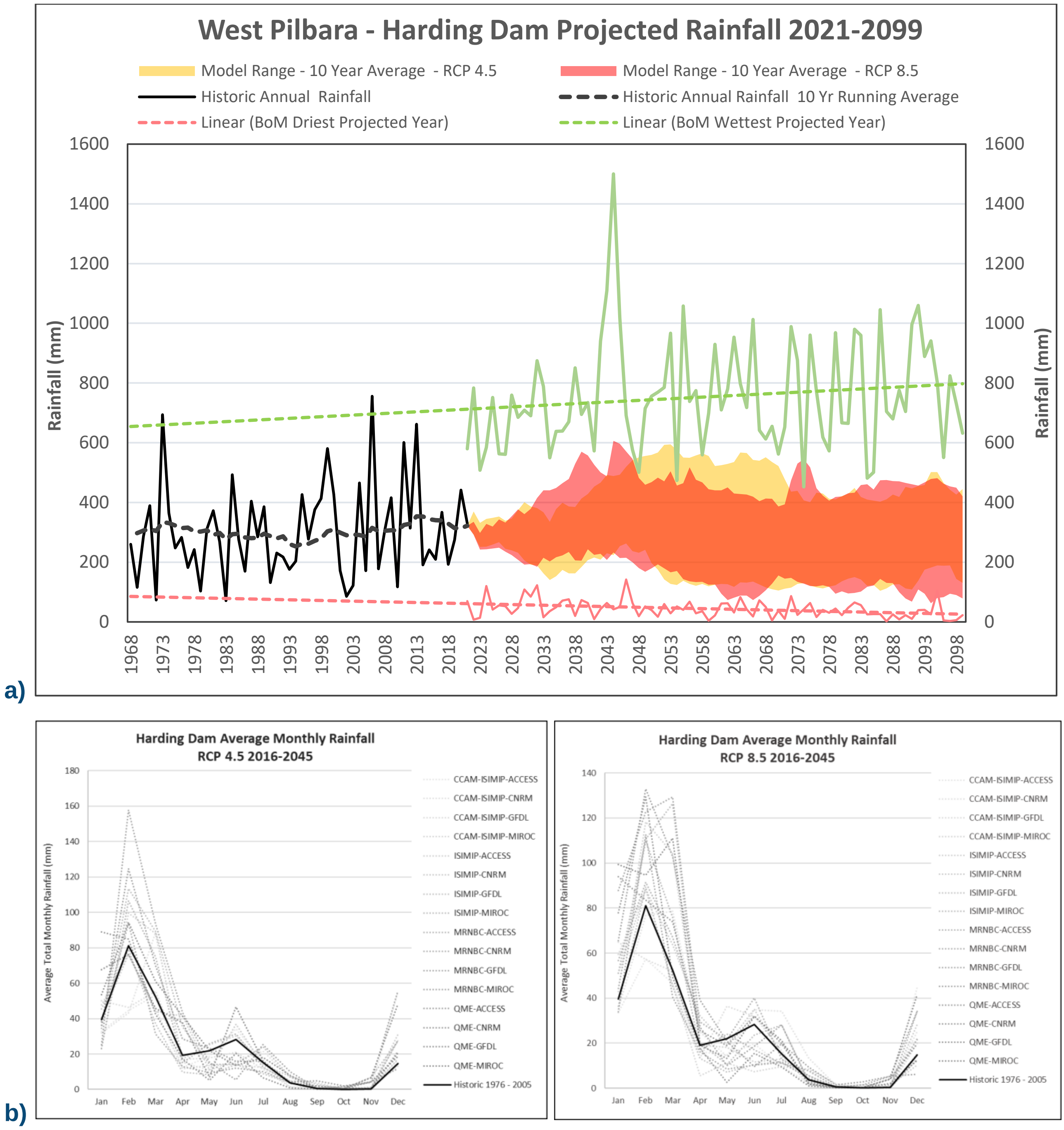


Figure 2: Historical and projected annual rainfall for the Harding Dam a) Annual b) Monthly.

Harding Dam

Figure 3: Harding Dam, West Pilbara

Harding Dam (Figure 3) was commissioned in 1985 after it was recognised that the Millstream Borefield (established in 1969) could not reliably sustain rates of abstraction above 6.0 GL/year, particularly when rainfall recharge was low.

The dam is supplied by the Harding River, known as the Ngurin in Ngarluma language. Ngurin and all the vegetation surrounding holds great significance to its Traditional Owners including the Ngarluma and Yindjibarndi people (City of Karratha, 2016). Lake Poongkaliyarra also contains cultural heritage sites, which were of ongoing significance at the time the area was flooded. Lake Poongkaliyarra's name is derived from the traditional owners' term for the river pool at the dam site and is linked with the complex mythology of other cultural features in the area. The literal meaning of Poongkaliyarra is "sisters-in-law" (City of Karratha, 2016).

Harding Dam, which at full supply level can store up to 63GL, can provide up to 2 to 2.5 years of drinking water under current climate and demand conditions. Evaporative loss from the lake surface averages 16GL per annum whilst town demand, is currently 9GL per annum. Storage below 18GL is considered unsuitable for supply due to poor water quality.

Harding Dam is dependent on catchment runoff mostly generated from episodic cyclones and tropical lows. The dam's continued ability to reliably meet supply needs is highly influenced by the magnitude and frequency of recharge events, the rate of evaporative loss, water quality within Lake Poongkaliyarra and town demand, wet season storage volume needs to peak above 43GL for Harding Dam to be able to fulfill the current town demand.

Since its commissioning, monitoring indicates Harding Dam storage has exceeded 43GL in storage 60% of the time (Figure 4). In addition, previous modelling using historical climate trends indicated the dam could continue to be a reliable source between 20 to 70% of the time (Figure 5).

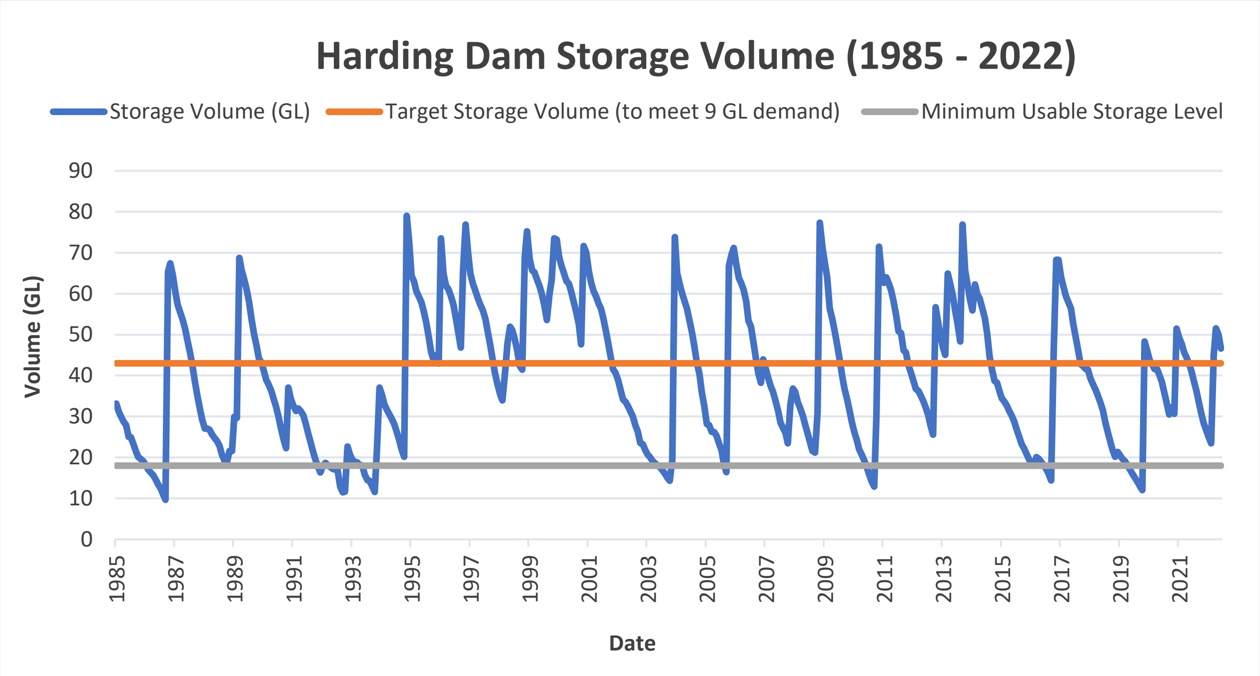


Figure 4: Harding Dam Storage Volumes

Understanding Water Resource Risk in the Western Australian Rangelands

To understand the future reliable yield from Harding Dam and potential compounding influence on the reliability of the Millstream Borefield, Water Corporation developed a rainfall runoff model, linked to a supply scheme water balance model, to simulate the rainfall-generated streamflow into the dam and the dam's ability to meet demand under a range of scenarios.

This modelling assists the Corporation's Asset Managers to understand, under a range of plausible future climate projections, the supply capacity of the dam and aids the assessment of future operational and supply options such as Managed Aquifer Recharge and seawater desalination.

To understand the sensitivity of the dam to changing climate conditions, Water Corporation generated multiple model simulations using a combination of rainfall and potential evaporation inputs representative of the historical climate trends (1940 to 2020) and projected climate, as presented by the Bureau's National Hydrological Projections, to 2060.

Water Corporation's objectives for the Harding Dam study include:

- Sustainable use of the existing surface and groundwater resources that supply the West Pilbara Water Supply Scheme.
- Identify future operational and supply options such as Managed Aquifer Recharge (MAR) and seawater desalination.
- Protection of significant environmental, social, and cultural values associated with water in the landscape.

Informing Water Resource Planning

The Bureau's National Hydrological Projections indicate a broad range of potential risk to Harding Dam's reliable yield. The overarching message from the assessment is that without effective adaptive management these risks have potential consequences for the ongoing reliability of supply to the scheme.

The modelling projected a noticeable decline in the proportion of time Harding Dam could reliably supply the West Pilbara Water Supply Scheme.

Water balance modelling, with the National Hydrological Projections, indicates a potential further decline in the dam's projected reliability. A majority indicating a reliability of 50% or less in response to a changing climate (Figure 5).

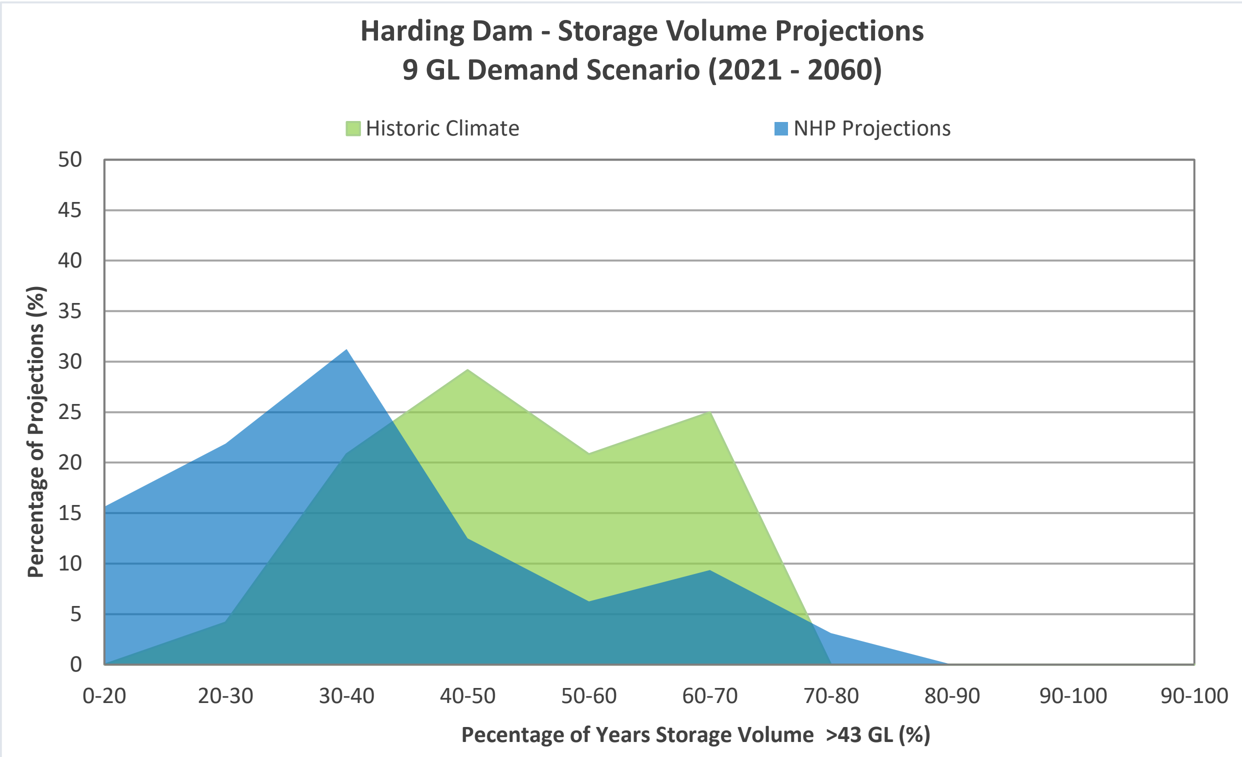


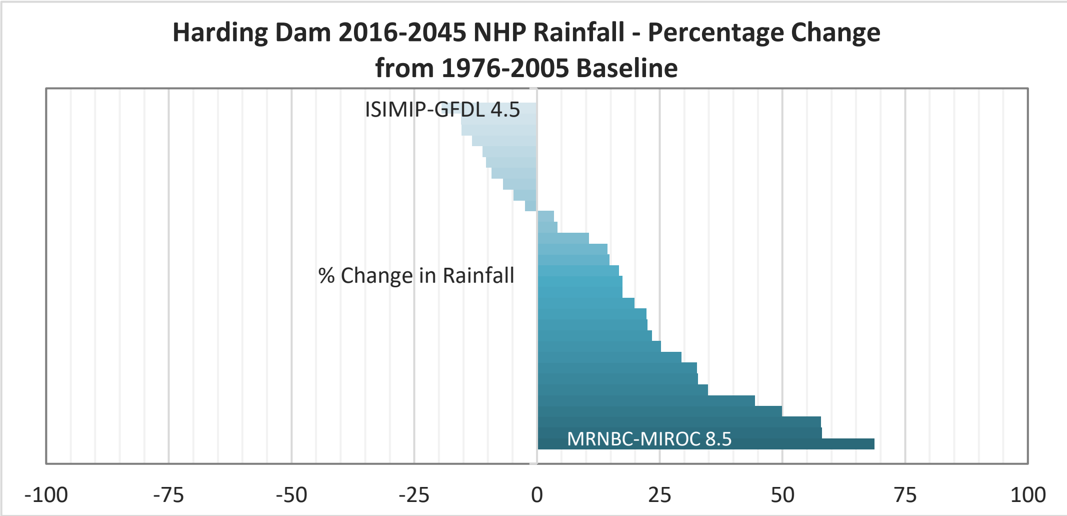
Figure 5: Percentage of Years Target Storage was Reached or Exceeded

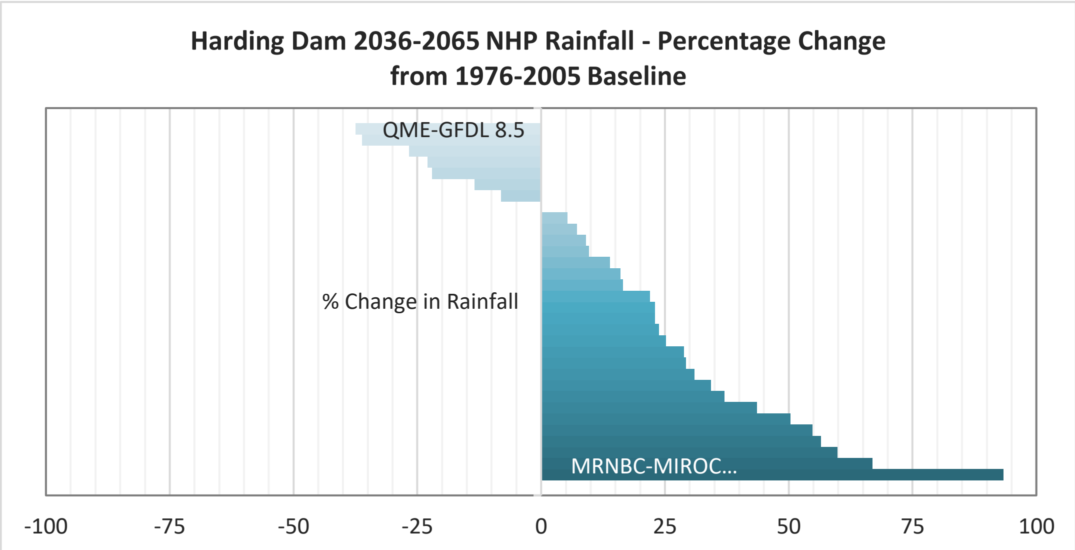
The duration of droughts is likely to increase under a warming climate.

The Bureau's National Hydrological Projections show a wide range of projected declines and increases to the average total annual rainfall out to the end of the century (Figure 6) but at first glance, these did not explain the reason for the projected decline in the future reliability.

Deeper analysis of the interannual variations in the modelled inflows indicate increases in the duration of hydrological droughts, periods when there are insufficient water resources, within the Harding dam, to meet the demand. This is known as drought duration.

To reliably fulfill public water supply demand for one year the wet season inflow into Harding Dam between November to April needs to be greater than or equal to 25GL. The drought duration is therefore defined as the consecutive number of years wet season inflow events are below 25GL.





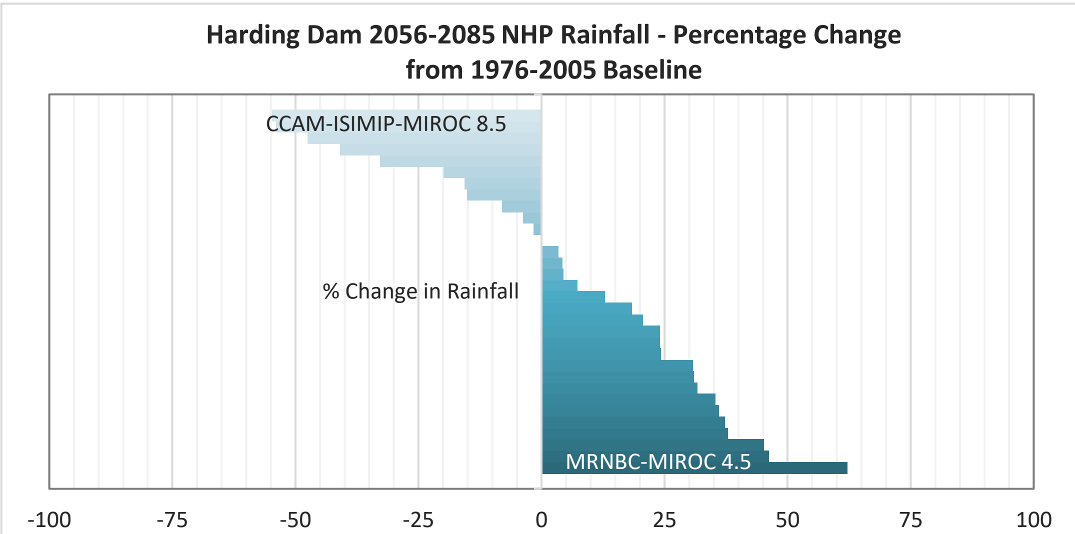


Figure 6: Percentage Change in Average Annual Rainfall from 1976-2005 baseline, projected at 2030 (2016-2045), 2050 (2036-2065), 2070 (2056-2085), for each of the 16-member ensemble and RCPs (4.5 and 8.5).

The range of projected drought durations for Harding Dam with respect to the percentage of time they were observed, has been illustrated in Figure 7. The chart compares historic drought duration trends to the model results using the Bureau's National Hydrological Projections.

A drought duration of 3 to 3.2 years or less historically occurs 90% of the time. The projections indicate potential drought durations ranging from 2.8 years to almost 14 years or less 90% of the time.

The projected increase in drought durations is a significant risk to the dam's ability to maintain continuity of supply.

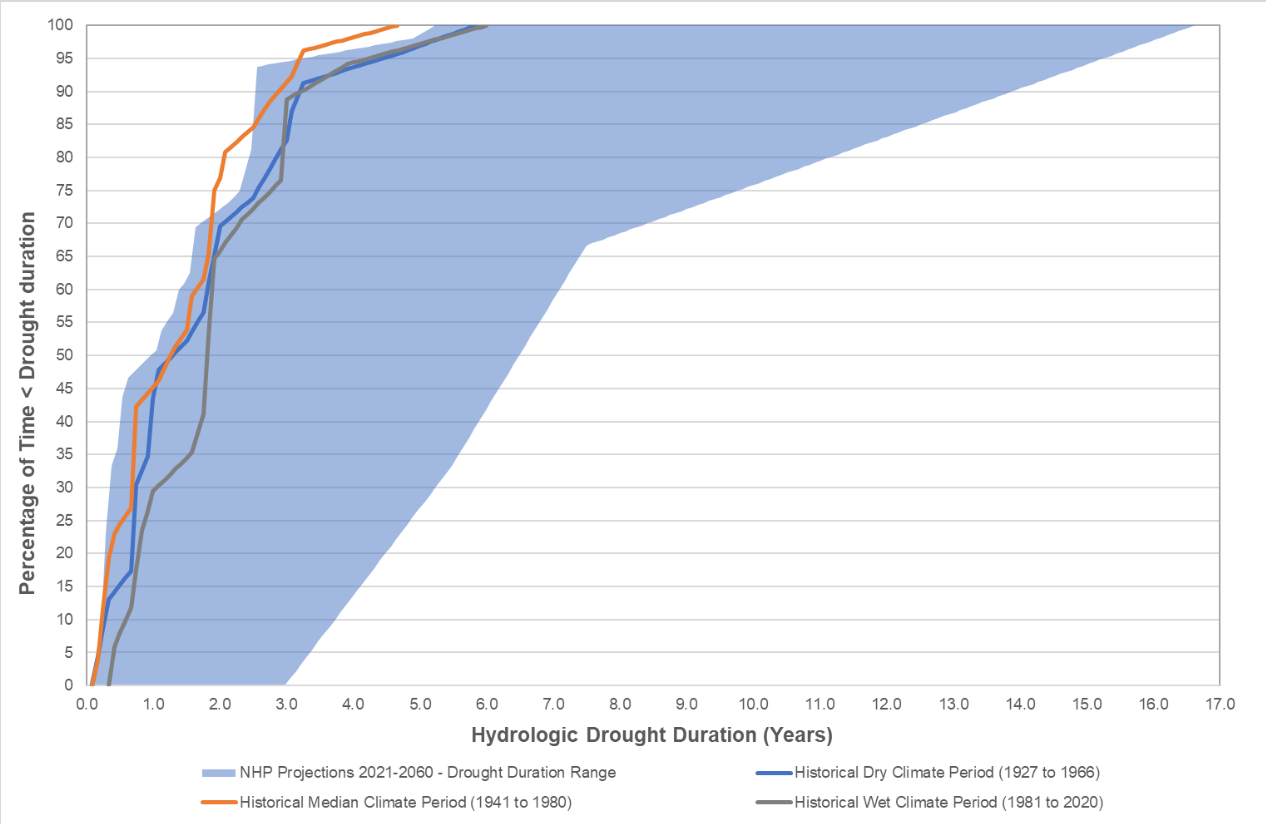


Figure 7: Harding Dam Projected Hydrologic Drought Durations

Communicating climate change impacts and risks in water service provision

This analysis has concentrated specifically on assessing the future reliability of the Harding Dam, in the Rangelands Region using the full range of 32 projections. Whilst it showcases how climate change projections can be used more broadly to delve deeper into assessing specific climate risks, the project also highlighted the complexities associated with this approach.

Assessing 32 equally plausible projections in combination with 24 potential operational scenarios generates a vast amount of output data. One challenge to the study was to communicate the results in a meaningful way so that they inform decision making.

As an example, Figure 7 shows the range of modelled drought durations for the next 40 years from 2021. It shows the large potential spread in projected drought durations. It should be noted that it is not reasonable to assign probabilities to the individual results because the 32 projections selected are equally plausible, and representative of the Western Australian climate, but do not represent all the plausible future climate projections.

When compiling results for multiple model scenarios, it is important to ensure that climate change is adequately incorporated into water resource management by using a range of projections to assess the climate risk to the water resource. It is beneficial for water managers to understand the full breadth of uncertainty in the climate projections and resulting supply reliabilities for a time horizon, and to consider the appropriate adaptation pathways for those futures where thresholds are exceeded.

It is essential water resource planners are equipped to choose the right fit-for-purpose information and data.

Choosing the most suitable climate projections to use

It is important to ensure climate change is adequately incorporated into water resource management by using a range of projections to assess the risk to the water resource. It is beneficial for water managers to understand the full breadth of uncertainty in the climate projections and resulting hydrologic responses for a time horizon.

The Harding Dam case study demonstrated that running model scenarios for the full range of 32 projections is a resource-intensive and data-intensive process. Although the 32 projections present a range of plausible climate change futures, there will be applications when it may not be instructive or necessary to run the full suite of projections, for instance, in low-risk applications.

The investment in time and resources to run multiple projections through large or complex hydrological models may not be beneficial. In other exercises, such as the Harding Dam example, exploring the full range of climate effects for risk assessment purposes by running all the available scenarios or a representative sample of scenarios may be justified. In any case, climate change needs to be adequately incorporated into water resource decision-making by using a range of projections and assessing the climate risk to the water resource – noting future climate information is just one part of decision-making processes.

The choice of projections to be used in water resource management needs to be carefully considered by water service providers and resource managers and will vary depending on the type of assessment (e.g., allocation versus drainage planning), project objectives, resourcing and the level of acceptable risk associated with decision-making. The level of acceptable risk will vary for different water sector assessments and according to the risk appetites and tolerances of decision-makers and stakeholders.

The department has prepared the *Guide to future climate projections for water resource management in Western Australia* to aid with selecting projections for decision-making and undertaking the associated risk assessment and to support the interpretation of future climate results. The basis of the guidance is a series of questions that help water resource managers and decision-makers to develop a storyline (discussed in the next section) and select the appropriate climate projections for their application. Examples of the questions to frame an understanding of climate and the water resource are:

- What do you already know and what do you need to know about the water system? What historical data is there that can help guide this?
- What is the best-case or worst-case water resource outcome for your assessment?
- What climate variables and statistics, metrics or indices are required for a full understanding of how your water resource will respond under future climates?
    - How are the climate metrics represented in the projections?
    - What is the appropriate time horizon for the assessment?
- Are there known thresholds or parameters that could inform the decision?

In addition, water resource managers need to consider how to communicate climate risk and uncertainty, including how it might impact confidence in decision-making and how to manage stakeholder risk perception and tolerance.

Using a storyline approach

With a storyline approach (Shepherd et al., 2018) we can use our knowledge of the system to identify and describe links between the water resource response being assessed and the aspects of climate change driving those responses.

A storyline approach requires a good understanding of system processes, potential vulnerabilities, and sensitivities in the system. Climate processes known to exacerbate system sensitivities can be identified in the projections and, in this way, we can narrow down the projections of particular interest to our system. When developed together with stakeholders, storylines can provide a useful way of communicating and assessing climate-related risk in a specific decision-making context (Sillmann et al., 2020). The premise of storylines can be used to select a subset of the 32 equally likely (plausible) projections for a more detailed analysis of water resource impact, risk, and management actions.

When assessing the risk to our water resources, the appropriate question, given the many, equally plausible futures in the north-west of Western Australia , is perhaps not necessarily ‘What will happen?’ but rather ‘What is the potential impact of particular influences or actions?’

Based on the lessons learnt during the Harding Dam case study, in particular the broad range of potential risk initially represented by the projected changes, it is suggested that the early application of the storylines approach would have been beneficial in refining the context and extent of the yield reliability study.

For Harding Dam, we know its reliability is sensitive to the duration of droughts. It is evident that using a storyline, which considered cumulative rainfall above a threshold to produce runoff, consecutive dry years, or frequency of wet years, to choose a subset of system specific projections would have been advantageous. When exploring a low water availability scenario, we might also avoid using projections which represent a wetter climate such as the MIROC ensemble (Figure 6).

Next steps

Water Corporation will undertake a comprehensive asset planning assessment of the West Pilbara Water Supply Scheme to support investment into new water sources.

This case study was prepared to inform the department's guidance on the Bureau's NHP dataset in water resource management (Bureau of Meteorology, 2021). It will provide a pathway for choosing a subset of projections based on system understanding and the management decisions being explored. *The Guide to future climate projections for water resource management in Western Australia* provides further information on a storyline approach and the NHP for climate change assessments.

Water Corporation, the department, the Bureau, and National Environmental Science Program (NESP) researchers are also collaborating on an additional case study, using the storyline approach, in the Pilbara region in Western Australia (Narsey et.al., 2023). This builds on the case study documented here.

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