# Climate Change Adaptation in BHP's Queensland Mine Water Planning and Hydrologic Designs

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**Abstract**

Little attention has been given to the consideration of climate change in hydrologic designs in the resource industry. As a leading resource company, BHP has a corporate strategy to build water resilience to climate change for long-term business success. This paper describes a set of practical procedures developed for BHP in Queensland that provides guidance to practitioners on how to incorporate climate projections into key hydrologic applications. The developed approaches also provide general guidance on climate data selection, processing and how to incorporate the effects of climate variabilities in hydrologic designs, water management and decision-making.

**Keywords:** Climate Change Adaptation, Hydrology, Mine Water Management

## Introduction

Despite the large body of research that has been undertaken on climate change and its impacts on global and regional water resources and hydrology (Arnell et at. 2011; Gosling et al. 2011), little attention has been given to the practical issues involved in incorporating climate change effects in hydrologic designs and water management.

As a leading resource company, BHP has a corporate strategy based on long-life assets. Building resilience to the physical effects of climate change is essential to long-term business success. The availability of water is regarded as both an asset and a risk to the long-term operations of BHP Queensland. Stretching far beyond the operational phase, hydrology is also a fundamental design input to the closure of BHP's mines. It is thus crucially important to have robust mine water management plans and hydrologic designs that can accommodate the deep uncertainty associated with changes to future climate. The development of procedures that account for a non-stationary climate will facilitate long-term water-related risk assessment and resilient decision making.

Many approaches to selecting climate projection downscaling techniques and data processing methods for hydrologic applications have been described in the literature (Fowler et al. 2007; Maraun et al. 2010) and this presents practitioners with a somewhat bewildering array of options when faced with quantifying the impacts of climate change. The array of choices is partially due to the high uncertainty and variability in climate projections and the ever-evolving nature of climate science investigations.

The procedures described here were developed to provide practitioners with guidance on how best to incorporate future climate projections, including data and downscaling method selection and data processing, into water management and hydrologic applications. While the target audience for these procedures are primarily those undertaking investigations and designs for BHP, the guidelines are of generic relevance to many similar design contexts and hydrologic applications.

## Key Hydrologic Applications and Variables

The guidelines are developed to suit the following key hydrologic designs and mine water planning activities:

- Long-term water inventory forecast and balance modelling
- Flood risk assessment for long service life water infrastructure and hydrologic /

hydraulic designs (e.g. diversions, dams, levees, major drainage and floodways)

- Water demand and supply reliability

The key climatic variables relevant to these applications include average annual and seasonal surface temperature, design rainfall intensities, daily rainfall sequences, and average seasonal potential evaporation rates.

## Overall Approach

There are four high level steps involved in climate change adaptation in hydrologic assessment:

- *Step 1: Set the effective service life or planning horizon*. Different planning horizons will apply to different assets depending on their expected operational life and legacy arrangements, but if less than 20 years from the baseline then no climate impact assessment is required.
- *Step 2: Review the design standards and criteria relevant to the activity*. For flood overtopping risks the criteria may vary typically between 18% annual exceedance probability (AEP) and 0.1% AEP, whereas water supply and containment criteria typically range between 10% and 1% AEP. Probable Maximum Precipitation (PMP) requires no climate change adjustment as recommended by Australian Rainfall and Runoff (AR&R) (Ball et al. 2019).
- *Step 3: Obtain climate change projections*. There is a considerable body of processed information available on climate change projections that is readily accessible to practitioners. Australia-wide projections are available from CSIRO and Bureau of Meteorology (2020), though region-specific projections are also available. In Queensland, the best source of information is the Queensland Future Climate Dashboard and the Climate Change Scenarios for Biophysical modelling (both accessible from https://longpaddock.qld.gov.au/). The latter is also applicable to the whole Australia.
- *Step 4: Adapt climate projections and undertake hydrologic assessment in planning and design*. Information on projected climate change scenarios are incorporated into the same hydrological modelling tools used for assessing risks under current conditions.

## Selection of Climate Projection Parameters, Data and Processing for Key Hydrologic Applications

A flow chart in **Figure 1** demonstrates the steps for climate data selection and processing for hydrologic assessment.

For event-based designs (e.g. flood risk assessment), BHP have adopted the guidance

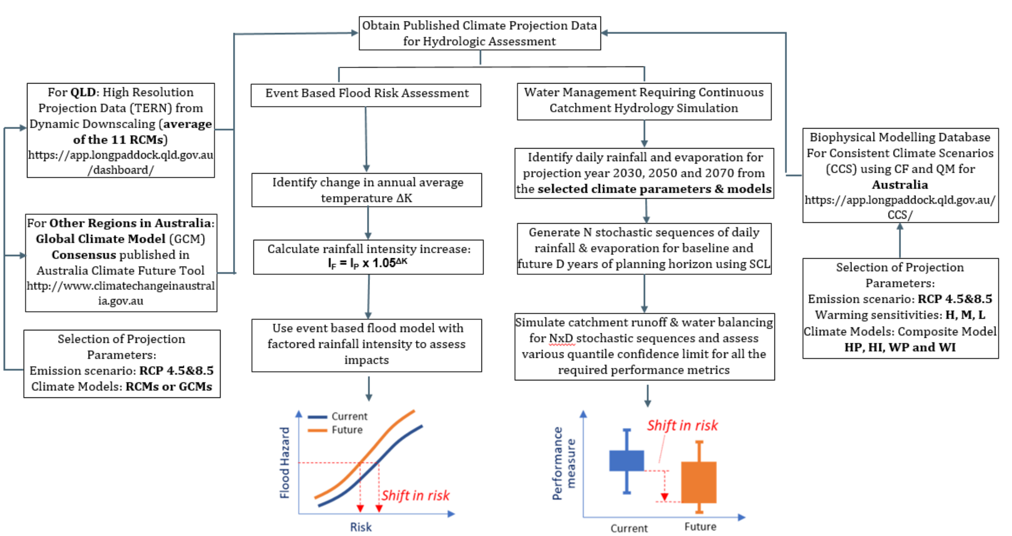



*Figure 1 Overview of steps for climate data selection and key hydrological assessments.*

provided in AR&R (Ball et al. 2019). The basis of this approach is to increase rainfall intensities by a factor related to the increase in annual mean surface temperature. For Queensland, high resolution (10 km) temperature projections using dynamic downscaling method are adopted; while for wider regions of Australia, the GCMs' consensus method recommended in AR&R can be used. This approach provides conservatively high estimates in that the influence of drying soils and other factors are not considered (Wasko and Nathan 2019), but as yet there are no established procedures for dealing with these other issues.

The approach developed to assess impacts on catchment hydrology and water management is more involved as it is desirable to differentiate between the impacts of climate change and those of natural variability, an important differentiation as it relates to the vulnerability to water availability under change. The key concept involved is to characterise system performance relative to the range of behaviour encountered under current climatic conditions, where the degree to which climate change causes the behaviour of a system to shift outside this baseline range provides an indication of the projected shift in risks due to climate change (Nathan et al. 2019). This concept is illustrated in the lower right panel of **Figure 1**, where the range in performance of the system under current climatic conditions (e.g. volume of water held in storage, or the likelihood that a dam is overtopped) is represented by the blue-coloured box and whisker plot. Under climate change, the range in system performance is altered, as represented by the orange-coloured box and whisker plot. The shift in risk can be assessed for typical (i.e. median) operating measures, or else any performance metric (e.g. 95%ile or 5%ile wet or dry resilience) that is of most relevance.

The assessment of the change in system performance due to climate change can be undertaken using a single climatic sequence obtained from historical records. For example, a baseline period of 1960–2018 is considered representative of current climate, and this provides a 59-year simulation period with which to assess baseline performance. The approaches to assessing climate change is referred to as the "Change Factor" (CF) (or "delta scaling") and Quantile Matching (QM). With CF method, the monthly mean values are shifted by the projected change in for the adopted climate scenario of interest (e.g. a Representative Concentration Pathway Scenario of 8.5 represents a future in which there are little curbing of emissions), at a future year that is relevant to the planning horizon of interest (e.g. 2100). For example, if a monthly mean rainfall is projected to decrease by 10%, then the rainfall of the corresponding month of the 59-year observational record is also reduced by 10%. With QM method, the shape of the probability distributions of future data is altered to provide wider climate variability (Ricketts et al. 2013). The simulation models of catchment runoff and water management are run for these adjusted time series, and the change in performance reported.

However, there is a drawback in the CF/QM approaches. A single sequence altered from historical climate is often insufficient to capture the climatic variability and assess the possible range of system behaviours, especially in those systems with storage volumes that are larger than expected annual inflows. Accordingly, one robust approach to assessing system performance is through the use of stochastic simulation techniques, where a range of suitable techniques are described by McMahon and Adeloye (2005). Practical tools for undertaking this analysis are provided by Srikanthan et al. (2007), and their application to mine water management studies is discussed by Nathan and McMahon (2016).

## Guidance on Selecting Climate Projection Parameters, Models and Databases

Detailed descriptions of the selected climate projection parameters, databases and stochastic data processing methods adopted in the Guideline as shown in **Figure 1** are available in Supplementary Materials.

## Results & Work Example

The direct outputs included in the Guideline are organised as a "one-stop-shop" for both internal (BHP) and external hydrologists / practitioners to extract the selected projection data for the target year(s) and location(s) of interest, and use the recommended procedures to process the data for the key hydrologic designs and applications. Due to the large volume of the selected databases, the direct outputs are not included here but summarised in Supplement Materials. They can be accessible for external readers and practitioners with the consent of BHP.

The following worked example demonstrates how to undertake continuous water balance modelling (WBM) and catchment simulations as indicated in Figure 1.

Both mine affected water (MAW) stored on site (e.g. pit storages and dams) and fresh water are crucial sources for production. Understanding future water inventories, shortfalls and demands as well as climate impact on them is critical for infrastructure planning and business decision making. Continuous WBM and catchment simulation with daily time step are adopted in inventory and demand forecast. Key elements included in WBM are the estimation of: 1) direct rainfall and catchment runoff into open pit water storages and dams; 2) evaporation from open water bodies and contributing catchments; 3) MAW and fresh water demands for production and dust suppression (not climate dependent); 4) Controlled MAW releases to downstream receiving creeks.

The Australia Water Balance Model (AWBM; Boughton 2004) was used to relate daily rainfall and evaporation to soil moisture and runoff. Selection of AWBM parameters (e.g. storage capacity, BFI, channel coefficient) is location and catchment specific. Generated stochastic daily rainfalls (single or multiple sites) and repeating pattern of monthly pan evaporation shown in Figure 1 are key inputs for AWBM simulations for calculating inventory, demand and shortfall volumes. The stochastic rainfall and runoff time series are also used in AWBM to produce synthetic river flow conditions which is a key controlling factor for MAW releases.

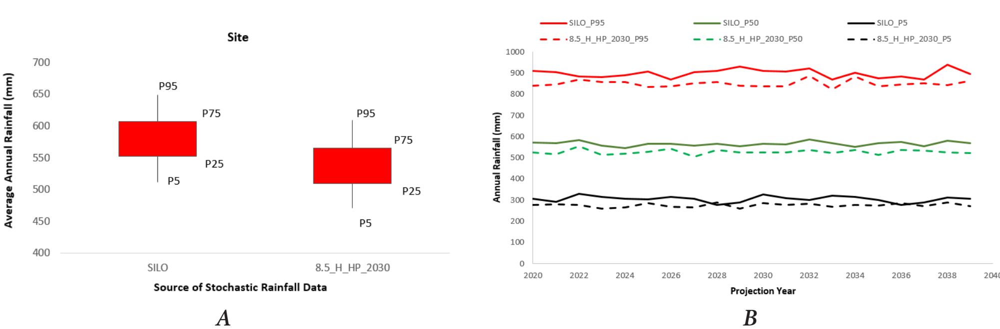
*Step 1*: Select SILO data (baseline: 1960–2018) & planning horizon (2020-2039), and recommended model (e.g. 8.5_H_HP_2030_Site) for projected rainfalls and evaporation;

*Step 2*: Generate stochastic rainfall sequences (500 realisations of 20-year sequences) for SILO and Projected data following the process in **Figure 1** (Detailed in Figure S2, *Supplementary Material*);

*Step 3*: Generate monthly evaporation patterns as per the process in **Figure 1** (Detailed in Figure S2, *Supplementary Material*);

*Step 4*: Run the WBM with the 500 realisations (both SILO and Projections) and analyse the impact of climate change on inventory, shortfall and freshwater demand forecasts between "BAU" (baseline) and "BAU+CC" (future climate). Example results are demonstrated in **Figure 2**, **Figure 3** and **Table 1**.

This worked example demonstrates that the cumulative effects from a slight decrease (40-60mm at various quantile levels in **Figure 2**) in annual rainfall and evaporation increase (**Table 1**) can propagate through catchment runoff simulations and may be magnified during back-to-back dry and wet year sequences contained in the stochastic

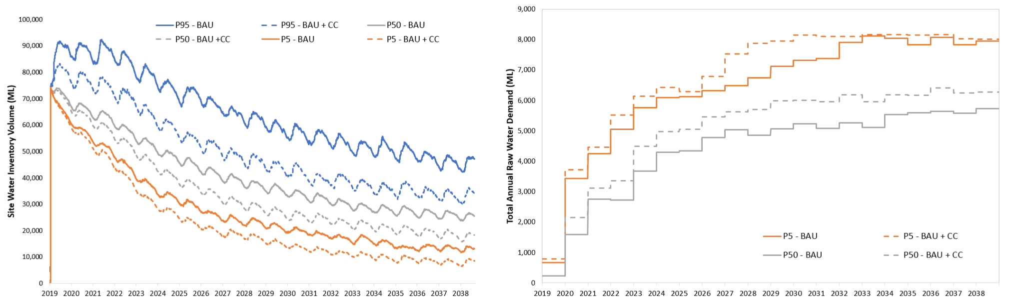



*A* *B*

***Figure 2** Comparison of Stochastic Rainfalls SILO vs. Future Projection (A) Quantile distribution of 20-year Average Annual Rainfall; (B) Annual Rainfall Quantile Envelopes (P95, P50, P5) from 2020 to 2039.*

*Table 1* Pan Evaporation Change Factor (%) for the "Site".

| Jan | Feb | Mar | Apr | May | June | July | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 5.63 | 5.58 | 5.79 | 4.61 | 4.61 | 5.06 | 3.53 | 3.90 | 4.20 | 4.82 | 4.25 | 4.35 |




*A* *B*

***Figure 3*** *Impact of Climate Change on (A) Site Water Inventory Forecast; (B) Fresh Water Demand Forecast (BAU: Simulation with SILO baseline data; BAU+CC: Simulation with Projected Climate Data).*

simulations. This could subsequently have substantial effects on water inventory and fresh water demand forecast, and drive change of management and business decisions. For instance, the confidence limit on wet condition (P95 **Figure 3A**) is used for site water storage capacity evaluation and planning purposes, while those representing median and dry conditions (P50 and P5 in **Figure 3B**) are normally adopted for water demand planning and evaluation of water supply reliability.

## Conclusions

The developed guideline meet the following key requirements: 1) *Simplicity*: The outcomes produced from the processes are easy to follow and are well suited to facilitate decision making; 2) *Practicality*: the procedures are straightforward for practitioners to follow and replicate; 3) *One-stop data sources*: the procedures take advantage of readily accessible information on baseline and projection data for the key climatic variables; 4) *Consistency and comparability*: The adopted data and means of data processing are consistent for similar types of hydrologic applications (e.g. event-based flood estimate, continuous water balance modelling) and allow comparison between the findings derived from projected climate data and the existing knowledge from the baseline studies.

The guidelines were developed to serve as an internal guidance and criteria for factoring climate projections into BHP's Queensland sites. However, given the generic nature of the guideline, the same or similar databases and approaches (as shown in Figure 1) can be applied to broader hydrologic designs in other regions across Australia.

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## Supplementary Materials

*Selection of Climate Projection Parameters, Databases and Data Processing for Key Hydrologic Applications*: As part of the guideline development and referenced in Figure 1, this document provides detailed descriptions of the selected climate projection parameters, databases and data processing methods adopted.

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