Science Plan

The proposed research plan covers a program of three years work spanning the calendar years from May 2013 to May 2016 inclusive. The work builds on research undertaken under the South Eastern Australian Climate Initiative (SEACI), and, in particular, focuses on some key unanswered questions that evolved from the SEACI2 work program that are of specific relevance for an improved understanding of Victoria's past and expected future climate. The goal at the end of three years is to provide improved guidance about whether and how the climate of SEA has changed, how SEA climate might change decades into the future (and the most appropriate techniques for making this assessment), and improved understanding of the ability to predict SEA climate at seasonal to multiyear lead times.

The intent is to provide appropriate guidance on climate variability, predictability, and change that will:

(a) improve predictions of water availability in the short-term (seasonal to interannual timescales) which have the potential to inform water security outlooks for urban supplies and associated responses to ensure the ongoing provision of reliable supplies, and processes for determining seasonal allocations and risks of spill for irrigation systems;

(b) underpin an improved assessment of the risks to water supplies from changes in climate over the medium to longer term, based on improved understanding of the climate system and its representation by climate models.

The proposed research program is integrated across timescales and foci so that the work to improve understanding of climate variability directly feeds into the work that assesses seasonal-multiyear predictability and into the work to assess climate model simulations that are used to provide projections of future SEA climate.

The seven component projects of the research program are described below. Project 1 is aimed at further improving seasonal climate predictions and exploring the potential for multi-year predictions. Projects 2, 3 and 4 are aimed at better understanding past climatic variability and change in Victoria. Project 5 will use the understanding developed in Projects 1-3 to inform an improved assessment of the utility of climate model projections of future change. Projects 6 and 7 are aimed at developing improved methodologies for producing updated runoff projections and for assessing risks to water supplies from climate change. Project 6 will explore the possibility of obtaining improved information about future changes to convective rainfall and, potentially therefore, improved information about the likelihood and magnitude of extreme events and warm season rainfall. Project 7 will determine the most appropriate methodology(s) for generating a plausible range of improved runoff projections out to ~2040 and 2065 (as required for developing the next round of Water-Supply Demand Strategies in 2016). It will draw on information generated in the first six projects, particularly that of Project 5 and 6, and other relevant international, national and state initiatives, as well as investigating the best ways of bias-correcting dynamically downscaled data from climate models.

Research in Projects 1 to 5 will be primarily undertaken by researchers at the BoM while that in Projects 6 and 7 will be primarily undertaken by researchers in CSIRO Land and Water's Water for a Healthy Country Flagship.

IMPROVED SHORT-TERM PREDICTABILITY

Project 1. Understanding decadal variation of seasonal climate predictability and the potential for multi-year predictions

Climate in SEA varies markedly on multi-year and decadal time scales, impacting the capability to make seasonal climate predictions but also obscuring detection of anthropogenic climate change (ACC). Importantly, the capability to make predictions of seasonal climate variability in SEA varies decadally, with decades of high skill being associated with high ENSO variability and decades of low skill being periods of quiescent ENSO variations. The relationship of these variations of ENSO predictability with epochs of increased global warming and intensification of the subtropical ridge needs to be explored. Furthermore, the epochs of high/low ENSO variability may be related to warm/cold phases of the Interdecadal Pacific Oscillation (IPO, noting that the IPO is not an oscillation in the true sense because its behaviour is more episodic without exhibiting a prominent periodicity). Furthermore, there is clear evidence that some specific ENSO events are predictable for 1-2 years but many are only predictable 2-3 seasons in advance. Further, ENSO variability today is acting on a warmer mean state and this warming may have played a role in changing both the behaviour of ENSO and the ENSO teleconnection to SEA (e.g. there is some evidence to suggest that the La Niña pluvial phase may be more intense now than previously). Understanding these changes will provide more confidence for predictions of short term climate variations in the future. Key questions to be addressed include:

a. What are the mechanisms of the observed multi-year variations of climate in south-eastern Australia? How predictable are they, especially the multi-year La Niña episodes that are the primary drivers of water resource replenishments (e.g., mid 1970's, late 1980's, 2010-12)?

b. Why did the last two La Niñas bring lots of rainfall to Australia, but the 2007-2009 La Nina did not?

c. What role did GHG forcing play in these multi-year wet/dry period?

d. Why has ENSO prediction skill been low since 1999 compared to the previous 20 years (1980-1999)? Can the drop in ENSO prediction skill be related to changes in the mean state and, in particular, to changes in the global circulation associated with an expansion of the HC?

e. What is the relationship of these epochal changes in ENSO activity/forecast skill and the PDO/IPO and the epochs of enhanced global warming/strengthening of the subtropical ridge?

f. How might ENSO prediction skill change in the future, if skill is tied to changes on the mean state and these changes on the mean state are associated with an expansion of the HC and a strengthening of the subtropical ridge?

g. What has been the impact of warming ocean temperatures to the north of Australia on ENSO and ENSO's impacts on Australian climate?

A first order draft of the proposed work to be undertaken is outlined below. This outlines the general direction of the research although details will be refined in developing the Annual Work Plans for the Project.

- Conduct retrospective case-study forecast experiments to 2-year lead times using the POAMA seasonal forecast model and the SINTEX-F seasonal forecast model (at JAMSTEC: Agency for Marine-Earth Science and Technology) for the three extended La Niña periods post-1997. Diagnose which events are predictable and identify sources of predictability (e.g. pre-existing heat content anomalies in the upper ocean).
- Diagnose changes in the tropical ocean-atmosphere mean state (i.e. increased trade winds/colder central Pacific) and relate to changes in behaviour of ENSO since 1999 and attempt to relate to changes in predictability of ENSO using ocean and atmosphere reanalyses and seasonal hindcasts 1960-2010.
- Explore the relationship of mean state changes/ENSO variability to IPO and epochs of increased global warming.
- Explore impact of warming SSTs for the extreme rainfall of the La Nina event in 2010 with idealized model studies (imposed SST runs).
- Repeat experiments to assess the impact of warming SST on SEA climate during La Niña but include time-varying greenhouse gases and ozone to assess impact of GHG and ozone on multiyear variability and predictability and especially on the La Niña teleconnection.
- Analyse observed datasets and perform model experiments to understand underlying mechanisms of SEA climate variability at multi-year timescales; in particular, how the tropical climate forces multi-year variability of SEA climate.
- Explore the relationship of multiyear La Niña events to rainfall in SEA and diagnose why some La Niña events were not wet. Do this using observations and idealized model simulation in order to identify sources of forcing (e.g. prescribe SST in Pacific but use climatological SSTs in the Indian Ocean).

Expected outcomes of the project are an improved understanding of the mechanisms giving rise to multi-year variability in climate, the changing behaviour of these mechanisms and associated impacts on climate, and the role of anthropogenic influences in these changes. In turn, this improved understanding will underpin more confident predictions of short term climate variations in the future.

IMPROVED UNDERSTANDING OF PAST CLIMATE VARIABILITY AND CHANGE

Project 2. Understanding the Mean Meridional Circulation (MMC) and its relevance to Victoria

A key outcome of SEACI2 is the confirmation that the Hadley cell is expanding and this expansion could be playing a key role in the recent climate variability experienced in SEA. Projections of future climate indicate a continued expansion of the Hadley cell, so it is imperative to understand its impact on SEA climate and the mechanism for, and likely limits to, the expansion.

The work in SEACI2 indicates that the recent expansion of the Hadley cell has been relatively greater over the Australia compared to the rest of the hemisphere. And, importantly, the seasonality of the expansion varies between different analyses, with calculations/simulations of the overturning circulation suggesting a summer/autumn expansion but in situ radiosonde observations showing little seasonality. The seasonality of the expansion (greatest in summer and autumn) bears on the issue of what is driving the expansion and on understanding the observed autumnal rainfall decline and how rainfall may respond to future changes. Outstanding questions to be addressed include:

a. Can we reconcile the seasonality of the expansion as given by different methodologies? Is it only due to methodology or is it about separate aspects of the MMC which are evolving differently?

b. The expansion is more pronounced over Australian longitudes, suggesting a role for local forcing. What role has the Australian land mass played (and how/why does it differ from the influence of South America and South Africa)? How would any such influence vary in a changing climate?

c. Some relationships have been investigated (STR vs. HC intensity and extent) but others have been assumed, especially the interactions across various time-scales (e.g. inter-annual vs. long-term trends). These need to be investigated.

d. What mechanism explains the relationship between the widening of the HC and the intensification of the STR? What is the role of the extra-tropical dynamics vs low latitude forcing (see Project 1.2)?

e. What are the underlying factors that determine the seasonality of the expansion and how are they affected by on-going changes?

Observed changes in MMC could be due to a range of climate factors on both seasonal and annual bases. The role of the various forcings is key to understanding future climate change in SEA, including Victoria, and will be dealt with using the CMIP5 dataset (see Project 3).

A first order draft of the proposed work to be undertaken is outlined below. This outlines the general direction of the research although details will be refined in developing the Annual Work Plans for the Project.

- Develop and adapt existing methods to evaluate the HC from a regional perspective: apply to re-analyses.
- Evaluate the relationship between tropopause height and HC metrics: apply to reanalyses.
- Evaluate other relationship with the MMC in light of the long-term trends observed: apply to re-analyses and ACCESS forced simulations.
- Continue perturbation experiments with ACCESS to understand role of SSTs warming patterns; as well as the role of the continental landmass in the current climate and in a warming world.

Expected outcomes of the project are an improved understanding of the mechanisms for an expanding Hadley Cell and associated future impacts on SEA climate.

Project 3. Understanding subtropical-extratropical interactions and their relevance to Victoria

Evidence is emerging that variations in extratropical circulation associated with the Southern Annular Mode (SAM) play a significant role in driving variations of the Hadley circulation, and especially rainfall on the poleward edge of the Hadley circulation: High SAM (i.e. a poleward shifted mid-latitude jet) is associated with an expanded Hadley Cell (HC) and increased rainfall in subtropical latitudes in summer. This relationship, which is primarily a summer time phenomenon, is captured in climate models to varying degrees. It is especially associated with ozone depletion, but increased CO_2 is also known to drive SAM to its high phase. Understanding the cause of this relationship between SAM and the HC is crucial to understanding the behaviour of the HC in the future. It furthermore bears on the ability to predict regional climate seasonally. There is strong evidence that tropical SSTs during ENSO directly affect the HC, which then affects the SAM (e.g., the HC contracts toward the equator during El Niño thereby resulting in a shift toward low SAM). These variations should be highly predictable. But, because SAM is primarily an internal mode of variability, to the degree that the SAM variations determine the poleward extent of the HC, this will reflect on the limits of predictability of HC variations. Key questions to be addressed are:

a. What is the nature and mechanism of the interaction of the SAM with the Hadley circulation? What role does ENSO or other tropical SST anomalies play in promoting these interactions? What determines the seasonality of these interactions (e.g., why does the SAM have the strongest relationship with the Hadley circulation in summer)? What is the best diagnostic to represent/understand these interactions?

b. What are the implications of the interaction of the SAM with the complete MMC including the HC, especially the seasonality of the interaction, for predictability of the SAM? If SAM (and its impact on the HC) is tightly tied to ENSO, then its seasonal predictability might be high. If, not, predictability of subtropical climate will be limited.

c. Can the interaction of extratropical circulation and the MMC explain the link between the HC expansion and the intensification of the STR and also with the SEA cool season rainfall deficit?

d. How will these interactions change in future climates and what is the implication of these interactions for future climate?

A first order draft of the proposed work to be undertaken is outlined below. This outlines the general direction of the research although details will be refined in developing the Annual Work Plans for the Project.

- Use the isentropic analyses (provide a synthetic view of these interactions) on reanalyses and compare with the classical view.
- Using reanalyses and satellite-observed rainfall, clarify the mechanism for the interaction of the SAM with the MMC and subtropical rainfall, especially revealing why the interaction is primarily a summertime phenomenon.
- Explore the predictive skill of summer time rainfall with POAMA hindcasts for epochs of active and suppressed SAM variability in order to elucidate the predictability that can be attributed to the SAM.
- Investigate the dynamics of the sub-tropical highs and in particular the role of storm-track eddies in affecting the extent of the HC, and hence the position as well as the intensity of the STR, to elucidate why a widening of the HC is conducive to a strengthening of the STR.
- Use single forcing experiments to assess the separate role of GHGs and stratospheric Ozone depletion on the interactions between SAM and the HC extent (as well as the intensity of STR and SEA rainfall)l focusing on the cool season. Complement this with simulations with ACCESS forced with simple forcings (ie SST anomalies or other idealized forcings) as required to form a full understanding of the mechanisms involved.
- Assess CMIP5 to see projected changes in the tropical-extratropical interactions with increasing greenhouse gases, especially focusing on SAM-ENSO relationship, seasonality of SAM-subtropical rainfall impacts and storm tracks-subtropical ridge relationship.

Expected outcomes of the project are an improved understanding of subtropical/extratropical interactions (Hadley Cell/Southern Annular mode), likely future changes and associated impacts on SEA climate.

Project 4. Evaluation of climate model simulations of current trends in order to attribute observed trends

Climate model simulations best represent observed recent changes in the MMC, especially its expansion, when ozone depletion and other anthropogenic external forcings are used, suggesting at least a partial human influence of recent changes. However, the expansion in the models is typically much weaker when compared to observations. Stratospheric ozone depletion, often poorly represented in GCMs, may play a significant role in the SH circulation, including the tropics and subtropics. It is thus critical to understand what is actually driving the changes and why the models are underestimating the change. Key questions to be addressed are:

a. What are the relative roles of greenhouse gases (GHG), stratospheric ozone depletion, and anthropogenic aerosols in producing the observed expansion of the HC and the associated impact on subtropical rainfall?

b. If ozone depletion is an important factor, what are the implications of the (expected) recovery of stratospheric ozone for projections at different time scales (e.g. 2020, 2050, etc) and how well this is captured in the existing projections?

c. If the HC expansion is driven by CO_2 and other GHG, then we might expect a continued expansion in the future.

d. If the HC expansion is primarily driven by variations in tropical sea surface temperatures (SST) (especially those associated with ENSO), then much of the HC expansion will depend on the nature of tropical SST changes in a future climate.

e. Do models underpredict the observed HC changes and if yes, why? Does it relate to the two individual forcings listed above?

f. What are the implications of the possibility of attributing a part of the observed changes to external forcings for our best estimate of the current climate baseline?

A first order draft of the proposed work to be undertaken is outlined below. This outlines the general direction of the research although details will be refined in developing the Annual Work Plans for the Project.

- Use statistical analyses to evaluate the role of several external forcing factors in tropopause height variations and the implications for future climate change.
- Analyse set of ensembles of simulations of current climate with explicit external forcings with a single GCM for as many as possible such suite of simulations in the CMIP5 dataset, with a focus on individual anthropogenic forcings.
- Evaluate the role of tropical SST variability in range of response from GCMs to external forcings to contribute to the understanding of natural variability in the observed trends.

Expected outcomes of the project are an improved understanding of the role of various external forcing factors in driving an expanding Hadley Cell, why climate models underestimate observed changes, and what this might mean for future climate change projections.

IMPROVED UNDERSTANDING OF FUTURE CLIMATE AND ASSOCIATED RISKS TO WATER SUPPLIES

Project 5. Critical assessment of climate model projections from a rainfall perspective

Climate projections from climate models are showing some consistent behaviour (e.g dry to the south and wet to the north across SEA) and some inconsistent behaviour (the degree of future rainfall change). Some of this uncertainty is linked to the models' ability to represent important teleconnections (e.g. the impact of the SAM on the HC) and climatic behaviour identified through SEACI research. In order to provide guidance as to which models to use for projecting future climate (with a particular focus on subsequent impacts on water availability), we need to assess individual models for the capability to simulate these key teleconnections. Specifically, key questions are:

a. How are model projections for either wet or dry tendencies related to the model's projections of tropical ocean warming (especially the relative warming between the Pacific and Indian Oceans)?

b. The relationship between the sub-tropical ridge (STR) and rainfall across SEA was poorly captured by most models in the CMIP3 dataset. Does it remain the case in CMIP5? Why this is poorly simulated and can it be related to the spatial resolution of the models and/or biases in the models mean climate? What implication does the poor representation of the STR-rainfall relationship have for future projections?

c. Follow up on the evaluation of the CMIP5 models ability to reproduce observed trends attributable to external forcings (as per Project 4). Can the ability of models to reproduce these trends be used to confirm or invalidate these models future projections? What is the best probabilistic approach to reconcile observed trends, model trends for the recent climate and future trends?

A first order draft of the proposed work to be undertaken is outlined below. This outlines the general direction of the research although details will be refined in developing the Annual Work Plans for the Project.

- Analyse CMIP5 simulations of current and future climate in the light of current understanding of the key influences on SEA rainfall: spatial patterns of tropical warming (in relation to the tri-pole index, IOD/ENSO indices); changes in sub-tropical ridge across Australia and the southern hemisphere; and changes in Mean Meridional Circulation (classical and isentropic views).
- Evaluate the linear assumption between projected changes and the global warming simulated by the models.

Expected outcomes of the project are an improved understanding of which climate models best capture the behaviour of key mechanisms influencing SEA rainfall and relationships between these mechanisms and rainfall. This in turn will improve our understanding of how best to make use of model projections of future climate.

Project 6. Convection-resolving dynamical downscaling

In SEACI, different statistical downscaling methodologies of varying complexity were used to derive local scale climate (empirical, analogue and NHMM). Most methods (with bias correction for some) can provide reasonable estimates of seasonal and annual rainfall means, although small errors in the rainfall are amplified as bigger errors in the runoff. A key weakness in all methods used within SEACI was the underestimation of 3-5 day rainfall totals and the magnitude of extremes (e.g. the persistence of rainfall events as well as their intensity), which leads to underestimation in the high runoff events and also the mean annual runoff.

Recent experiments by the UK MetOffice has shown that improved spatial and temporal characteristics of rainfall can be obtained when using convective resolving high resolution regional climate models (RCMs) (Kendon et al., 2012). Whilst their high resolution version (1.5 km) tended to produce too intense heavy events compared to observed data, overall it provided much better representation of the duration and spatial extent of heavy events compared to the coarse resolution model (12 km). In particular, the heavy rainfall in the coarser resolution model was found to be too persistent and widespread. Further, commonly known RCM problems such as too much persistent light rain and errors in the diurnal cycle were much reduced in the high resolution model version.

In Project 6, convection-resolving model experiments will be conducted to simulate the current climate in Victoria (1989-present), the purpose being to assess the potential for high-resolution experiments to improve on spatio-temporal characteristics of rainfall, as simulated in previous dynamical downscaling exercises (Evans et al., 2012, Evans and McCabe, 2010). This, in turn, has the potential to inform the development of improved methodologies for future runoff projections and, potentially, assessments of future flood risk.

A first order draft of the proposed work to be undertaken is outlined below. This outlines the general direction of the research although details will be refined in developing the Annual Work Plans for the Project.

In Australia, there are two established models that are used for climate change experiments on regional scale (Conformal Cubic Atmospheric Model (CCAM),(McGregor and Dix, 2008); Weather Research and Forecasting (WRF),(Skamarock and Klemp, 2008)), and one being developed for use in regional applications (Australian Community Climate and Earth System Simulator (ACCESS), (Bi and Marsland, 2010). Of CCAM and WRF, only WRF is able to simulate regional climates on the very high spatial resolution that is of interest in this project.

Previous experiments using WRF at CLW were optimised for a final nesting at 10 km. The very high resolution experiment will require one additional nest with less than 4 km resolution to enable convective resolving physics (Done et al., 2004). However, moving down to this scale requires not only a higher spatial resolution but the need to consider processes that become more important on these scales and thus requiring more detailed input. The proposed activities in Project 6 are as follows (see Table for approx. timelines):

- Domain identification

a) In discussion with DSE and BoM, identify geographical regions in Victoria where convective systems are dominant rainfall drivers. The regions should also reflect regions that are likely to benefit from higher resolution model simulations of atmospheric small scale processes and surface-atmosphere interactions.
b) Identify size and location of intermediate domain (9-10km resolution with convective parameterisation scheme) and inner final domain (3-4 km resolution with explicit convection) based on theoretical constraints as identified in peer review literature and in discussion with numerical weather prediction (NWP) forecasters at the BoM (Denis et al., 2002, Warner et al., 1997, Warner and Hsu, 2000, Trapp et al., 2007, Trapp et al., 2011).

- Sensitivity testing – in the form of a case study (multiple storm events)
  a) Selection of micro-physics scheme (resolving all hydrometeors) and possibly planetary boundary scheme
  b) Implement appropriate orography data.
  c) Assess the need for, and implement a finer information land-surface scheme.

- Experiment
  a) Using ERA interim re-analysis data. Hind cast experiment for a time period to be discussed in collaboration with stakeholders (depends partly on accessibility of validation data sets).
- Validation
  a) Aggregate downscaled data to resolution of validation data set (AWAP and radar derived gridded data) and assess distributional and spatio-temporal characteristics.

Expected outcomes of the project are an assessment of the potential for high-resolution dynamical downscaling experiments to improve on spatio-temporal characteristics of projected future rainfall. In turn, this has the potential to inform the development of improved methodologies for future runoff projections (see Project 7) and, potentially, assessments of future flood risk.

Project 7. Identification and application of improved methodologies for water availability projections

The aim of this project is to provide information about model behaviour and methodological choices that can improve the reliability and usefulness of runoff projections for mid- to long-term future time horizons (2040 and 2065), which are needed for the next round of Water-Supply Demand Strategies (WSDS) in 2016.

The 2012 projections of streamflow for Victoria utilised information derived from the SEACI2 runoff projections, including estimates for a low, medium, and high climate change scenario as well as a "return to dry' conditions scenario. These projections were informed by climates simulated by the third Coupled Model Intercomparison Project (CMIP3), which underpinned the climate projections presented in the Intergovernmental Panel of Climate Change (IPCC) fourth assessment report (AR4).

Future flow scenarios for the next WSDS will be based primarily on information from climates simulated in CMIP5 used for informing the IPCC's fifth assessment report (AR5), due to be finalised in 2014. In comparison to CMIP3, CMIP5 comprise a larger data set, with many models operating at higher resolution and with more complex physics (Meehl and Bony, 2011). Further, the updated scenarios will draw on information on model evaluation, ensemble creation and downscaling outputs generated in other international and national research initiatives, These initiatives include:

- Downscaling outputs accessible via the World Climate Research Programme (WCRP) strategic framework: CORDEX: A CoOrdinated Regional climate Downscaling Experiment the CORDEX (Giorgi et al., 2009)
- Model evaluation insights and other methodological learnings from the ongoing CSIRO lead Climate Change Projection framework, providing regional climate projections for the Natural Resources Management clusters – a project funded by the Commonwealth Government's Department of Climate Change and Energy Efficiency (DCCEE).

- Dynamical downscaling outputs (10km) from the NSW government funded NSW/ACT regional Climate Modelling (NARCliM) project (publically available from mid-2014).
- Learnings from relevant ongoing ARC research grants concerning hydroclimate non-stationarity and uncertainties associated with GCM runs, e.g. University of Melbourne ARC Linkage Project LP 100100756, "Narrowing the scatter and assessing the uncertainty of climate change projections of Australian river flows".

Work conducted in Project 7 will be integrated with outcomes from Project 5, which will provide guidance on CMIP5 model characteristics in terms of skill in representing regionally important rainfall drivers.

Project 7 will focus on the following research questions:

a. Can statistical downscaling tools provide useful insight into the origin of the range of projections from CMIP5 models and associated uncertainties?
b. What CMIP5 models show best skill in reproducing rainfall characteristics that define regional flow characteristics, with regard to the spatial and temporal behaviour of runoff in space and time across different meteorological seasons and time frames?
c. How are outputs from different CMIP5 models and subsequent downscaling methods most appropriately merged into projections of future streamflow?
d. What existing bias-correct methods are best suited to adjust distributional characteristics of climate model data to observed data(a process necessary in order to use model output directly in hydrological models that are conditioned on relationships based on observed data)? Whilst a wide range of methods have been proposed, such as monthly scaling of the mean (Fowler and Kilsby, 2007), delta change method (Hay et al., 2000), power law correction (Leander and Buishand, 2007, Leander et al., 2008), quantile mapping (Bennett et al., 2012) and nested methodologies to capture persistence at different time-scales (Johnson and Sharma, 2011, 2012), there are concerns that the method can interfere with the interpretation of the climate change signal by altering the spatiotemporal field of consistency, and modify relationships amongst variables by violating conservation principles (Ehret et al., 2012). The choice of approach is non-trivial, where a poor choice can significantly impact the range of the projected changes.
e. What are the best methods for generating updated runoff projections for ~2040 and 2065?

A first order draft of the proposed work to be undertaken for Project 7 is outlined below. This outlines the general direction of the research although details will be refined in developing the Annual Work Plans for the Project.

- Evaluate seasonal rainfall trends and relevant predictors used to statistically downscale rainfall (e.g., MSLP, atmospheric flow and humidity) in CMIP5 models: e.g. use the statistical downscaling tools to provide insight into the rainfall projections and the origin of the range of projections from CMIP5 models. A particular focus will be to quantify the role of coarse model resolution on the severity and the uncertainty of the rainfall projections for Victoria.

  [Note: While downscaled climate change projections will be generated with the Bureau of Meteorology's analogue-based statistical downscaling technique as part of National NRM Climate Futures program, specifically for this VicCI Program, the analogue downscaling tool will be further used to better understand the rainfall projections from the CMIP5 GCMs and shed further light on the uncertainties of these projections.]

- Undertake an evaluation of methodologies for bias correction of existing dynamically downscaled data, such as outputs from CSIRO's Conformal Cubic Atmospheric Model (CCAM) (McGregor and Dix, 2008), and available integrations of the Weather Research and Forecasting (WRF) model (Skamarock and Klemp, 2008). Suitable methods will be identified following a literature survey.
- Using reanalysis data as input to downscaling methods, assess output from dynamical downscaling (with identified bias-correction methods) and other downscaling methodologies, such as analogue scaling (Frost et al., 2011, Timbal and McAvaney, 2001), against observed gridded rainfall data (such as AWAP). The comparison of methodologies provides important insights into the strengths and weaknesses of different methods in terms of capturing processes occurring on spatial scales smaller than the grid resolution of the host GCM. Further, the downscaled rainfall from various methods will be used to estimate runoff, which will be assessed against observed stream flow.

- In the context of the GCM evaluation undertaken in Projects 1-6, provide an assessment of which CMIP3/CMIP5 models are most suited to provide the climate change signal for the updated runoff projections for Victoria. Of key importance here is the ability of downscaled data (using GCM baseline climate) to robustly and realistically capture rainfall and runoff characteristics that are important for water supply planning purposes and flood risk evaluation in Victoria. The identification of such characteristics will be based on stakeholder knowledge of how climate can influence the performance of water supply systems (see examples below), and refined in a small workshop with contributions from CSIRO and Victorian water managers. Characteristics that are likely to be important include representation of:
    - length of runs of below average rainfall/runoff years and years of below average cool season rainfall/runoff;
    - relative contribution and seasonality of different rainfall processes (e.g. warm vs. cool season rainfall)
    - magnitude and frequency of daily/multi-day extreme rainfalls, and return periods for different daily/multi-day rainfall amounts and related consequences for flood risks.

  [Note: The types of metrics outlined above will be calculated for baseline climates of GCMs identified as reliably simulating regionally important rainfall drivers in Project 5. The GCM-downscaled metrics will subsequently be validated against observed data sets of rainfall and runoff.]

- Considering available downscaled data sets and user needs, provide an evaluation of the utility of the downscaled projections in the light of the assumptions and uncertainties involved, and identify the most appropriate format, scale and projection method for delivering the 2045 and 2065 runoff projections for Victoria – time permitting and depending on data availability, these projections will be delivered within the timeframe of VicCI together with at least qualitative information on model/method uncertainty.

  [Note: The temporal and spatial scales and format for delivery of these projections will be determined when developing the relevant Annual Work Plan, but is likely to involve characterisation of expected changes in annual and seasonal runoff at the level of upper/lower AWRC river basins for a range of plausible future climates].

- In addition to runoff projections, design and, if time and data permitting, deliver projections of key runoff characteristics, such as those identified in point c.

- Potentially, via a case study, assess the relative importance of climate risks to the performance of water supply systems in comparison to other inputs that are set/managed by water corporations, such as the adopted system reliability or other performance criteria, the setting of restriction rule curves, target filling curves, other operational rules and procedures and the level of demand.

Expected outcomes of the project are a recommended methodology for delivering updated runoff projections, and time and resources permitting, the actual delivery of these updated projections across the State for 2040 and 2065, and an assessment of the relative importance of climate risks to the performance of water supply systems.