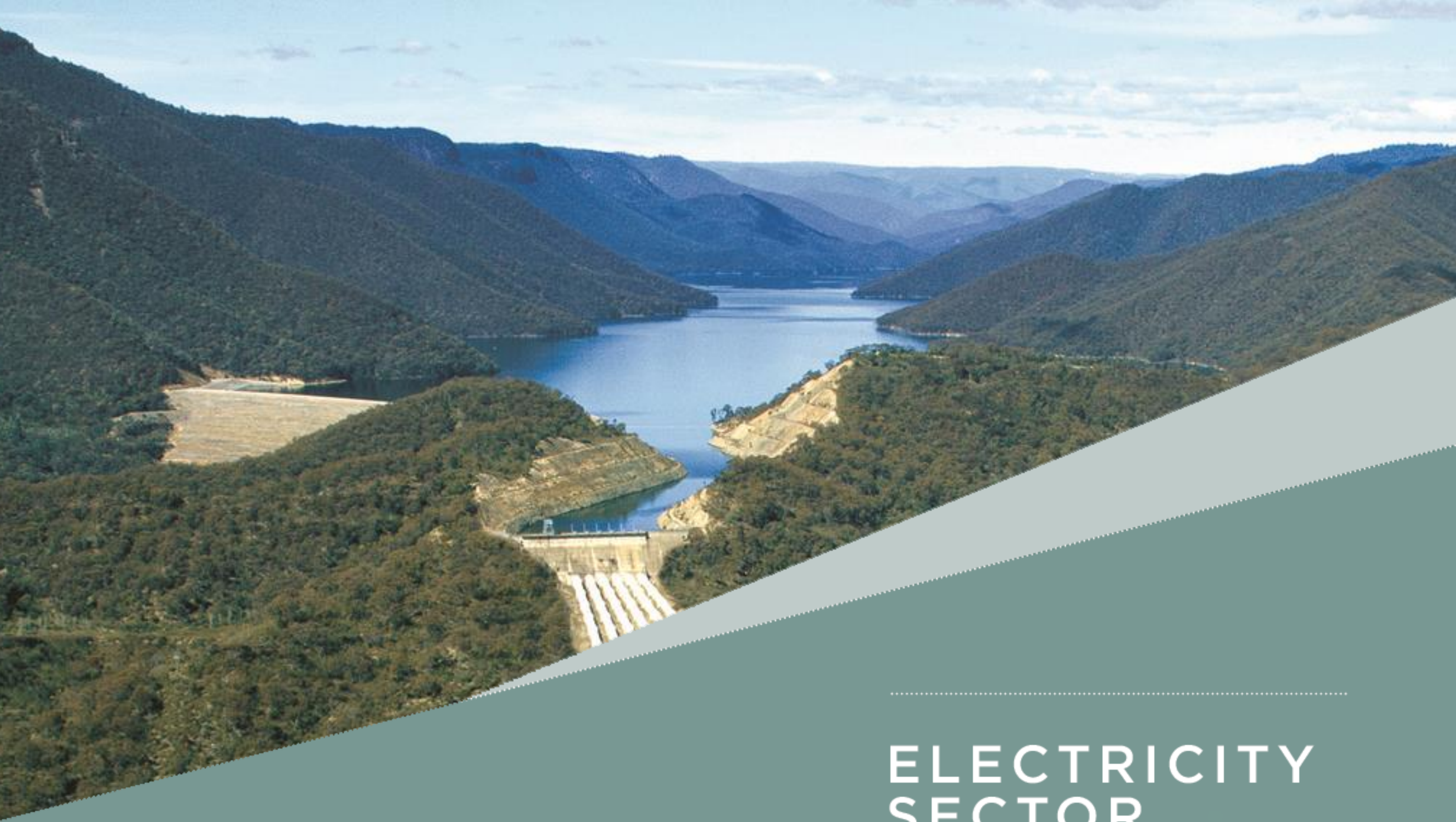

ELECTRICITY SECTOR CLIMATE INFORMATION PROJECT

Report for the Second ESCI Weather and Climate Risk Workshop:

Climate Change and Hydroelectric Power

July 23, 2019

Australian Government
Department of Industry, Science, Energy and Resources

CSIRO

AEMO
AUSTRALIAN ENERGY MARKET OPERATOR

Australian Government
Bureau of Meteorology

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Executive summary

Purpose

The objectives of the Electricity Sector Climate Information (ESCI) Project are:

1. Support decision-makers in the National Electricity Market (NEM) to access and use tailored climate information to improve long-term climate risk planning by collaborating on existing information and planning processes. This will include identifying and where possible providing priority climate information that is critical to support these long-term planning processes.
2. Develop and demonstrate a best practice methodology for analysing climate change risks that can also be used by other sectors, for example, telecommunications.
3. Contribute towards a longer-term vision for the next generation of climate projections and seamless climate and weather services.

The second workshop targeted a specific generation asset class, hydro-electric generation (hydro), that is vulnerable to climate change due to changing rainfall patterns, declining rainfall and increasing evapotranspiration leading to reduced dam inflows[1] and declines in stored water. Unlike the first ESCI industry workshop, the second workshop was not a scenario planning exercise. Instead, it explored the current best practice in climate projection and hydrological modelling, and case studies of how this is used in risk-based decision-making. In particular, the workshop reviewed how water managers, who have commissioned perhaps the largest proportion of applied climate projection research in Australia to date, have led in exploring future water availability scenarios for strategic, tactical and operational planning of water resources.

The workshop focused on the likely long-term (30 year) impacts of changing weather patterns and rainfall over southern Australia and changing runoff and inflow under climate change, leading to reduced reliability and availability of inflows and stored water for hydro generation in the NEM.

Workshop objectives were to:

a. Understand what NEM decisions require future inflow and water storage information.
b. Understand what form of inflow and storage information is currently used by AEMO.
c. Understand what form this information should take in the future, to account for climate change impacts on hydro generation.
d. Understand existing science which informs decisions in the broader water resource management sector, and what new data and information will be coming online over the life of ESCI.
e. Understand how major players in the water industry have used that information in the context of risk-based decision making and investment.
f. Understand to what extent NEM hydro forecasting for strategic planning needs can be met by currently available projections, and what additional model analysis, regional climate modelling or downscaling, within the scope of the ESCI project, could provide significant additional benefits.

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[1] While inflow and streamflow are very closely related and the terms are often used interchangeably, in this document 'streamflow' is used when referring to hydrological science and modelling, and 'inflow' is used specifically to refer to measurement of water collected in dams.

For hydro-electric generation, water stored in dams is the fuel used to produce electricity, therefore there is a need to model the influence of climate change on the availability of that fuel over time.

Structure of the workshop

The workshop consisted of the following elements:

- Presentations on the considerable work being undertaken (outside of the ESCI project) to improve national projections of inflow and water resources in the water sector, including preliminary output from ongoing downscaling and hydrological modelling projects.
- Case studies on modelling the impact of climate change on hydrological flows to support improved risk-based decision-making in DELWP, Melbourne Water and Hydro Tasmania.
- Presentations of historical reanalysis data and application ready climate change projection data which could provide climate-change-adjusted inputs for hydro generation modelling.
- Discussion on best available hydro-climate science to guide hydro generation modelling.
- Breakout groups to identify how the hydro-climate science can be used today, and whether new projections would significantly improve decision-making.

Outcome of the workshop

The workshop largely achieved its objectives as follows:

a. AEMO and market participants took away immediate value through a better understanding of the factors that affect hydro generation.

    - AEMO developed a greater understanding that rainfall projections, or simple empirical relationships between future rainfall and run-off, are unlikely to provide an accurate portrayal of future water resources for hydro generation. Instead, coupled or downstream hydrological modelling, including the impacts of temperature, soil moisture, evapotranspiration and other factors such as rainfall sequencing are required, particularly under future global warming. Climate-adjusted dam inflows are being included in the 2019 ISP, and future versions will be informed more fully by the information covered in this workshop.
    - Some of the hydrological scientists came into the workshop with a poor understanding of the electricity industry requirements, so the workshop helped to bridge the gap between the scientists and the market.

b. The presentations covered the best science available today that informs the water sector.

    - Forecasting dam inflows is complex as it requires information on streamflow, runoff and evapotranspiration rather than rainfall.
    - Underlying long-term trends are evident in some regions.
        - Drying in recent decades across southern Australia is the most sustained large-scale change in rainfall since national records began in 1900, and the trend is expected to continue.
        - The drying signal in the southwest of the country has been one of the most consistent climate change signals globally, appearing in virtually every GCM.
        - Most models also suggest that run-off has declined faster than rainfall; this appears to be more acute in alpine regions.

- The data developed by Chiew et al (CSIRO) on climate-adjusted catchment specific inflows should be adopted where possible for NEM applications. Within the life of the ESCI project it is expected that the Bureau of Meteorology National Hydrological Projections (NHP) Project will provide incrementally better information – this expected to be available in 2020.

c. The presentations on how Hydro Tasmania and Melbourne Water use the available climate science to make decisions dependent on projected water availability provide useful frameworks for hydro forecasting for AEMO and other industry players. This thinking will be incorporated into the development of the risk framework for decision-making, under development by ESCI.

d. The workshop assisted in characterising the current uses of hydrological projections for the NEM, with different levels of maturity across different industry participants.
    - Hydro generation operators indicated climate and hydroclimate projections were in use and had been incorporated with their operational hydrology considerations.
    - AEMO had not previously used climate projections for modelling dam inflows.
    - Melbourne Water has detailed future supply and demand scenarios with trigger points for investment (for example in future desalination plant). Similarly, SA Water and Sydney Water have advanced strategic planning for future water availability.

The workshop itself did not fully canvass the hydrological modelling data needs of AEMO and the industry, however it formed the basis for follow up discussions, and these needs have now largely been covered. For the interests of the project, this report clearly differentiates between information gathered at the workshop and that gathered subsequently.

Contribution to ESCI project outcomes

The ESCI project is currently drafting guidance material for using climate projections in risk assessments. These will be relevant to the hydro sector and will be informed by the industry needs identified in the workshop. The guidance material is supported by 'Master Classes' in climate change conducted within AEMO to enable new data to be integrated quickly and efficiently into AEMO demand and supply modelling.

The workshop identified two existing, or shortly available, sources of tailored climate information which will improve the quality of data for the hydro sector.

1. The ESCI project will work with CSIRO to provide their currently available runoff projections for major catchments. This information will immediately provide relevant climate-adjusted data to AEMO for hydro forecasting.
2. The National Hydrological Projections Project will provide a seamless national climate service for water which will further refine assessment of the impact of climate change on hydro assets. The ESCI project will work with the NHP to make this information available to AEMO and the NEM.

The project is also developing a standard approach for generating climate scenarios which can be used to stress-test physical and transition risk. The outcome is expected to be a scenario-based framework which can be used by the electricity sector for identifying vulnerability to extreme and compound weather events. The presentation and discussion from Melbourne Water included an approach to scenario-based decision-making which will help inform this work.

A key deliverable of the ESCI project is to develop a new standardised methodology for producing multi-hazard climate change data and information when there is no good quality existing information. The process of integrating the data identified in the workshop into AEMO modelling will help inform the development of the standardised methodology, leading to a consistent set of climate projections for all variables and sectors of the NEM.

Finally, The ESCI project is developing a ‘best practice’ standardised climate change risk framework for identifying the vulnerability of and risks to critical NEM infrastructure and capacity. This holistic approach is consistent with the request of workshop participants and will support the electricity sector in analysing and managing long-term climate risk. Further interviews will be conducted with the hydro sector so that a detailed case study can be prepared to test the path to market impact of climate change data for hydro generation.

1. Workshop Goal and Objectives

The Australian Government is providing $6.1 million over three years, from 2018-20, to improve climate and extreme weather information for the electricity sector. The objectives of the Electricity Sector Climate Information (ESCI) Project are:

1. Support decision-makers in the National Electricity Market (NEM) to access and use tailored climate information to improve long-term climate risk planning by collaborating on existing information and planning processes. This will include identifying and where possible providing priority climate information that is critical to support these long-term planning processes.
2. Develop and demonstrate a best practice methodology for analysing climate change risks that can also be used by other sectors, for example, telecommunications.
3. Contribute towards a longer-term vision for the next generation of climate projections and seamless climate and weather services.

The ESCI project will develop and demonstrate the use of a best practice climate change risk framework. The risk framework will provide guidance on designing scenarios for assessing resilience, and a standardised methodology for developing multi-hazard climate change data and information. The standardised methodology will consider:

- Planning horizon, e.g. next 10-30 years, 50-100 years;
- Assumptions about future scenarios of greenhouse gas emissions or global warming scenarios, e.g., low, medium, high;
- Climate variables, e.g. temperature, rainfall, evaporation, evapotranspiration, runoff, solar radiation, wind;
- Spatial scale, e.g., site(s), region(s) and temporal scale, e.g. hourly, daily, monthly, seasonal, annual, decadal;
- Statistical analysis methods, e.g., averages, time-series, threshold exceedances, probabilities, including guidance on what is or isn't appropriate for given situations;

This workshop focused on potential impacts of observed and projected reductions in rainfall and increases in temperature under climate change, leading to reduced reliability and availability of hydroelectric generation ('hydro power') in the NEM. Scientists from the Bureau of Meteorology, CSIRO and DELWP presented the best available science on observed and future climate change and hydrological flows, and representatives from Melbourne Water and CSIRO (for Hydro Tasmania) gave presentations on how they currently use climate science to inform strategic decision making.

Information on hydrological projections and the associated changes to dam inflow is expected to influence modelling for AEMO's Integrated System Plan (ISP) and Electricity Statement of Opportunities (ESOO) (see Section 3) and to be of value to Hydro Tas and Snowy Hydro (which together provide 80% of Australia's total hydro energy).

Workshop objectives were:

a. Understand what NEM decisions require future inflow[2] and water storage information.
b. Understand what form of inflow and storage information is currently used by AEMO.
c. Understand what form this information should take in the future, to account for climate change impacts on hydro generation.
d. Understand existing science which informs decisions in the broader water resource sector, and what new data and information will be coming online over the life of ESCI.
e. Understand how major players in the water industry have used that information in context.
f. Understand to what extent NEM hydro forecasting for strategic planning needs can be met by currently available projections, and what additional model analysis, regional climate modelling or downscaling, within the scope of the ESCI project, could provide significant additional benefits.

2. Identification of industry data needs

The discussion at the workshop was focused on pragmatic decisions about what data are useful now and what is becoming available over the next 18 months to assess risk for hydro generation. It is apparent that the hydro generation companies are already using quite sophisticated hydrological models and that there were "no surprises" in the science presentations, however this is not currently the case for AEMO. It is worth noting that some of the modelling (for example 'Climate Futures for Tasmania') relies on models which could be considered superseded (e.g., CMIP 3).

Hydro-power companies need to understand fuel (water) availability and consider market opportunities created by wind and solar generation variability. This opportunity increases as the energy market shifts away from coal and gas-fired thermal power generation so the need for weather/climate/water information will grow with an ever more coupled energy market. Given the ability to store water, hydro generation needs less temporal granularity in their weather information than solar and wind generation.

The workshop identified key requirements for hydro power modelling:

- Dam inflows. This is derived from: precipitation and its partition into rain and snow, snow storage (snowpack), evapotranspiration, dam evaporation, soil moisture, runoff, streamflow and streamflow elasticities. These all vary with altitude.
- Inflow resolution. In the past, AEMO has modelled monthly dam inflows. Hydropower companies use more granular data to better represent the ability of certain hydro assets to respond to spot price market fluctuations and convective rainfall (inflow) events. In general, the smaller and steeper the storage catchment, the smaller the time-step that needs to be considered.
- Dam managers also need to consider seepage losses and wastage attributable to storms and heavy rainfall events, safety requirements, e.g., scheduling of spills, and the need for other water uses including environmental flows, irrigation supply and recreational flows.

[2] While inflow and streamflow are very closely related and the terms are often used interchangeably, in this document 'streamflow' is used when referring to hydrological science and modelling, and 'inflow' is used specifically to refer to measurement of water collected in dams.

The discussion concluded that:

- Agreement is needed on a methodology for climate change risk assessment that includes the selection of emission scenarios, GCMs, downscaling, bias correction and hydrological modelling. Monthly dam inflow information is sufficient for AEMO modelling purposes.
- The industry should consider both top-down scenarios which use GCM data and bottom up approaches such as decision scaling and adaptation pathway assessments. There is a need to stress-test output – for example, to compare bottom-up calculations (from hydrology models) with top down projections from GCMs.
- Dam inflow modelling for each major catchment is needed out to 2050 which incorporates both current and future variability and extreme events. AEMO modelling currently uses too short a time-series to sufficiently sample historical variability. The industry needs an assessment of whether the data are likely to be representative of future dry periods (including information about intensity, frequency and duration).
- Supply forecasts require information on coincident variables (wind, temperature, solar irradiance) as these have cascading impacts given the increasing importance of hydro power to 'firm' intermittent renewable energy sources.
- As well as energy market modelling, the hydro generators need hydropower data for design of future infrastructure (size, safety) and to understand future environmental impacts and the impacts on other water users.

Other factors that affect hydro generation forecasting:

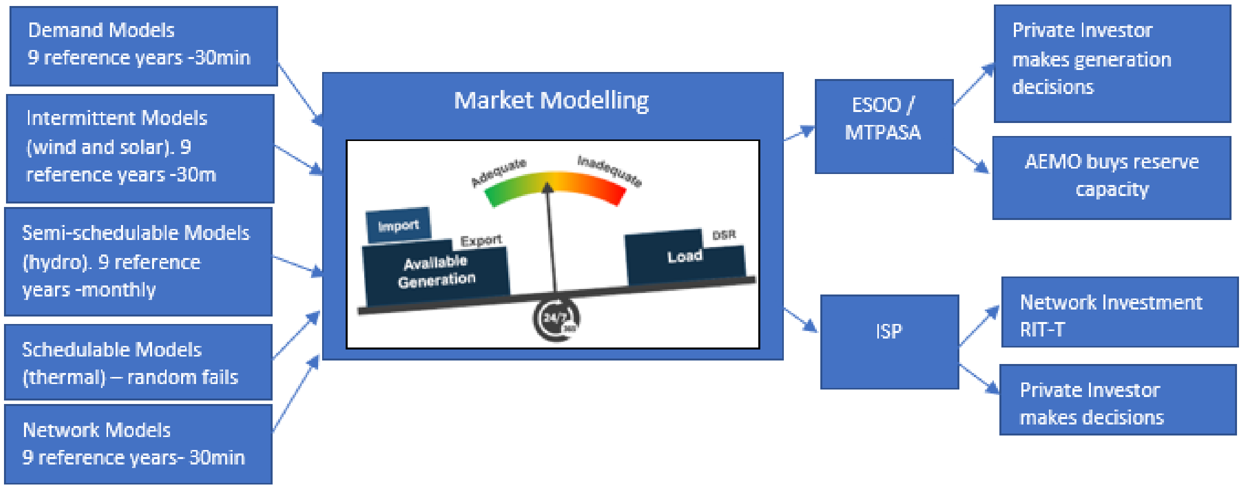
- Hydro operators noted that inflow variability is a minor component of the business model compared with economic drivers, for example, contracts with gas, diesel, and the provision of solar and wind generation determine when hydro generation is needed.
- There is a need to educate people in the sector on probability-based projections and demonstrate climate model reliability/performance. It is also important to explain climate processes driving observed and projected changes.

3. AEMO supply context and needs of hydro forecasting

3.1. NEM and hydro-electric investment context

AEMO produces two primary documents that inform long-term investment in the NEM: the Electricity Statement of Opportunities (ESOO) and the Integrated System Plan (ISP). The ESOO provides technical and market data that informs the decision-making processes of market participants, new investors and jurisdictional bodies over a 10-year outlook period. The ISP delivers a 30-year strategic infrastructure development plan, based on sound engineering and economics, which can facilitate an orderly energy system transition under a range of scenarios. The ISP is technology-neutral, taking into consideration a broad set of thermal and renewable generation, transmission, and storage investment opportunities across the NEM to assess the transmission development needed to deliver the ‘least resource cost’ future energy. The result of this modelling and engineering analysis is the identification of those investments in the power grid that can best unlock the value of existing and new resources in the system, at the lowest cost, while also delivering energy reliably to consumers[3].

Figure 1: Relationship between demand and supply modelling and NEM investment decisions



The principal inputs to the ISP relate to forecast changes in customer demand, the anticipated retirements of existing supply resources, and the economic profile and other attributes of new supply resources, including storage resources. Weather is one of many factors considered in both the demand profile, and supply output (see Figure 1).

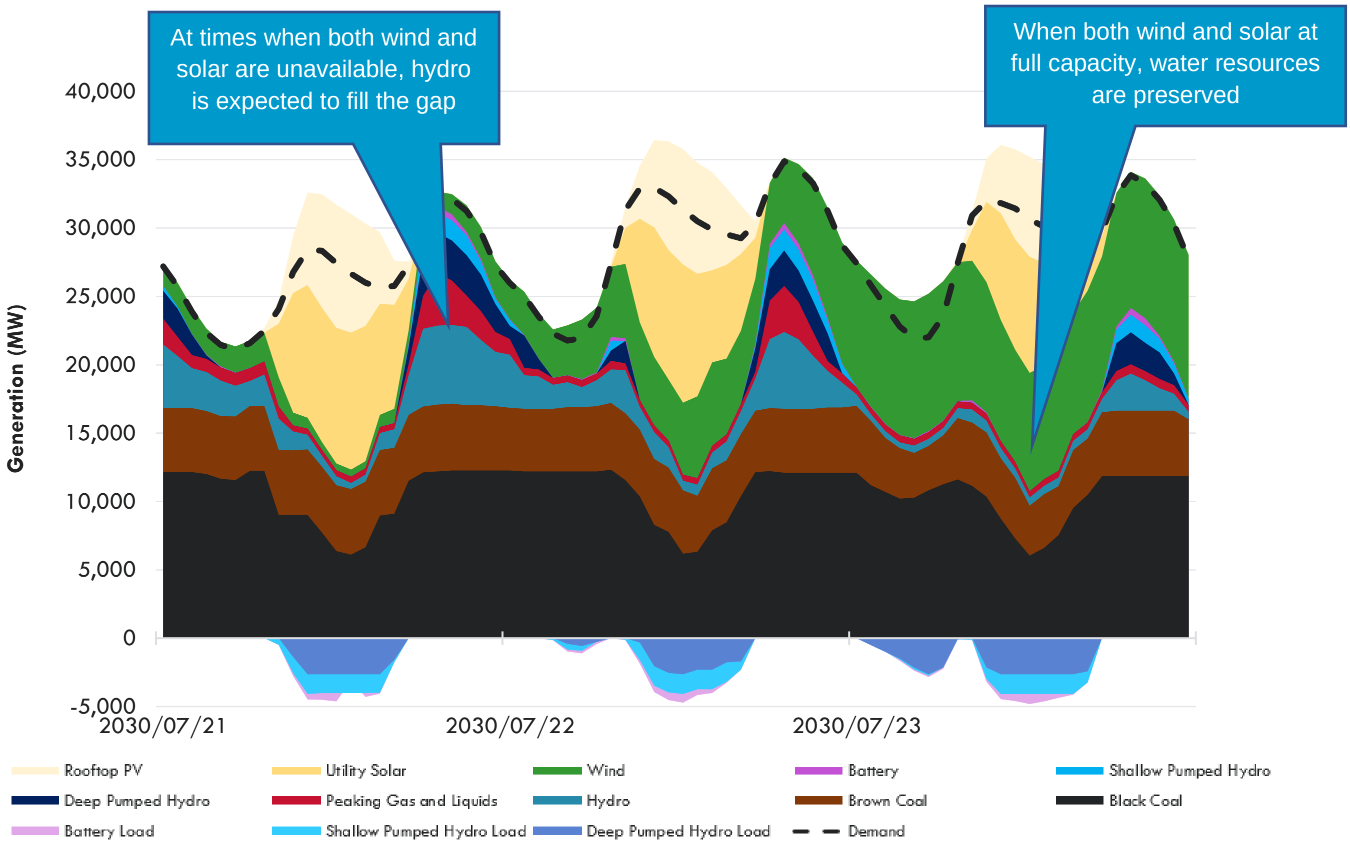
The NEM demand profile, proposed transmission network (providing access to current and future supply) and supply scenarios in the ISP, then inform cost-benefit analyses by energy supply companies, including the hydro-electric generation companies. It is worth noting that due to the very high volatility of wholesale electricity prices, revenue models used to justify hydro-electric investments are more dependent on market conditions than on fuel availability (dam levels); actual scheduling of hydro energy generation occurs in response to market price and retailer contracts.

3.2. Current state and future needs of hydro forecasting in AEMO

Hydro power is a semi-schedulable energy source, subject to availability. The ISP indicates that under all scenarios intermittent generation (wind, solar) is forecast to displace scheduled generation (coal, gas), and hydro and pumped hydro will play an increasingly important role in stabilising energy supply (see Figure 2). This means that accurate estimates of future hydrological storage and generation capacity are essential for planning for reliability and resilience.

[3] Source: AEMO **Integrated System Plan 2018**

Figure 2: Typical winter NEM generation profile in 2030, with portfolio of storages[4]



AEMO forecasters use the PLEXOS market model with 9 reference years of historical monthly dam inflow data as input[5]. AEMOs market models assume that there is no borrowing of water across (fiscal) years, i.e. at the end of each year the volume of the reservoir is returned to the initial volume, which is static for the entire horizon, based on historical data. They use a 'rolling reference year' approach which repeats the 8 historical water years into the future plus a representative drought year from the millennium drought into the future. Given the very short climatology used, natural variability in inflows is probably underestimated, for example, a 9-year period may not properly sample variability in inflow associated with the Indian Ocean Dipole or El Niño-Southern Oscillation natural modes of climate variability[6].

High quality climate projections that include information about future trends in dam inflows over the next 10-30 years, and which also preserve the intervariable correlations between wind, solar and hydro inflows, are vital to assess the changing electricity supply interaction. AEMO will consider climate-change impacts on median stream flows in their hydro modelling in the 2019

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[4] Source: AEMO. 2019. Building power system resilience with pumped hydro energy storage.
[5] Source: WPA interview with Cristina Rocca and Keith Ruddell, June 2019.
[6] It is generally accepted that around 30 years of data is needed to sample IOD and ENSO variability; see for example the description of IOD and ENSO here: http://www.bom.gov.au/climate/ahead/#tabs=Outlooks-and-monitoring.

ISP (see Section 8)[7]. Further refinements could include improving the ability to capture the historical variability of inflows, varying reservoir levels at the start of year and including sequences of dry years. This will improve the accuracy of business cases for investments including pumped hydro (**Snowy 2.0, Battery of the Nation** and others) and accompanying transmission augmentation.

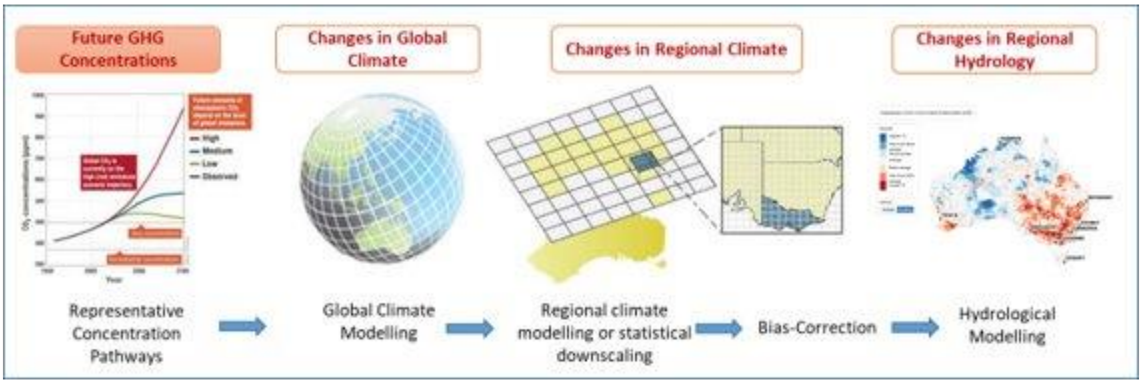
4. Developing hydrology projections for dam inflows:

The impact of climate change on water availability in Australia is complex, and typically a range of projected futures is provided to the stakeholder. A detailed description of how climate projections are developed, including sources of uncertainty, is provided in the *Climate Data Inventory,* a key document for the ESCI project; a brief description is provided below.

Developing projections of future hydrology (runoff, inflow and water storages) is a multi-step process which starts with consideration of the Representative Concentration Pathways (RCPs) and the projections of future climate from Global Circulation Models[8] (GCMs) (see Figure 3). As hydrological functioning is subject to non-linear and sometimes threshold-based responses to rainfall as well as interaction between rainfall and evapotranspiration, hydrological models are used to simulate the hydrological response to future climate: such as runoff, streamflow and dam inflows.

It should be noted that in some water applications, rather than using data derived from GCMs, a longer (e.g. 1000 year) times-series of rainfall and potential evapo-transpiration (PET) data is stochastically generated from the observed historical record and the delta change method (using climate models to derive a scale factor to apply to historical data) applied to the time-series before using in a hydrological model (e.g. SEQWater, DES Qld).

Figure 3: Process for developing hydrological projections from GCMs (Source: Adapted from VicCI)



[7] Using a straightforward 'delta shift' approach which adjusts the historical streamflow by adding a GCM-derived rainfall projection. See Section 8 for a more detailed discussion
[8] It is best to use as many as feasible of these climate models to sample the range of uncertainty. Note: choosing the driest and wettest GCM for rainfall does not necessarily mean you will get the wettest and driest scenario for runoff. It may be instructive to choose the four corners of a change matrix, i.e. the coolest-driest, coolest-wettest, warmest-wettest and warmest-driest GCM.

Users of climate projections should consider:

1. Australia experiences large and coherent natural variability in rainfall. Large in the sense that year-to-year and decade-to-decade changes are dramatic, with rapid shifts from drought to flood. Coherent in the sense that large tracts of the Australian continent are subject to rainfall changes associated with this natural variability, meaning that drought and flood conditions are typically widespread and often multi-jurisdictional. Australia's natural rainfall and temperature variability is superimposed on climate change, making it difficult to distinguish the climate change signal/trend from natural fluctuations. This presents difficulties in attributing, for example, key factors in the Millennium drought.
2. There are a range of emissions scenarios due to different socio-economic futures and greenhouse gas emissions, known as representative concentration pathways (RCPs). Climate projections are similar for all RCP scenarios over the next 10-20 years; however, it may be prudent to use high emissions scenarios for stress testing applications where there is a high consequence of impacts from extreme events.
3. Climate downscaling introduces further uncertainties to the GCM modelling, due to limitations in scientists' ability to simulate smaller scale climate responses, including the ability to describe boundary conditions.
4. Even after downscaling, residual biases in GCMs, Regional Climate Models (RCMs) or statistically downscaled rainfall and other climate variables remain. This makes the data unsuitable for direct use in hydrological models. For example, some climate models produce a constant 'drizzle' (very light rainfall every day). Scientists are still developing the best approach for connecting climate model outputs with hydrological models.

Modelling studies over the south east Australia region show that the largest uncertainty comes from the GCM projections. The difference in simulation using different downscaling methods is about half the range of future projections from different GCMs, and the difference in runoff simulation using different lumped conceptual rainfall-runoff model is small compared to the differences amongst GCM projections and downscaling methods[9], particularly for the long-term averages/mean runoff and medium/high flows. For other hydrological characteristics related to estimating mean runoff/streamflow changes there can be significant uncertainty in the hydrological modelling[10], in particular, the estimation of potential evapotranspiration is uncertain.

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[9] Based on a result of SEACI work presented by Teng etal on a SEACI Workshop (20 July 2011). See for example:

- CSIRO (2010) Program Annual Report 2009/10. South Eastern Australian Climate Initiative (SEACI). CSIRO, Australia
- Chiew FHS, Kirono DGC, Kent DM, Frost AJ, Charles SP, Timbal B, Nguyen KC, Fu G. 2010. Comparison of runoff modelled using rainfall from different downscaling methods for historical and future climates. *Journal of Hydrology*, 387, 1-2, 10-23. doi:10.1016/j.jhydrol.2010.03.025
- Teng J., Chiew F, Timbal B, Vaze J. Wang Y, Wang B, Evans A, Kent D, Kirono D, Post D. 2011. Assessing historical and future runoff modelled using rainfall from the analogue downscaling method, In Chan, F., Marinova, D. and Anderssen, R.S. (eds) MODSIM2011, 19th International Congress on Modelling and Simulation. Modelling and Simulation Society of Australia and New Zealand, December 2011, pp. 1652-1658. ISBN: 978-0-9872143-1-7. **www.mssanz.org.au/modsim2011/D10/teng.pdf**

[10] Chiew et al. 2018. Regional Hydroclimate Projections for Victoria, a presentation to the VicWaCI Annual Seminar, 10 October 2018). It must be noted that these studies have not assessed/included the uncertainty from future emission and concentration of greenhouse gases and aerosol.

Finally, the state-of-the-art in hydrological projection modelling generally ignores the impacts of land use and land cover change and the changing stomatal effect of carbon dioxide on plants; these are known limitations (but second order effects).

5. Presentations on current science related to dam inflows:

The following section is a summary of the presentations given at the workshop. Copies of the original presentations were made available to workshop participants.

5.1. Dr Geoff Steendam (Vic DELWP) - Vic WaCI project

Dr Steendam leads the DELWP Hydrology and Climate Science Team and manages the Vic Water and Climate Initiative (Vic WaCI).

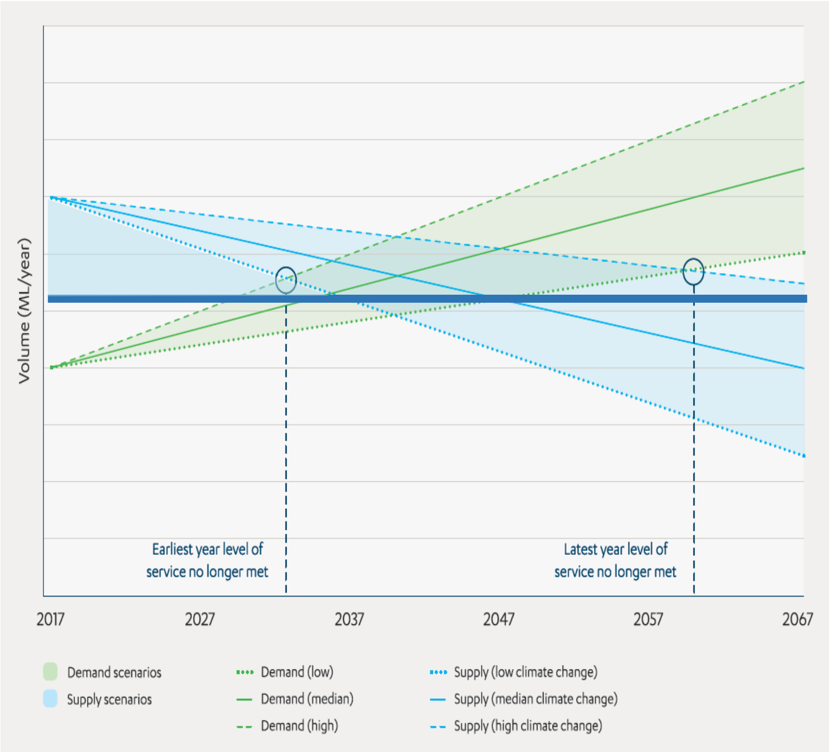
DELWP commissioned the South Eastern Australian Climate Initiative (SEACI) and the Victorian Climate Initiative (VicCI) along with other partners, and the Victorian Water and Climate Initiative (VicWaCI). These application-focused research initiatives were in response to the need for better information about water availability in Victoria, including for the 19 Victorian water corporations. While climate change is a key variable in hydrological change, water resources are impacted by many factors in addition to climate; for example, Victoria's (and eastern Australia more generally) growing population is likely to increase the demand for water in the future. The nexus between increasing demand and declining supply represents a significant challenge for water resource management (see Figure 4).

Vic WaCI builds on previous research programs, namely SEACI and **VicCI** and reached the following conclusions:

- Over the past 30 years there has been an increasing trend for reduction in cool season rainfall. As this is expected to continue, the baseline for water planning has been adjusted to reflect more recent decades rather than the longer-term historical record. Cool season rainfall has declined over Southern and Eastern Australia, cool season and warm season rainfall has declined over Tasmania.
- Over the past two decades the observed trend is far larger than the mean projected change, but consistent with some of the drier model simulations and some downscaled projections. Additionally, there are some differences between the seasonality of observed and modelled rainfall declines. This highlights the need for expert guidance on the use of the GCMs — in particular issues related to model selection.
- When viewed through observed timeseries, it is possible to characterise changes in some climate variables as step changes rather than continuous trends. For example, it is possible to model changes to inflows across parts of southern Australia as a series of step changes. Similarly, it is possible to model changes to fire weather across parts of southern Australia as occurring abruptly over a matter of years. These changes in the real world may be due to natural variability being superimposed on weaker underlying trends, or an expression of climate change itself (such as shifts in prevailing synoptic weather patterns), or statistical artefacts from the timeseries analysis. If there are underlying physical mechanisms that determine future step changes in rainfall, this presents some difficulty to providing projection information, since such changes may not be represented in the multi-model ensemble mean. For practical applications, it will be worthwhile considering whether AEMO requires an understanding of possible abrupt changes as part of their risk provisioning.

DELWP has provided **Guidelines for Assessing the Impact of Climate Change on Water Supplies in Victoria** (December 2016). These were developed with the 19 water corporations across Victoria, fit within the planning processes and the governance frameworks for the sector, are application ready and promote consistency in application across water corporations. More improvements may be possible, a key one being the appropriate baseline which will provide a better understanding of our situation today, and therefore how the scenarios connect to history.

Figure 4: Water availability Scenarios



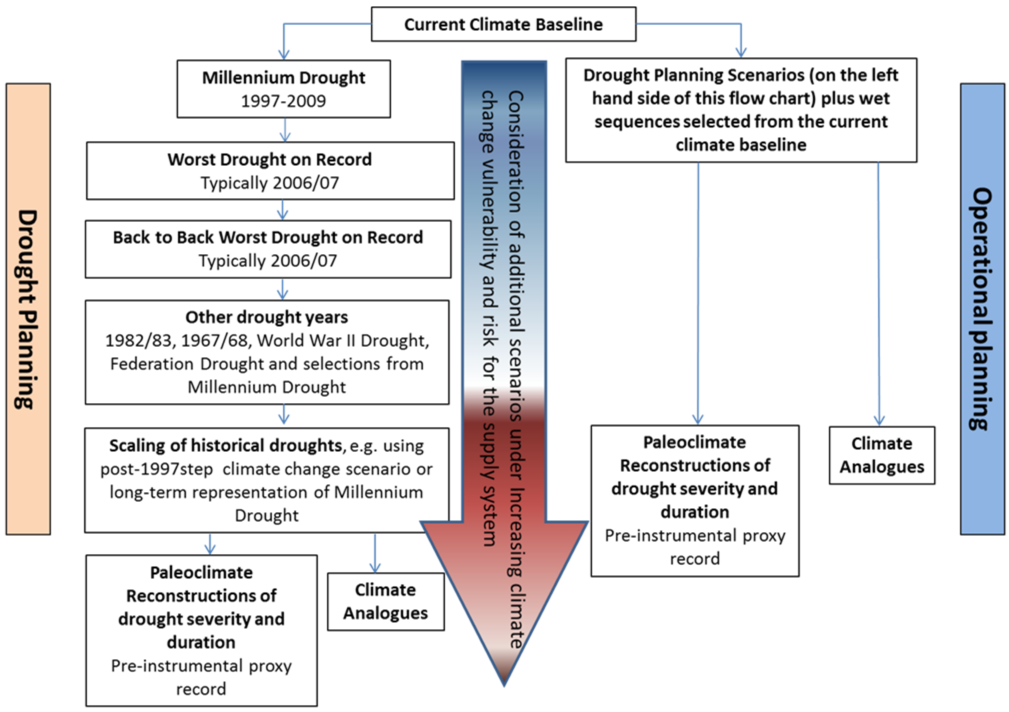
DELWP long-term modelling in Figure 4 used the following approach:

- GCM projections are used to define a low, mid and high climate change scenario for water yield.
- Change factors are applied to a long period of recorded inflow data, so the year to year variability is built into the analysis.

There are two shortcomings of the presentation of the light blue lines in Figure 4: (1) it assumes there is no uncertainty about climate change impact now, ie 2017, and (2) it gives the impression that climate change will gradually reduce the supply/inflow: So an additional scenario was included, based on the science but not based directly on GCM projections; this is shown in the thick blue line. This is a scenario, rather than a projection, which suggests a step change in climate or the water resource situation.

For short term planning (1-24 months), including operation time scale decisions or drought planning, GCM projections are not suitable but the DELWP guidelines present a range of other approaches (see Figure 5).

Figure 5: Range of approaches used by DELWP for short term planning



5.2. Dr Pandora Hope (Bureau of Meteorology) – Understanding rainfall variability and change

Dr Hope is the Lead Scientist for the Bureau of Meteorology on the DELWP Victorian Water and Climate Initiative, also Lead Investigator on the National Environmental Science Program (NESP) Earth System and Climate Change Hub – 'Understanding climate variability and change'; also Climate Lead for the Bureau of Meteorology Hydro Projections.

Patterns of the mean meridional circulation (north-south average circulation) are changing. There are multiple large-scale factors that affect the climate of Victoria on interannual time scales, namely the El Niño Southern Oscillation (ENSO), Indian Ocean Dipole (IOD), Southern Annular Mode (SAM) and Inter-decadal Pacifica Oscillation (IPO). Climate change is influencing these factors and the average north-south circulation (e.g. expansion of the tropics and strengthening of the sub-tropical high-pressure ridge).

There also appears to be some (poorly understood) decadal variability. Winter and summer trends 1979-2015 show that:

- Winter rainfall decreased because of a strengthened ridge of high pressure pushing storms south.
- Summer rainfall increased because the tropics expanded with a southward shifted ridge and because of a "La Niña like" pressure trend in the tropics.

VicCI research revealed new insights for the role of decadal variability for Victorian climate variability: the mechanism of IPO is not understood and predictability has yet to be demonstrated, however, knowledge of the current state of the IPO provides insight into expected variability (See Figure 6) .

Figure 6: Large-scale drivers, weather and rainfall of Victoria, and how they are changing

Warm IPO (eg 1980-1998)

- ENSO and IOD stronger and predictable
- ENSO-IOD strongly covary

Positive IOD with El Nino
Negative IOD with La Nina

- ENSO and IOD individual impacts on Vic rainfall weaken

Cold IPO (eg 2000-2014)

- ENSO and IOD weaker and less predictable
- ENSO-IOD more independent

Increased chance of positive IOD with La Nina (eg during Millennium drought)

- ENSO and IOD individual impacts on Vic rainfall strengthen

More likely to have extreme rainfall from IOD due to

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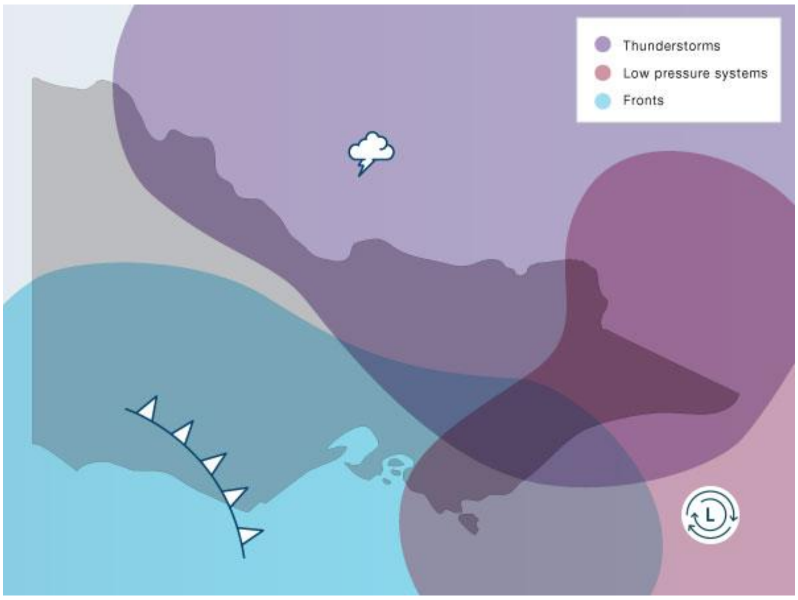
Year-to-year variability drivers can interact and differ by season:

- La Niña generally brings wet conditions to south-east Australia.
- El Niño is often associated with drier conditions over Australia.
- Negative Indian Ocean Dipole (unusually warm tropical waters to Australia's north and north west) is often associated with wetter than average conditions for Victoria.
- Positive IOD generally brings drier conditions to Victoria.
- High Southern Annular Mode (SAM) (higher pressures over southern Australia, and anomalous easterly winds) often brings dry conditions to Victoria in winter, but *wet in other seasons.*
- Low SAM is often associated with wet conditions across Victoria in winter, but dry conditions in spring and summer

Additional information is available by looking regionally, as different rain-bearing systems dominate in different parts of the state (see Figure 7).

Figure 7: Dominant weather systems over Victoria differ in different parts of the state (Dowdy)



The main driver behind an increase in intensity of rainfall extremes under warmer conditions is well understood: An increase in temperature leads to increase in moisture capacity at a rate of 7% per 1^{o}C. However, there are a number of processes that may increase or decrease the rate of change (e.g. changes in stability, moisture availability, atmospheric circulation changes). The rate of change in intensity is also likely to vary with: duration, season, severity, location.

5.3. Dr Dewi Kirono (CSIRO) – hydroclimate projections; Science challenges, applications and opportunities

Dr Kirono presented an overview of current knowledge and state-of-the-art projections of hydroclimate over Australia and Victoria based on the work by Dr Francis Chiew, Dr Kirono and Dr Jai Vaze of CSIRO. The presentation included a discussion of the challenges in developing robust projections[11], existing and upcoming hydroclimate projections data sources and products, and opportunities for enhancing and delivering relevant information to support best practice in long-term planning and management decisions.

While there is considerable variation in outcomes depending on the methodology used, Figure 8 shows that median rainfall and run-off are all expected to reduce for 2046-2075 relative to 1976-2005, especially over the south of Australia:

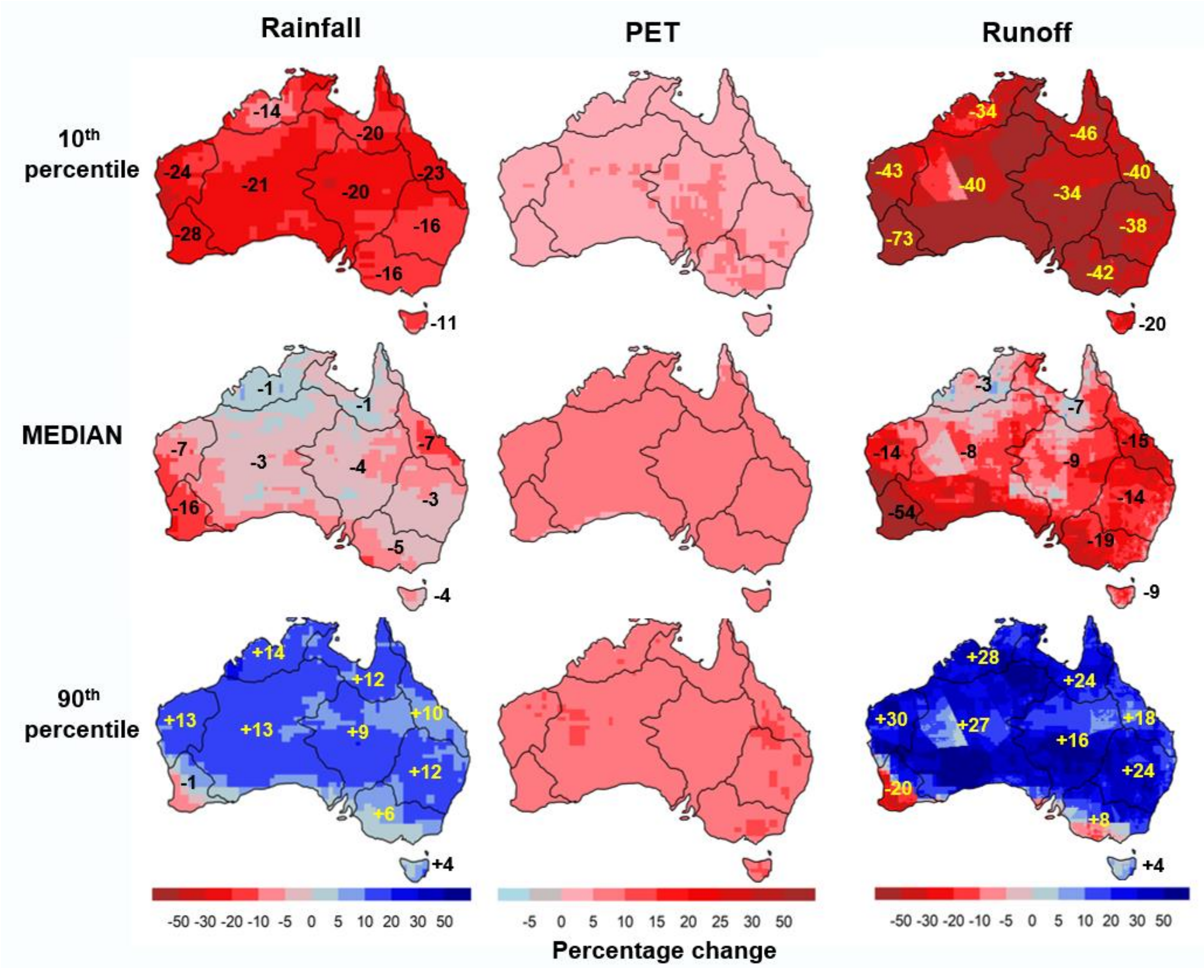
- Compared with other countries, Australia has a low runoff coefficient, high interannual rainfall variability, strong ENSO-runoff correlation, and large rainfall-runoff elasticity.
- Projections from 42 GCMs (RCP 8.5) over Australia show drier conditions in winter, with uncertain rainfall changes in summer.

[11] The overview of sources of uncertainty in climate projections was included in Section 4.

- The uncertainty in the projected rainfall is amplified in the runoff projections.

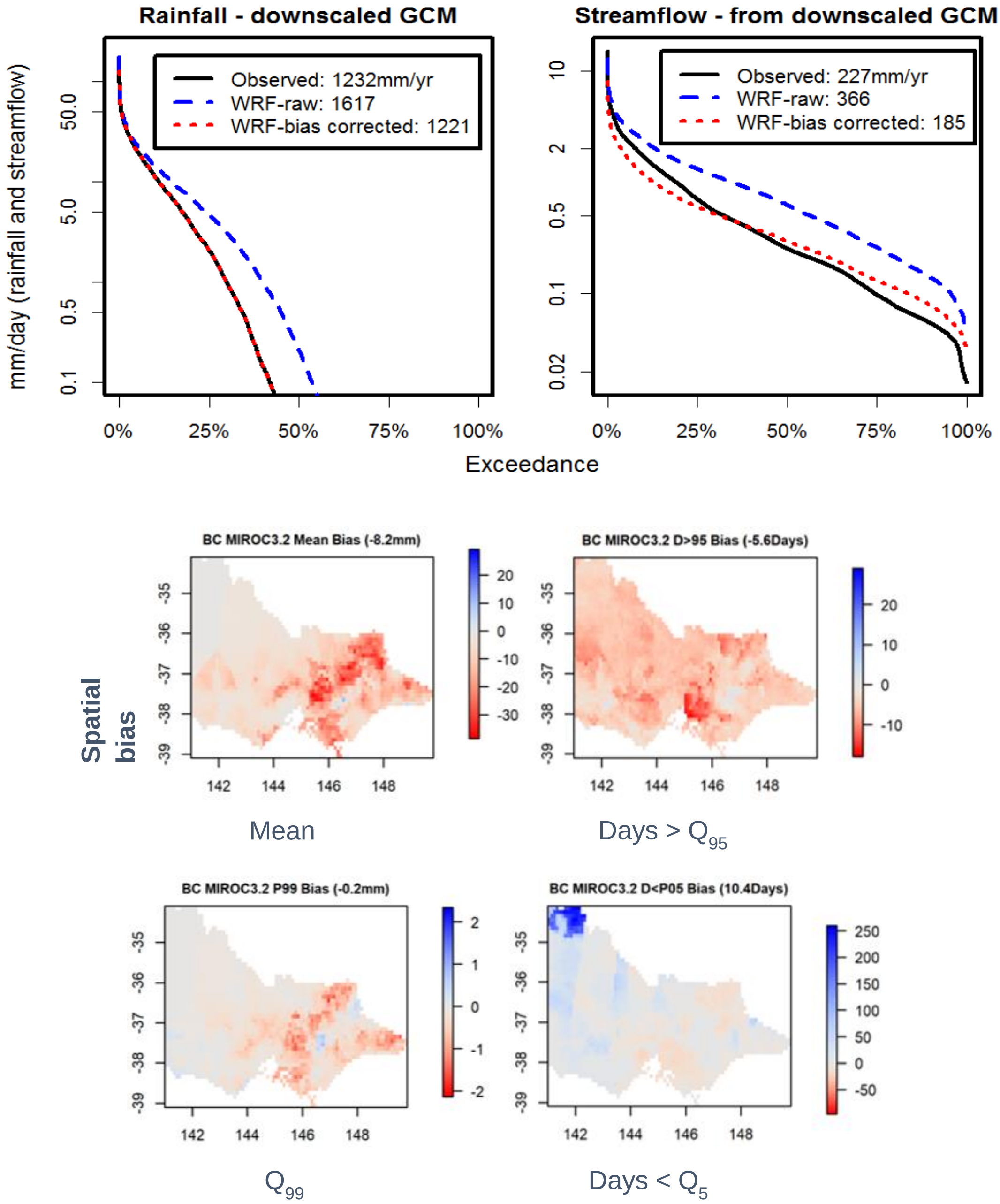
Future rainfall projections are sensitive to global climate models and downscaling models and can span a large range. Dynamic downscaling models like CCAM and WRF can help understand high resolution dynamics, for example higher rainfall reduction in the windward slopes of the Victorian alps.

Figure 8: Projections of rainfall, potential evapotranspiration (PET), and runoff for 2046-2075 relative to 1976-2005 for RCP8.5 for 10th, 50th and 90th percentiles. Projections are based on hydrological modelling informed by projections from 42 CMIP5 GCMs. Source: Chiew et al., MODSIM, 2017



Downscaling offers another (and higher resolution) projection data source, but must be considered together with and in the context of GCM projections as well as process understanding and causality. This is because of (i) limited downscaling models (e.g. now only two in Victoria), (ii) downscaling runs with boundary conditions from limited number of host GCMs, and (iii) continuing progress and development of downscaling models. Where dynamic downscaling outputs are used, they must be robustly bias corrected[12] for hydrological simulations[13] (for example, traditional bias correction methods will underestimate runoff, see Figure 9 below).

Figure 9: Downscaled rainfall input underestimates streamflow. Sources: Charles et al, 2018, Potter et al (2018)



[12] 'Bias' refers to a model being consistently different (e.g. hotter/colder, wetter/drier) than observations for simulations of the present. Expressing rainfall changes as a percentage is usually used as a simple method to adjust for bias.

[13] Hydrological models may respond to errors in the mean rainfall, intensity of rainfall and frequency of rainfall. This response may be non-linear, which obscures what is the prediction due to climate change and what is arising from errors in rainfall data. Bias correction reduces this confusion.

Future hydrological projections for Australia demonstrate a reduction of winter rainfall and water availability over south-east Australia, however, there is a large range of plausible projections due to large uncertainty in the rainfall projections. Science challenges in developing next generation projection include:

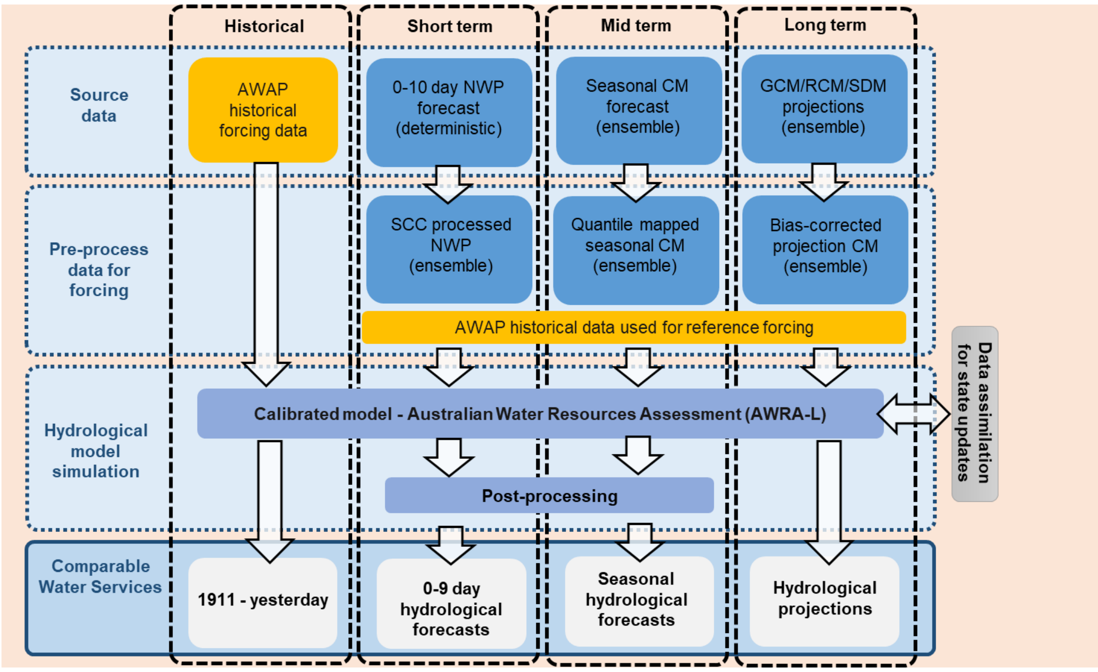
- Integrating/interpreting climate projections from the different sources;
- using higher resolution downscaled data, with robust bias correction for hydrological application;
- extrapolating hydrological models to project water futures under changed hydrological regimes and under warmer and higher CO_2 conditions;
- including hydrological response to land use changes that are likely to occur as a result of climate change and future policy.

5.4. Dr Chantal Donnelly and Dr Louise Wilson (Bureau of Meteorology) - National hydrological projections

Dr Donnelly presented the work of the Bureau of Meteorology's National Hydrological Projections Project. This project builds on CCiA projections for climate variables and extends these to cover water (hydrology) variables. The work aims to support infrastructure planning, water utilities, energy, emergency services and transport.

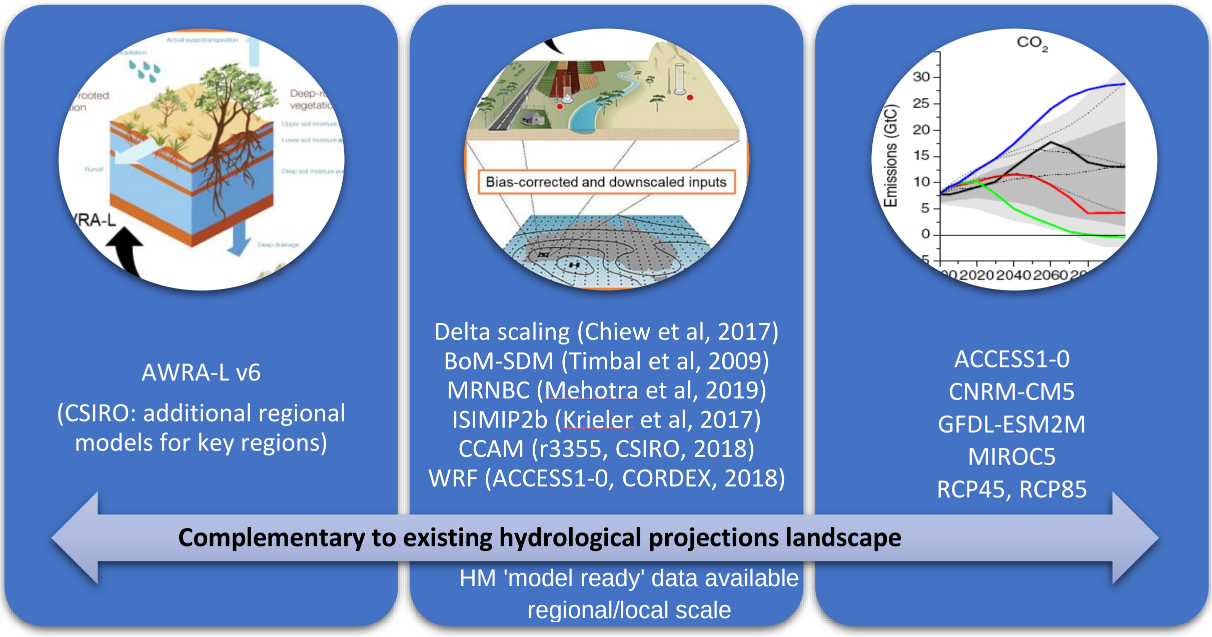
The National Hydrological Projections Project is part of a larger body of work to provide quasi seamless national climate services for water, spanning past hydrological variability and 0-9 day forecasts, seasonal forecasts, to multi-decadal projections (see Figure 10). The project uses the AWRA-L national hydrological model.

Figure 10: Seamless National Climate Service for Weather



In order to adequately plan for future climate conditions, AEMO, or other clients, must be able to describe the magnitude and likelihood of change. As discussed earlier, there are multiple sources of uncertainty, although variance can be estimated by using multiple Regional Climate Projections (RCPs), multiple GCMs, multiple downscaling methods, multiple bias correction methods and appropriate hydrological models. Historically, state-based agencies have tended to rely on a single method, differing by State/Territory (for example, CCAM, Weather Research and Forecasting – WRF – model, delta-scaling, statistical methods), to estimate the response of changing climate *at local scales*. This limits the coherence of information across the continent with limited indication of uncertainty and confidence.

Figure 11: Combining different approaches gives a national scale model tailored to local requirements



The National Hydrological Projections Project provides a unified national view using the methodology described earlier in this document, and then:

i. makes ' hydrological model ready' data available for others to run hydrological models of choice (see Figure 11 above); and
ii. makes national projections of changes to runoff and other hydrological variables including actual and potential ET, soil moisture and runoff, noting that at monthly time-scale runoff can be accumulated over a catchment to give streamflow.

The focus of this work has been on a consistent national approach which will provide value to several sectors, including the water resources sector and the electricity sector.

The AWRA-L model (Australian Water Resource Assessment Model – Landscape) was co-developed by the Bureau of Meteorology and CSIRO with the Bureau of Meteorology maintaining and providing operational versions and outputs via the AWRA-CMS (Community Modelling System) and Australian Landscape Water Balance, **www.bom.gov.au/water/landscape**. This model calculates soil moisture in multiple layers, canopy interception, PET, evapo-transpiration and runoff on an approximately 5 km grid nationally. The existing operational system is:

- Widely used national, daily water balance model.
- Routing coming in v7, currently no snow simulated.
- Comprehensively benchmarked nationally across the water cycle, including the ability to simulate previously observed changes in streamflow (trends).

The national approach of AWRA-L demonstrates the model's ability to simulate across a wide range of climatic variability which gives more information about how the model may respond to climate change and increases confidence in its responses[14].

The goal of the National Hydrological Projections Project is to make publicly available, by mid to late 2020, national impacts of climate change on water, which can be visualised in maps and graphs, together with confidence statements and guidance material. The data will be provided as transient time-series at 5x5 km resolution from today and out to 2100[15].

6. Case studies

6.1. Climate research for Hydro Tasmania (Dr Michael Grose)

Hydro Tasmania uses weather and climate modelling to guarantee supply and manage volatility as well as to inform the strategy and timing of upgrades and system efficiency investment.

Climate modelling has been critical for the business case for the 'Battery of the Nation' (pumped hydro). Climate and weather modelling are also inputs into managing natural hazard risks, e.g. low flows, fish kills, bushfires; these are strategic decisions, but are also ultimately investment decisions.

Regional insights into future weather indicate enhanced drying on the slopes of Tasmanian mountain ranges in cool seasons (autumn, winter, spring) and increased convective rainfall in summer (see Figure 12). Given that hydro power is on or near mountains, ‘added value’ (AV) analysis of change in climate from downscaling has proved to be important. AV is defined as improved simulation of the current climate relative to host GCMs; Realized Added Value (RAV) is new information about projected climate relative to host GCMs and indicates enhanced drying over mountains.

Reliable regional rainfall projections are difficult. A clear understanding is needed at both:

- large scale (from global models) – including useful constraints on change, and
- regional scale (from regional modelling).

Climate information is most useful when matched to bottom-up scan of thresholds; then decisions can inform:

- Managing risks from shocks and volatility – floods, supply failures ($90m was spent on diesel in 2015-16), bushfires, fish kills, heatwaves (infrastructure failures);
- Strategy and timing of upgrades, efficiencies;

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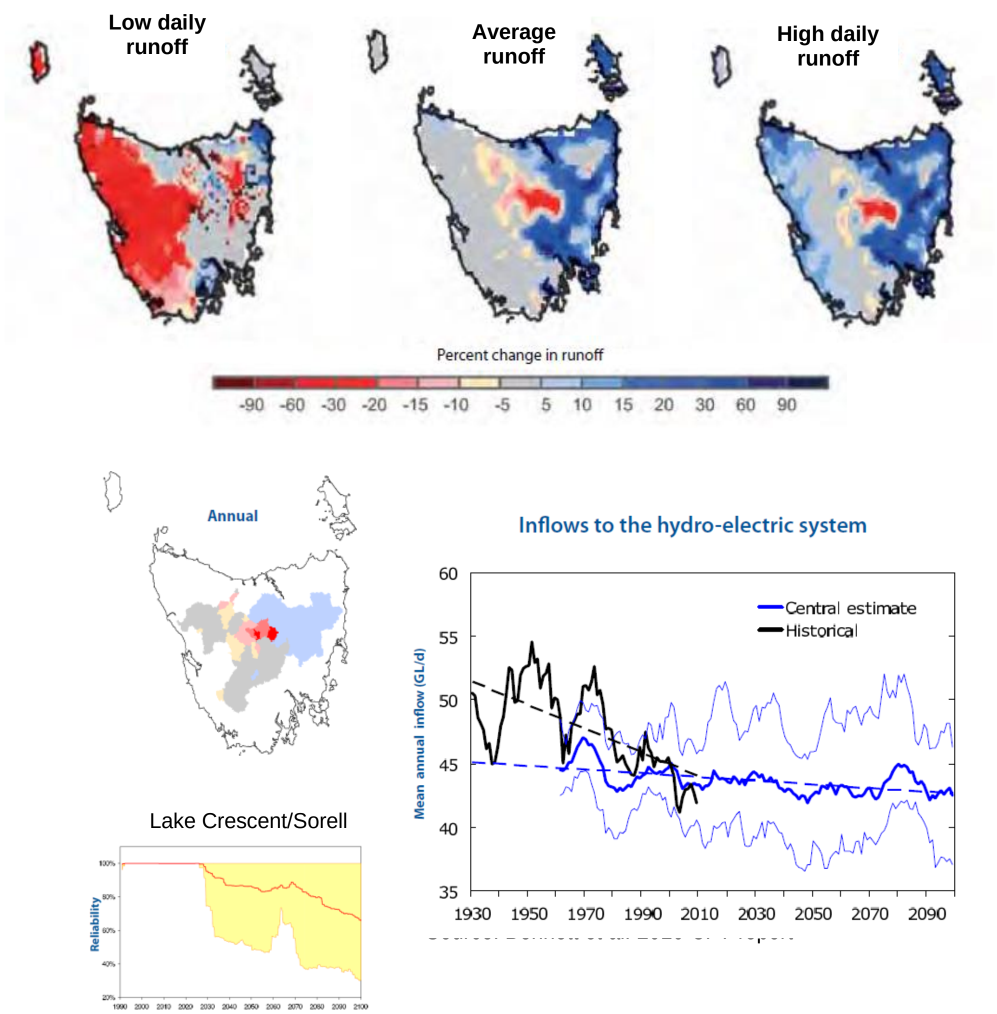
[14] Note: some users might consider the AWRA-L streamflow outputs to be less accurate than locally simulated historical streamflow (where tight model calibration is used).

[15] The data, including the downscaled and bias-corrected climate inputs (precipitation, max and min temp, solar radiation, wind) as well as the hydrological projections, will be available via a cloud service through BOM. The possibility of making the projections available through CCiA is being explored but is not yet confirmed.

- Flexible management with conservative minimums;
- Short-term practices, e.g. management that is more resilient.

Figure 12: Climate futures for Tasmania: maps show projections for 2070-2099

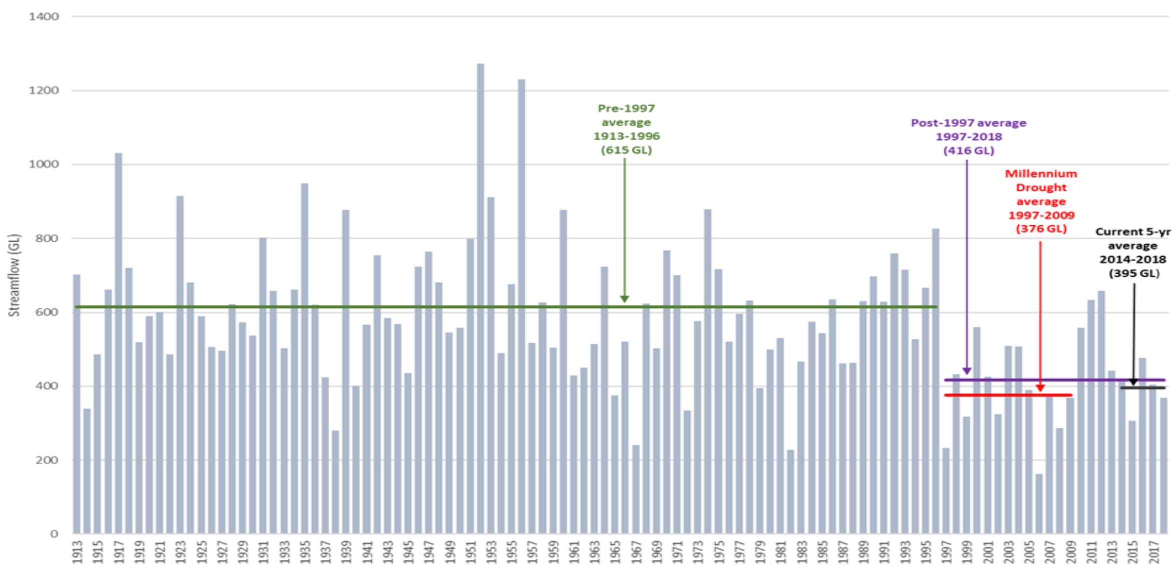


6.2. Melbourne Water resources management (Mr Bruce Rhodes)

Melbourne Water (MW) is owned by the Victorian Government and manages water supply catchments, removes and treats most of Melbourne's sewage and manages waterways across the Port Phillip and Westernport region. The water supply area includes 156,700 hectares of catchments, 10 major storage reservoirs and an extensive network of pipes, sewers and pumps. Per capita daily water consumption in MW's area has decreased since 1997 while remaining stable in recent years; total annual water demand decreased between 1997 and 2007 due to water savings measures introduced during the Millennium Drought but started increasing again from 2007 in line with population growth.

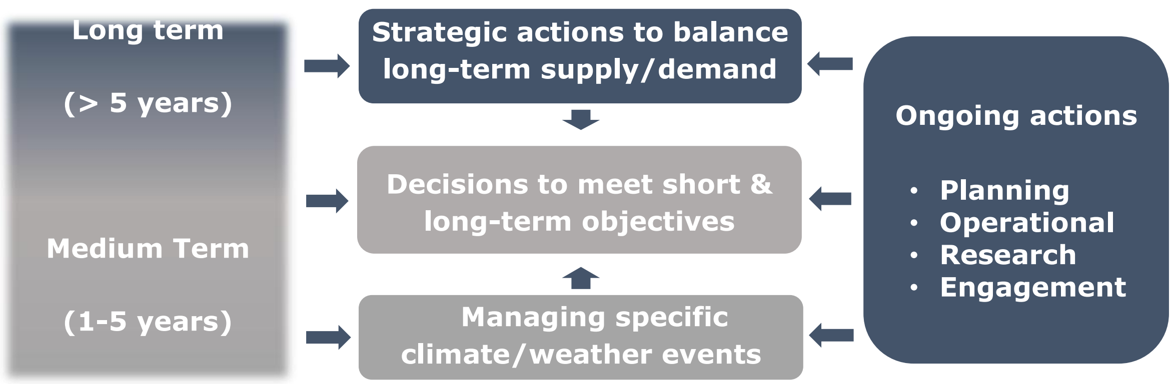
Annual inflow into Melbourne's main storages dropped during the Millennium Drought and has not recovered, with the 5 year average 2014-2018 at 395 GL compared with a pre-1997 average of 615 GL (see Figure 13).

Figure 13: Water storage volume 1960-2019



Like AEMO, MW needs to take action to balance supply and demand for the next 50 years as well as managing variability in supply from year to year based on seasonal climate outlooks. The Millennium Drought in the mid-2000s led MW to commission extensive climate and resource modelling as part of the Central Regional Supply and Demand Strategy, the Melbourne Supply and Demand Strategy and Our Water, Our Future; which led to major infrastructure investment (Wonthaggi desalination plant, north south pipeline). The framework that they use to make decisions about water reliability is very similar to the approach used by AEMO (see Figure 14)

Figure 14: Melbourne Water Framework and Instruments for water security



The Melbourne Water System Strategy (MWSS) is the key strategy outlining water supply actions for a 50-year outlook, including demand and supply projections, and is updated every 5 years. Information to support the development of the MWSS is taken from multiple sources, including proprietary modelling by MW. Applications of hydro-meteorological information is shown in Table 2 below.

Table 2: Melbourne Water applications of hydro-meteorology information

Hydro-meteorological Information	Some Applications
Short term forecasts (BoM)	• Operational decisions • Environmental flow releases • Flood forecasting • Bushfire management
Seasonal Climate Outlooks (BoM)	• Annual Operating Plan • Water Outlook • Drought response planning • Communications • Bushfire planning
Seasonal Streamflow outlooks (BoM)	• Operational decisions • Drought response planning • Environmental flow release planning
Climate change streamflow Projections (DELWP/CSIRO)	• Strategies: water supply, waterways and sewerage • Government strategies and Policy
Stochastic streamflow data (MW)	• Long term and short-term water planning • Drought and hydrologic analysis
Catchment and System modelling (MW)	• Water storage outlooks • Desalinated water order advice • Yield analysis • Drought Planning • Strategies, policy and decision support

Yield estimation example for Melbourne Water (Figure 15):

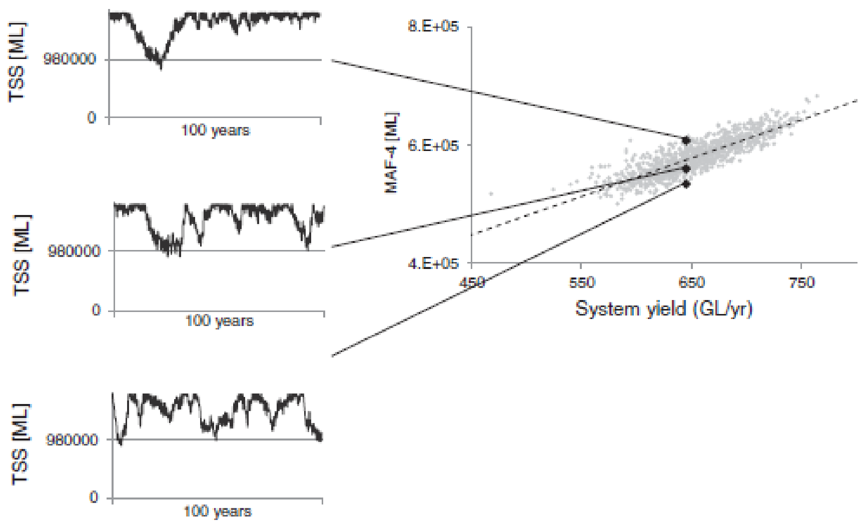
- Incorporates the use of stochastic data;
- Rainfall/runoff representativeness;
- Linked to climate scenarios;
- System performance linked to drought sequences;
- Uncertainty in climate, demand and yield estimates;
- Baseline climate.

Example of how the modelling is used: **Water Outlook for Melbourne** is published by 1 December each year and is a joint document produced by the Melbourne water service providers including Melbourne Water, South East Water, Yarra Valley Water and City West Water. It includes:

- Storage condition vs outlook zones;
- Water usage information;
- BoM's seasonal climate outlook;
- Actions to maintain water security.

It is the basis for water businesses' Drought Preparedness Plan implementation.

Figure 15: Yield estimates for Melbourne Water. Source: Turner, et al (2014) [16]



7. Discussion on the case studies and utility of the science

7.1. Synthesis of the state of the science

The impact of climate change on water availability in Australia is complex; however, the presentations in the workshop, and additional material provided by CSIRO and the Bureau of Meteorology, provide guidance for AEMO and the hydro-generation sector.

Forecasting dam inflows requires information on evapotranspiration, streamflow and runoff rather than rainfall. Compared with other countries, Australia has a low runoff coefficient, high interannual rainfall variability, strong ENSO-runoff correlation, and large rainfall-runoff elasticity.

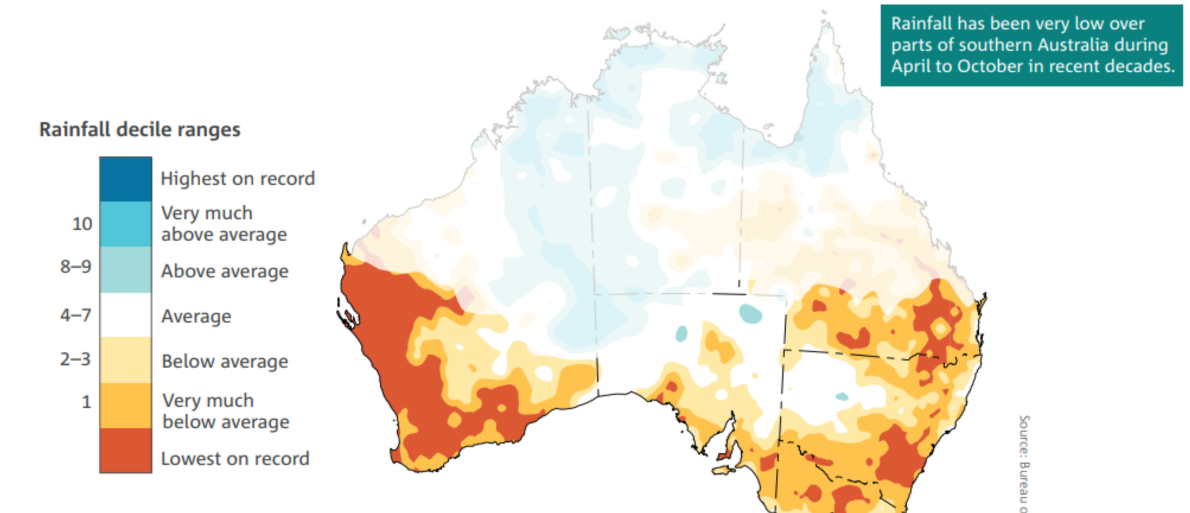
Projecting dam inflows requires expert judgement across multiple stages starting from the selection of RCPs and identifying the appropriate GCMs. GCMs can provide regional data on rainfall (or snowfall) timing and sequencing, also temperature, radiation and wind. This data can be downscaled and bias-corrected to provide local information. Hydrological models can then provide estimates of stream flow, evapotranspiration, dam evaporation and dam inflows. There are multiple sources of uncertainty in these projections, although variance can be estimated by using multiple RCPs, multiple GCMs, multiple downscaling methods, multiple bias correction methods and appropriate hydrological models.

Australian rainfall is highly variable and is strongly influenced by phenomena such as El Niño, La Niña, and the Indian Ocean Dipole. Despite this large natural variability, underlying long-term trends are evident in some regions. Drying in recent decades across southern Australia is the most sustained large-scale change in rainfall since national records began in 1900. The drying

[16] Turner, S.W.D., D.Marlow, M. Ekstrom, B.G.Rhodes, U.Kularathna, and P.J.Jeffrey (2014), Linking climate projections to performance: A yield-based decision scaling assessment of a large urban water resources system, Water Resour. Res., 50, doi:1

trend has been most evident in the southwestern and southeastern corners of the country, especially during April to October (see Figure 16). There has also been a reduction in the number of cold fronts impacting the southwest, and a decrease in the incidence and intensity of weather systems known as cut-off lows in the southeast regions of Australia. Cut-off lows bring the majority of rainfall and the most intense rainfalls in some regions of eastern Victoria and Tasmania.

Figure 16: Rainfall decile changes over the last 20 years. (Source: State of the Climate 2018)



April to October rainfall deciles for the last 20 years (1999–2018). A decile map shows where rainfall is above average, average or below average for the recent period, in comparison with the entire rainfall record from 1900. Areas across northern and central Australia that receive less than 40 per cent of their annual rainfall during April to October have been faded.

There is significant uncertainty about the magnitude of the climate change impact, relative to natural variability, but the observed reduction in rainfall has been larger than predicted and the trend is expected to continue; the drying signal in the southwest of the country has been one of the most consistent climate change signals globally, appearing in virtually every GCM. Most models also suggest that runoff has declined faster than rainfall; this appears to be more acute in alpine regions.

Despite the uncertainty it is widely expected that reduction in cool season rainfall is expected to continue; DEWLP and Melbourne Water, for example, have both adjusted their baseline for water planning to reflect this.

7.2. Currently or nearly available data sets

The discussion at the workshop, and the articulation of industry needs, resulted in the identification of the best data currently available for the hydro industry[17]. The work of **Chiew et**

[17] A more complete discussion of data sets relevant to the water industry is included in the ESCI core document: *Climate Data Inventory*.

al. 2017 (see Section 5.3) can provide run-off data that covers all the relevant catchments from a single data source. This is an ensemble of national projections of runoff using a delta-change methodology which applies the mid-century change signal from 42 GCMs to historical time-series which are then run through a national runoff model, GR4J. CSIRO has said this can be made immediately available to NEM partners.

The National Hydrological Projection project, currently under development at the Bureau of Meteorology, is using accepted, state-of-the-art projection methodology and the Australian Water Resource Assessment Model – Landscape (AWRA-L) to develop nationally consistent water resource data analysed with key messages and confidence statements (see Section 5.4). This will be available late in 2020 and will provide transient time series, daily, for the period 1960 – 2100, at 5x5km resolution for multiple RCPs. As the data is transient, users will be able to analyse the climate impacts for any decadal future period of interest in this range. This will be the best available source of physical climate risk for the hydro industry in the lifetime of the ESCI project, particularly given its consistent application of the science and uncertainty across all major hydropower regions in Australia.

8. 2019 ISP proposed implementation

In the 2018 ISP, AEMO did not consider climate change when making its supply forecasts. In addition, the use of 9 years of inflows is unlikely to fully capture natural variability (for example long-term droughts, or the effect of the ENSO)[18].

AEMO uses monthly inflow data to support hydro generation (in contrast to 30 minute data for wind and solar generation). The 2019 Planning and Forecasting Consultation Paper for the ISP (published in August) includes annual-average rainfall change data[19] downloaded from **climatechangeinaustralia.gov.au**. A linear trend is fitted to AWAP history and GCM future to develop an estimate of the 2050 mean rainfall reduction. This mean rainfall reduction is then converted to an inflow reduction using a 2-3x streamflow elasticity (see Figure 17). The modelling will still use 9 reference years, but this delta-change methodology, while simple, will introduce a climate signal to AEMO hydro forecasting for the first time. By including these factors, AEMO hopes to improve the accuracy of market modelling, which will allow for the most economically efficient climate risk mitigation to emerge. For example, by better capturing climate uncertainty on dam inflows, the market models may resolve the risk by advancing the development of new regional interconnectors, and/or scheduling gas generators to provide additional energy market solutions. This is an early contribution of the ESCI project to better forecasting in AEMO.

This approach is currently out for consultation as part of the development of the 2019 ISP. In the future, the additional precision from the Chiew et al data and from the National Hydrological Projections project will be included in AEMO forecasting models.

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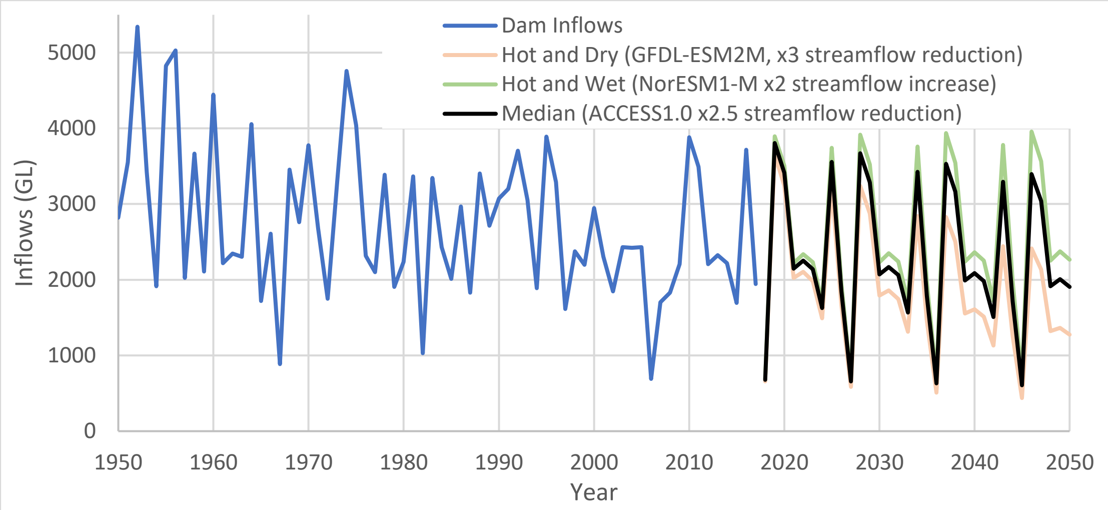
[18] The 2018 ISP methodology paper can be found **here**: there is no discussion of climate change impacts.
[19] Time series explorer for the Southern Australia super-cluster:

- ACCESS1-0 RCP8.5 & RCP4.5. Note: this is a sub-set of the GCMs recommended by CCiA
- NorESM1-M RCP8.5 & RCP4.5
- GFDL-ESM2M RCP8.5 & RCP 4.5

Figure 17: Proposed modelling for 2019 ISP



9. Next Steps for ESCI

The primary objective of the ESCI project[20] is to "support decision-makers in the NEM to access and use tailored climate information to improve long-term climate risk planning by collaborating on existing information and planning processes. This will include identifying and where possible providing priority climate information that is critical to support these long-term planning processes".

The workshop identified two existing, or shortly available, sources of tailored climate information for the hydro sector outside of the ESCI project.

1. The ESCI project will work with CSIRO[21] to provide their currently available runoff projections for major catchments, including the Murray basin, for 42 GCMs for RCP 8.5 for 2046-2075 vs 1976-2005. This information will provide relevant climate-adjusted data to AEMO for hydro forecasting.

2. The National Hydrological Projections project, described in Section 5.4, will provide a seamless national climate service for water which will be a further refinement of the impact of climate change on hydro assets. This will include past hydrological variability, 0-9 day forecasts, seasonal forecasts and multi-decadal projections. This work is expected to be complete within the lifetime of the ESCI project, and so the ESCI project will work with the NHP to make this information available to AEMO and the NEM.

Workshop participants (in particular, the scientists who participated) emphasised the need for a consistent guidance on:

- The definition of an extreme event;
- Climate scenarios that are relevant to the hydro industry;

[20] Source: DoEE Part A Statement of Requirement (Services) Reference Number 2000005129
[21] Chiew et al. See section 5.3

- Business decisions that need to take climate change into account, including, perhaps a taxonomy/typology of decision-making processes;
- Guidance on where detailed modelling is required (e.g. bushfires, extreme rainfall) vs where qualitative information and simple modelling is sufficient to inform risk.

The ESCI project is currently drafting guidance material for the electricity sector which is consistent with the areas of need identified above. The guidance material will be made available through knowledge-brokering and communications work including 'Master Classes' in climate change being conducted within AEMO. The National Hydrological Projections Project will be producing standard guidance to users, and so the ESCI project will collaborate to ensure that it is consistent with and informs the guidance that ESCI is producing.

The project is also developing a standard approach for generating climate scenarios which can be used to stress-test physical and transition risk. The outcome is expected to be a scenario-based framework for identifying vulnerability to extreme and compound weather events which can be used for the electricity sector. The presentation and discussion from Melbourne Water (Section 6.2) included an approach to scenario-based decision-making which will help inform the work of ESCI.

A key deliverable of the ESCI project is to develop a new standardised methodology for producing multi-hazard climate change data and information when there is no good quality existing information. The output from the workshop will help inform this work which will continue for the life of the project, making it easier to provide a consistent set of climate projections for all variables and sectors of the NEM.

Finally, the ESCI Project is developing a ‘best practice’ standardised climate change risk framework for identifying vulnerability of and risks to critical NEM infrastructure and capacity. This framework will integrate the recommended approach to scenario development and stress-testing, and the standardised methodology for climate-adjusted data development. This holistic approach is consistent with the request of workshop participants and will support the electricity sector in analysing and managing long-term climate risk. Further interviews will be conducted with the hydro sector so that a full case study can be prepared to test the path to market impact of climate change data for hydro generation, which will, in turn inform the development of the risk framework.

Appendix A: Glossary of terms

AWAP: Australian Water Availability Project

CCiA: Climate Change in Australia **w**ebsite jointly developed by CSIRO and BoM

CMIP5: Climate Model Intercomparison 5

CORDEX: Coordinated Regional Climate Downscaling Experiment Intercomparison project.

El Niño: refers to the extensive warming of the central and eastern tropical Pacific that leads to a major shift in weather patterns across the Pacific. El Niño events are often accompanied by cooler than normal sea surface temperatures (SSTs) in the western Pacific, and to the north of Australia.

ESOO: Electricity Statement of Opportunities (produced by AEMO)

IOD: Indian Ocean Dipole

IPO: Interdecadal Pacific Oscillation

ISP: Integrated System Plan (produced by AEMO)

La Niña: refers to the extensive cooling of the central and eastern tropical Pacific Ocean, often accompanied by warmer than normal sea surface temperatures (SSTs) in the western Pacific, and to the north of Australia. La Niña events are associated with increased probability of wetter conditions over much of Australia, particularly over eastern and northern areas.

GCMs: Global Circulation Models

NEM: National Electricity Market

NESP ESCC: National Environmental Science Program, Earth System and Climate Change Hub

Reanalysis data: combining observations and numerical models to generate a synthesised estimate of the state of the system.

RCP: Representative Concentration Pathways – produced by the IPCC

SEACI: South East Australia Climate Initiative (2006 – 2012)

VicCI: Victorian Climate Initiative (2013-2017)

VicWaCI: Victorian Water and Climate Initiative (2018-2020)

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PROJECT