ACTEW Future Climate Update

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Peer Review Statement

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7th September 2012

Tim Watt
Engineer, Modelling and Analysis Section
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Dear Tim

Re: Review of Urban Water Security Program Future Climate Update - 2012

As an experienced water scientist I have reviewed the report and its proposed approach and I believe the proposed improvements to climate scenarios are based on sound science and the latest assessment methods. Their use in an overall approach of adaptive readiness planning should minimise the water security risks associated with future climate extremes.

With water supply storages full from recent wet seasons, and the upcoming completion of ACTEW Water's major water security projects it would be easy to neglect future water security planning. However one thing that is certain is there will be future droughts due to natural climate variability, and when combined with a changing climate, and growing population this risk means that ongoing planning for ACT's water security is essential.

ACTEW Water's 2012 Future Climate Update provides a description of how climate impacts on the water security of the ACT, and how ACTEW Water incorporates climate variability and climate change into its planning. In this document ACTEW has taken account of the most recent findings of climate scientists and mapped out a program to improve the future climate scenarios it currently uses for water security planning.

Dr Ian Prosser
Science Director
Water for a Healthy Country Flagship

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Glossary

Catchment	An area that collects and drains rainwater (IPCC, 2007b).
Climate Change	Climate change refers to a change in the state of the climate that can be identified (e.g., by using statistical tests) by changes in the mean and/or the variability of its properties, and that persists for an extended period, typically decades or longer (IPCC, 2007b).
Climate Variability	Climate variability refers to variations in the mean state and other statistics (such as standard deviations, the occurrence of extremes, etc.) of the climate on all spatial and temporal scales beyond that of individual weather events (IPCC, 2007b).
Downscaling	Downscaling methods are used to derive estimates of local scale climate variables from large-scale global climate model outputs. These methods are typically classed as either statistical or dynamical, where the former includes regression or weather pattern based relationships between large and local scale variables and the latter refers to the use of a fine-scale regional climate model (CSIRO, 2012).
Emission Scenarios	Plausible representations of the future development of emissions of substances with potential to impact incoming solar radiation or outgoing heat from Earth (e.g., greenhouse gases, aerosols), based on a coherent and internally consistent set of assumptions about driving forces (such as demographic and socioeconomic development, technological change) and their key relationships (IPCC, 2007b).
Environmental Flows	Environmental flows are the flows of water in our streams, rivers and impoundments that are necessary to maintain aquatic ecosystems (ACT Govt., 2010).
Global Circulation/ Climate Models	Numerical representations of the climate system, including the global circulation of the atmosphere and oceans, used to simulate climate. These models provide a representation of the climate system that is near the most comprehensive currently available (IPCC, 2007b).
Global Warming	Increases in the mean annual temperature compared with a 1990 baseline mean annual temperature.
Hadley Cell	Large atmospheric circulation that transports heat from the tropics to the sub-tropics (CSIRO, 2012).
Inflows	The volume of water flowing into water storages.
Primary Water Supply System	The reticulated potable water supply network managed by ACTEW (ICRC, 2012).
Runoff	The amount of rainfall which is converted to steam flows (see stream flow).
Reliability	The proportion of time that water supply system is able to meet the demand for water (WSAA, 2005).
Step Change	A sudden shift to a changed climate state.
Stochastic Climate Data	Stochastically generated time series data that has the statistical characteristics of the historical record for the data in question. The main advantage is to allow the

	examination of the effect of alternative sequences of flow (WSAA, 2005).
Stream flow	Streamflow is the flow of water in watercourses including creeks, streams, rivers and other channels.
Sub-Tropical Ridge	The region of high pressure that exists across the mid-latitudes resulting from the descending branch of the Hadley circulation (CSIRO, 2012).
Water security	The reliability of a water supply system (see reliability).
Water Security Major Projects	ACTEW's suite of water supply projects currently being implemented, including the enlargement of the Cotter Dam, The Murrumbidgee to Googong Water Transfer, and the Tantangara Transfers (ACTEW, 2007).

Abbreviations

ACT	Australian Capital Territory
ACTEW	ACTEW Corporation Ltd
ACTEW Water	ACTEW Corporation’s water and sewerage business
ActewAGL	Public/private company (50% ACTEW, 50% by AGL)
ACTPLA	ACT Planning and Land Authority
CMCD	Chief Minister and Cabinet Directorate (ACT)
COAG	Council of Australian Governments
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DHI	Danish Hydrological Institute
Ecowise	Ecowise Environmental Pty Ltd
ECD	Enlarged Cotter Dam
ESDD	Environment and Sustainable Development Directorate (ACT)
FWO	Future Water Options
GCM	Global Climate Model
GL	Gigalitre (1,000,000,000 litres)
ICRC	Independent Competition and Regulatory Commission (ACT)
IPART	Independent Pricing and Regulatory Tribunal (NSW)
IPCC	Intergovernmental Panel on Climate Change
ISF	Institute of Sustainable Futures
L	Litre
LMWQCC	Lower Molonglo Water Quality Control Centre
M2G	Murrumbidgee to Googong Water Transfer
ML	Megalitre (1,000,000 litres)
ML/day	Megalitres per day
NARCliM	NSW and ACT Regional Climate Model
NSW	New South Wales
NWC	National Water Commission
RCM	Regional Climate Model
SEACI	South East Australia Climate Initiative
SILO	Historic climate data bank
SKM	Sinclair Knight Mertz Pty Ltd
TTO	Tantangara Transfer Operation
WSAA	Water Services Association of Australia

Executive Summary

The water resources and water consumption of the Australian Capital Territory (ACT) region are highly influenced by climate. The spatial and temporal variability of temperature, evaporation and rainfall largely determine the level of urban water supply security (i.e. reliability). Future climate scenarios are fundamental to ACTEW Water's planning for future water security.

This report looks at the ACT region's past climate variability as a basis for projecting future climate, and at the expected impacts of global warming. It examines the future climate scenarios currently used by ACTEW, compares these to recent observed weather, outlines the current scientific understandings, draws guidance from the practices of other water managers, and examines any risks associated with ACTEW's current approach. Actions are proposed to better understand future climate uncertainty and to manage the risks of unavoidable uncertainty.

Natural Climate Variability. The most notable feature of Australia's climate is its high year-to-year rainfall variability. Australia is one continent most affected by the El Niño-Southern Oscillation (ENSO). It experiences lengthy and severe droughts interspersed with wet periods. Its seasons are strongly influenced by the position and intensity of the Sub-tropical Ridge (STR). The low rainfall combined with high inland evaporation leads to highly seasonal stream flows.

ACT Region Climate. The ACT region experiences a "continental" style climate due to its elevation and distance from the coast. This is typified by four distinct seasons with relatively hot summers and cold winters. Just as Australia's climate extremes and unpredictability have largely determined its unique ecology, the ACT climate has largely determined ACTEW's approach to providing future water security.

Water Sources. ACT's primary water supply is sourced from ACTEW's four in-stream dams and two river pump stations. Total storage capacity has increased to 278 GL with the completion of the Enlarged Cotter Dam. Historic inflows into the four dams have ranged from 25 GL/year in 1982, to over 1,150 GL/year in 1956. ACTEW relies heavily on this storage to sustain its supply through extended dry periods.

In very extended dry periods, when storage levels are low, ACTEW can pump water from two pump stations located on the upper Murrumbidgee River. For even more protracted dry periods, when the river's natural flows are low, extra water can be released to the river from Snowy Hydro's Tantangara Reservoir.

Water Consumption. Canberra's metered potable water consumption has ranged from 90 ML/day on a wet winter day, to over 300 ML/day on a hot summer day. The wide range results from extensive outdoor irrigation of sport fields, urban open space, domestic gardens and lawns during summer, with little irrigation needed over winter.

Secondary Water. The urban climates of Canberra and Queanbeyan determine the water available for the smaller scale secondary supply system. This supply includes potable water substitution schemes such as rainwater and storm water harvesting schemes.

The Millennium Drought. South-eastern Australia experienced 14 years of severe drought between 1996 and 2009. The duration and impacts of this "Millennium Drought" were unprecedented in ACT's historic record back to 1871. Stream flows reduced by around 60%, water storage fell to almost 30% of full capacity, and severe water restrictions (Stage 3) were imposed for almost 4.5 years between 2003 and 2010.

2004 Future Climate Scenarios

ACTEW last updated its future climate scenarios in 2004. The scenarios were based on the historic record back to 1871, stochastic data generated in 2004 (SKM, 2004) and adjusted for the Commonwealth Scientific and Industrial Research Organisation (CSIRO) climate change forecasts made in 2003 (Bates, et al, 2003; Suppiah, et al, 2003).

Stochastic Climate Baseline. Because of the relatively short length of the historic record, it is probable that longer and more severe droughts occurred before record keeping began and will occur again in the future. To account for this, ACTEW created 10,000 years of stochastic climate baseline, based on the intra- and inter-decadal variability of the historic record, and the mean of the 28 year period centred on 1990.

CSIRO 2030 (2004) Scenario. The climate baseline was adjusted by CSIRO's climate change projections for the year 2030. The forecast annual and seasonal changes were forecast from a range of Intergovernmental Panel on Climate Change (IPCC) emissions scenarios and empirically downscaled Global Climate Model (GCMs) outputs for the ACT region. The forecast roughly corresponds to the expected impacts of around 1^{o}C of global warming. The seasonal adjustments equate to a 9% annual rainfall reduction and a 9% increase in evaporation spread evenly across all catchments. This adjustment was applied as a step change (i.e. an immediate change) to the baseline. This was thought prudent in the earlier stages of the Millennium Drought given that a step change in climate had been observed in south-western Australia during the mid-seventies.

Figure ES1 shows the relative frequency of modelled inflows of each of the 10,000 years of the stochastic baseline and CSIRO 2030 (2004) scenarios. This includes the relatively minor impact of possible future bushfires (approximately 4%). The climate change adjustment causes the spread of modelled inflows to decrease, lowers the median by around 40% and increases the frequency of the severe dry years. The median of the CSIRO 2030 (2004) closely matched the Millennium Drought annual median inflows.

This scenario has become ACTEW's preferred scenario as it has best replicated observed inflows since 1996. The 10,000 years of data are usually modelled as 50 year sequences to give a range of 200 equally possible hypothetical water security outcomes.

ACTEW WATER

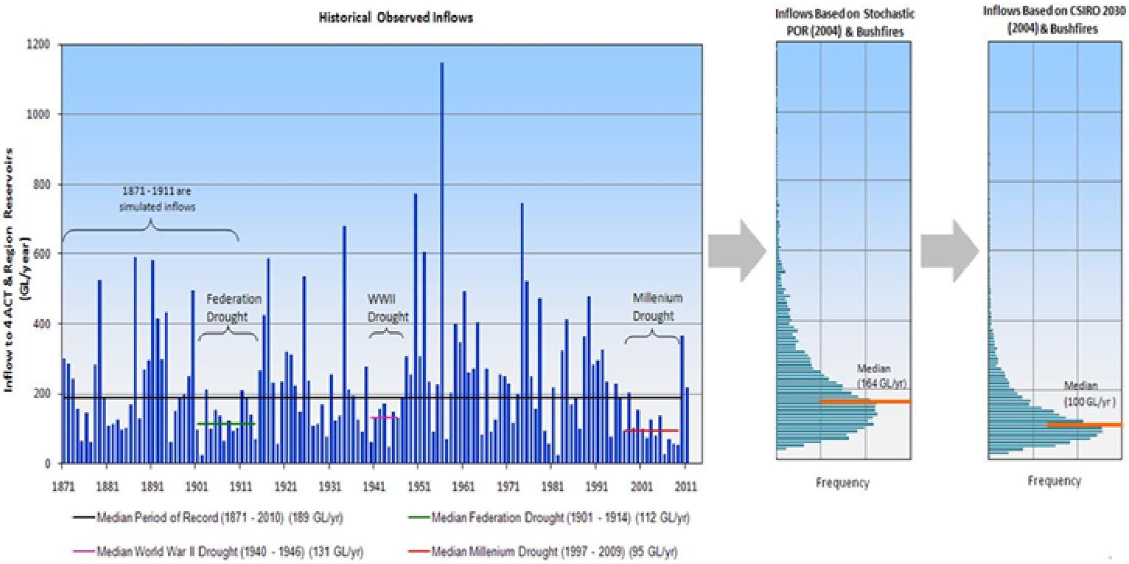

Figure ES1: **ACT And Region Historic, Stochastic And 2030 Climate Change Adjusted Inflows**

Recent Climate Observations

Seasonality has changed: Close examination of the ACT region's climate since the start of the Millennium Drought reveals a change in rainfall seasonality. Autumn rainfall has decreased significantly, with an almost 40% reduction observed over the period 1997 to 2010. Spring and summer rainfalls have increased. This change has continued through the 2010/2011 wet years. The South Eastern Australian Climate Initiative (SEACI) noted a similar autumn rainfall decline (CSIRO, 2012).

Catchment responses have changed. Autumn rainfall reductions are significant for stream flows. During dry periods, less autumn (and early winter) rainfall will reduce inflows into ACTEW's dams for a given rainfall. During the Millennium Drought, the Cotter catchment rainfall reduced by around 10% from the long-term median and inflow reduced by almost 40%. In the Googong catchment, rainfall reduced by around 7% and inflows by 62%. These inflow reductions contrast with previous expectations that each 1% reduction in rainfall will generally result in a 2 - 3.5% reduction in stream flows.

Again similar observations have been made by SEACI. SEACI's 2010 Synthesis Report noted a 13% rainfall decline in the southern Murray-Darling Basin (MDB) area over 1997 to 2006 resulted in a 44% decline in stream flows. By comparison, their modelling of the Federation and World War II Droughts gave stream flow reductions of 27% and 23% respectively (CSIRO, 2010)(CSIRO, 2012).

The changes will most likely persist. SEACI research has demonstrated the tropics are expanding; and that modelling only reproduces this expansion when forced by global warming. These changes have been occurring at least since the 1950's. The expansion is linked to an intensification of the Sub-Tropical Ridge (STR); this pushes westerly low pressure weather systems further south and has caused the decline in later autumn to early spring rainfall over south-eastern Australia, particularly in April and May (CSIRO, 2012). Consequently, ACTEW can reasonably expect the observed seasonal changes (and inflow reductions) to persist (at least until global warming is reversed).

Scenario Update

The Millennium Drought provided many lessons, and renewed ACTEW's respect for future climate uncertainty. The Drought, the more recent 2010/11 wet period and improved climate science understandings present ACTEW with the opportunity to review and update its future climate scenarios. With storages now at full capacity, and major augmentation works complete, this review can be undertaken in a much less emotive setting than was possible during the latter stages of the Millennium Drought.

ACTEW has two objectives in updating its future climate scenarios:

- To better understand future climate uncertainty, and
- Accepting that some significant uncertainty will remain at this time, to minimise the risks associated with future climate extremes.

Update Stochastic Data. ACTEW has updated its 2004 stochastic climate baseline by using the latest stochastic data generation techniques and including the more recent climate observations. 50,000 years of stochastic data have been created (1000 versions of the next 50 years) to increase the resolution in ACTEW's planning.

Apply latest climate change. The new baseline is adjusted by recent climate change projections, paying particular attention to the replication of the observed cooler month rainfall reductions. Two approaches were used to scale seasonal rainfall and evaporation in order to generate future climate scenarios:

- Use outputs from SEACI, statistically downscaled from the 200 km global climate model grids to 5km grid scale, allowing tailored climate factors for each catchment (SKM, 2013).
- Use observed changes in recent rainfall and evaporation in each water supply catchment

Wet, Medium and Dry Scenarios. ACTEW looks at the risks of both wet and dry future climate. If climate emerges drier than projected it may compromise water security; if it emerges wetter then ACTEW may make substantial investments in major supply augmentation or other measures before they are actually needed (resulting in unnecessary or premature water price rises).

To examine these risks, ACTEW has developed a wider range of future climate change scenarios. Looking at wet, medium and dry scenarios will align ACTEW with many other leading water managers in Australia, and with the expectations of some of its key stakeholders. These scenarios come from the range of GCM outputs of one IPCC emission scenario rather than from a range of emission scenarios, as the latter differs little within ACTEW's planning horizon.

Recent climate. As discussed above, recent climate in the ACT region has been marked by a pronounced reduction in autumn rainfall. This reduction characterised the Millennium Drought and appears to have persisted in the wetter period following the breaking of the drought. However, the GCM outputs typically show little change in autumn rainfall, while more significant rainfall reductions may be present in spring and winter. ACTEW has developed a fourth scenario that more closely matches observed climate by scaling the stochastic data to match the seasonal means experienced in the past 20 years, where the reduction in autumn rainfall is apparent. This scenario preserves the variability observed across the historical record while considering the observed climate trend.

Figure ES2 compares the median inflow from the four proposed stochastic scenarios to the historical inflow sequence. The median future inflow projections vary from 111 GL/year in the dry scenario to 151 GL/year in the wet scenario. Each of these scenarios contains the same high variability as the historical record. All of these proposed scenarios are wetter than the existing scenario developed in 2004.

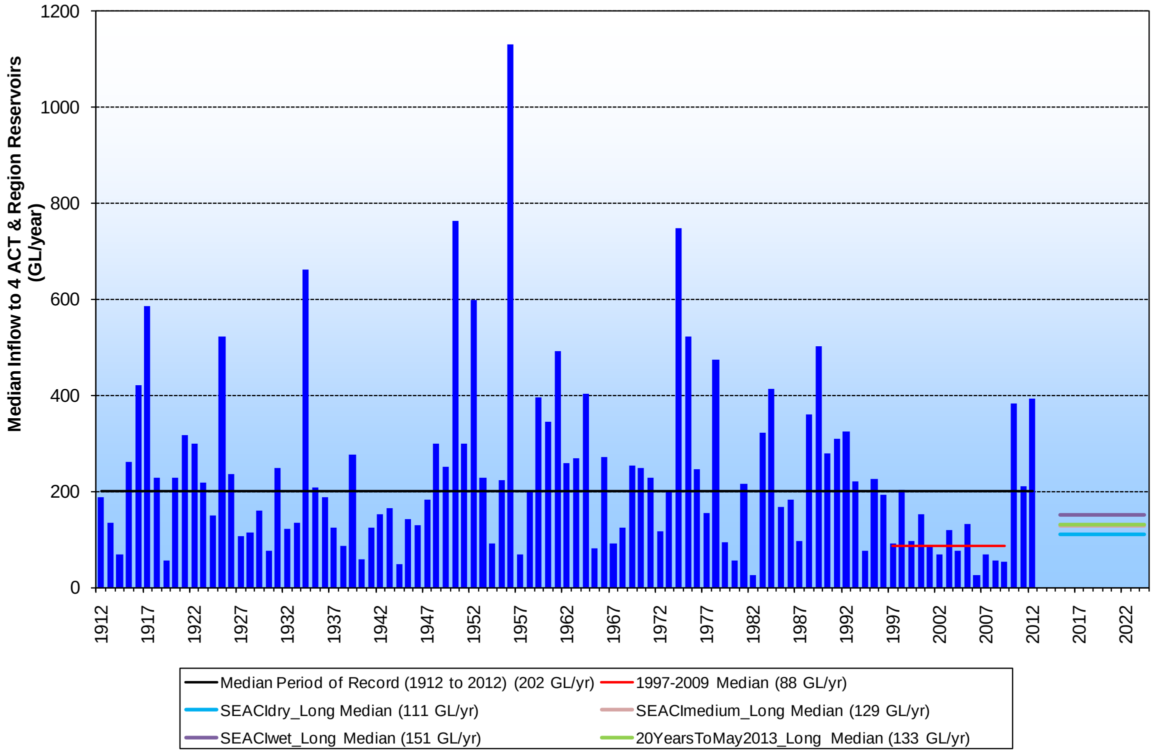

Figure ES2: ACT and region historical inflows and median proposed stochastic inflows

"Severe drought" scenario. The consequences of running out of water are far greater than prematurely investing in major augmentation infrastructure. Therefore ACTEW will develop one or more "severe drought" scenarios. At a very minimum, these scenarios will include a number of consecutive dry years from the Millennium Drought.

Adaptive readiness. The dual risk of water shortage due to severe drought or premature expenditure should a drought not eventuate can also be mitigated by flexible and adaptive planning strategies. ACTEW proposes to apply an "adaptive readiness" approach in its ongoing planning. Major cost options will be progressed in stages only when needed by an emerging climate extreme. The rate of progression will match the timeframes needed to make the option(s) operational before water security is compromised.

Conclusion

ACTEW's 2004 stochastically based and climate change adjusted scenarios were innovative, soundly based and robust for that time. The modelled spread of 200 possible climate futures proved invaluable in ACTEW's understanding of future climate uncertainty and in its 2007 water security major projects recommendations now being implemented.

ACTEW proposes to build on this future water security planning approach by adopting new future climate scenarios using the latest stochastic generation techniques and regional climate change projections. The update, in combination with a flexible, adaptive and integrated planning approach, will best allow ACTEW to meet its future water security objectives for the foreseeable future.

1. Introduction

“The only thing we know about the future is that it will be different”

Peter Drucker, Management: Tasks, Responsibilities, Practices (1973)

The Australian Capital Territory (ACT) region water resources and water consumption are highly influenced by the climatic factors of temperature, evaporation and rainfall. In Canberra, water consumption can vary from 90 ML/day during a wet winter to over 300 ML/day during a dry summer. Inflows into ACTEW’s water storage reservoirs have ranged from a low of 25 GL/year in 1982, to almost 50 times greater at 1150 GL/year in 1956. That's why the future climate of the ACT region will be a key determinant of the reliability of Canberra's primary water supply into the future.

Past records show that the ACT climate varies considerably depending on location, season, and natural year to year climate variability. Long periods of dry have been experienced in the past and are expected to reoccur in the future. However the impacts of the recent Millennium Drought (1997 to 2009) were unprecedented in ACTEW’s past climate and streamflow records. This drought caused ACTEW’s water storages to deplete more quickly, and then take longer to recover, than was expected from records of previous droughts.

Average annual rainfall during the Millennium Drought was around 11% less than the long-term average before the drought; and reservoir inflows reduced by over 50%. Storage levels fell to almost 30%, and severe (Stage 3) water restrictions were in place for almost 4.5 years of the seven years between 2003 and 2010. There is compelling evidence the global climate system is warming (IPCC, 2007); and the Millennium Drought was caused by a combination of natural climate variability and global warming induced climate change (SEACI, 2011).

ACTEW expects the past natural year to year variability of the ACT climate to continue, and that it will be modified by the continuing impacts of global warming. Consequently, more frequent and more severe (i.e. longer and drier) droughts are expected to occur in the future than have occurred in the past ACT record.

This report looks at the ACT's past climate trends and the expected impacts of global warming. It examines the future climate scenarios currently in use by its planners, highlights recent climate observations and scientific understanding, draws guidance from the practices of peak or similar water managers, and examines the risks associated with its current climate scenarios. It proposes a set of actions to manage future climate uncertainty and further actions to manage the residual uncertainty.

2. Background

The ACT region lies within the broad Köppen *"temperate"* climatic zone, however it experiences a more *"continental"* style climate due to its elevation (higher than 650 m) and distance from the coast (~150 km inland).[1] Little moderated by the sea, the ACT climate is typified by four distinct seasons with relatively hot summers (up to ~40^{o}C) and cold winters (minimums to -10^{o}C).

Just as climate varies from region to region, climate also varies within the ACT region due to local topographical and other climate modifying features. Average annual rainfall in Canberra is around 630 mm, but varies widely over the ACT water supply catchments. The rainfall has generally been distributed uniformly throughout the year, but this appears to be changing since around 1996. Winter rains generally originate from west to east movements of cold fronts across southern Australia; with summer rainfall originating from thunderstorms occurring from October through to March.

ACT's historic rainfall and stream flow records show a high spatial and temporal variability (see Section 4). The past long periods of dry have prompted the construction of large on-stream dams to provide for ACT's primary (i.e. potable) water supply. For even longer periods of dry ACTEW also has the capacity to pump from the Murrumbidgee River. For very protracted dry periods (i.e. severe drought), it can further release purchased water from Snowy Hydro's Tantangara Reservoir to the Murrumbidgee River to augment the river's flows.

Figure 2-1 shows the locations of ACT's primary water supply catchments. It is the climate of these areas that is of most interest to ACTEW.

2.1. Primary Water Supply Sources

The ACTEW controlled water storage catchments are listed below in decreasing order of preferential use corresponding with water quality and unit cost. This also corresponds to the order of increasing importance during escalating droughts.

- Cotter River – rises on the divide of the 1900m elevation Brindabella Ranges and is protected within the Namadgi National Park west of Canberra. The Brindabella's trap very reliable precipitation in the form of snow and rain from westerly weather systems. This catchment is relatively steep, largely pristine; includes alpine grasslands, native wet sclerophyll forest and well developed granitic soils, which collectively produce a high quality water requiring little treatment to potable standards
- Queanbeyan River – rises in the 1400m high Tinderry Ranges to the south-east of Canberra. Being located to the east of the Brindabella's, this catchment receives less rainfall from the westerly weather systems, but receives more rainfall from the less reliable east coast low pressure weather systems. The catchment is larger than the Cotter River catchment but does not yield correspondingly more water. It is less steep and largely developed as grazing farmlands and rural-residential communities. It includes some dry sclerophyll native forest but is largely open grasslands and shallow, poor quality shaly soil profiles. Collectively this source provides a poorer quality water requiring more treatment than Cotter

[1] Köppen classification: Cfb (Maritime temperate climate / European climate)

- Murrumbidgee River (below Tantangara Dam) – rising in the Kosciusko National Park and the Eastern Coastal Great Divide and draining the Monaro Plains from Cooma to the south of Canberra, the Murrumbidgee River provides a catchment as diverse as any in Australia. The catchment receives precipitation, including rain and snow from westerly, easterly and southern weather systems. The central Monaro plains comprise grasslands and extensive grazing and are largely in a rain shadow. The mountains on either side receive snow, have large areas of dry and wet sclerophyll forest and alpine pastures. The geology and soil profiles are diverse and together with small but significant urban development gives a quite reliable but variable quality water source requiring significant treatment for potable use
- Murrumbidgee River (above Tantangara Dam) - situated in the Snowy Mountains, this catchment is one the highest yielding catchments in the Murray Darling Basin due to its high rainfall, low evaporation and runoff from snow melt. On average, the Tantangara Dam diverts more than 285 GL to Eucumbene Reservoir and out of the Upper Murrumbidgee catchment annually and will almost certainly be available to provide supplementary water to the ACT if required.

The water availability from these sources (but not Tantangara releases) is also limited by ACT Government requirements to provide downstream environmental flows (ACT Govt., 2010)

2.2. Secondary Water Supply Sources

Secondary water provides the alternative to potable water sourced from ACTEW's reticulated supply system and comes from Canberra's urban catchments.[2] The principles of integrated resource management require secondary water options be assessed equally as potential future sources alongside primary water sources. The climate data for these secondary water sources is generally sourced from the Canberra Airport weather station.

2.3. Urban Water Demand

A number of ACTEW studies of water consumption in the ACT have consistently found that the recent weather (i.e. rainfall, evaporation/and or temperature) and time of year correlate well with the recorded daily consumption. The climate data for urban water demand is also sourced from the Canberra Airport weather station.

[2] The ICRC define secondary water as follows: *"Secondary water is water provided from any source other than the ACT's primary water source, ACTEW's primary water network. It includes water sourced from wastewater (such as treated effluent from a water treatment plant or sewer mining scheme and grey water from bathrooms and laundries), storm water and rainwater"* (ICRC, 2012).

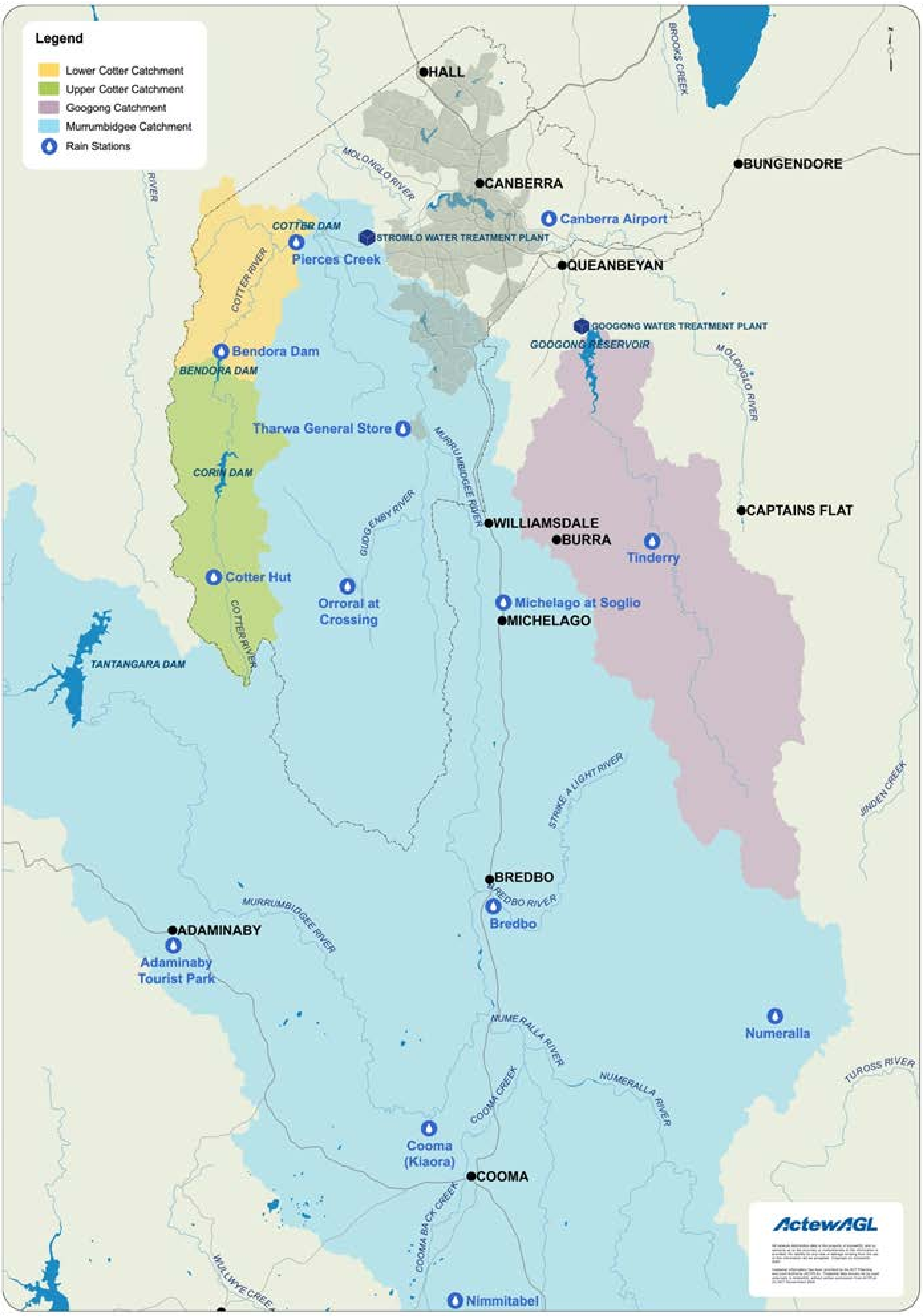

Figure 2-1: ACT Region Water Supply Catchments and Key Weather Stations

3. The 2004 Future Climate Scenarios

This section lists the future climate scenarios developed by ACTEW in 2004 to address the relatively short period of climate records and the forecast impacts of global warming. These scenarios underpinned its 2005 Future Water Options studies (ACTEW , 2005), 2007 Water Security for the ACT and Region report (ACTEW, 2007), and are still currently used in its water security assessments. Table 3-1 below lists the scenarios and the key features of each.

Table 3-1: ACTEW's 2004 Future Climate Scenarios

Ref.	Scenario	Description	Notes
A	Historic record	Climate observations from 1871 to date; with some minor in-filling where actual records are missing	Includes past droughts; in-filling uses well accepted methods to generate rainfall and evaporation data
B	Stochastic data (2004)	10,000 years of synthetic climate data based on mean of 28 year. centred on 1990 and variability of A	Includes longer and more severe dry and wet periods than A
C	CSIRO 2030 (2004)	Empirical "step" adjustment of B by a prudent interpretation of CSIRO's 2030 climate change forecasts	Includes more frequent severe dry periods than B
D	CSIRO 2070 (2004)	Empirical "step" adjustment of B by a prudent interpretation of CSIRO's 2070 climate change forecasts	Includes more frequent severe dry periods than C

3.1. Historic Record

Up to 2003, ACTEW's planning was based on the region's historic climate record back to 1871. There were some relatively short data gaps in these records, and these were "in-filled" using accepted hydrological techniques. The record includes three significant dry periods:

- Federation Drought (1901 - 1914)
- World War II Drought (1940 - 1946)
- Millennium Drought (1997 - 2009).

Figure 3-1 shows the annual rainfall record at Canberra Airport and the median *"four-dam inflows*[3]*"* for the historic record. The annual median inflow for the full period back to 1871 is around 189 GL per year; this dropped to 95 GL per year during the Millennium Drought.

[3] It is useful to have a single value which describes the approximate middle or central tendency of the data. Two common measures are the median and the mean (i.e. average). The median is the value of the middle point; the mean is the sum of the data values divided by the number of data points. ActewAGL generally reports the median as it is more representative of the central tendency when dealing with highly skewed stream flow distributions (i.e. low to medium flows occur most of the time, with the occasional very large floods skewing the records to give an average that may mislead).

ACTEW uses "four-dam inflows" or the volume of inflow into the Cotter, Bendora, Corin and Googong reservoirs had they been built at the time. As inflows are dependent on a wide variety of climate variables including annual rainfall and evaporation, rainfall seasonality, rainfall intensity and spatial and temporal state, they present a useful surrogate for climate in this context.

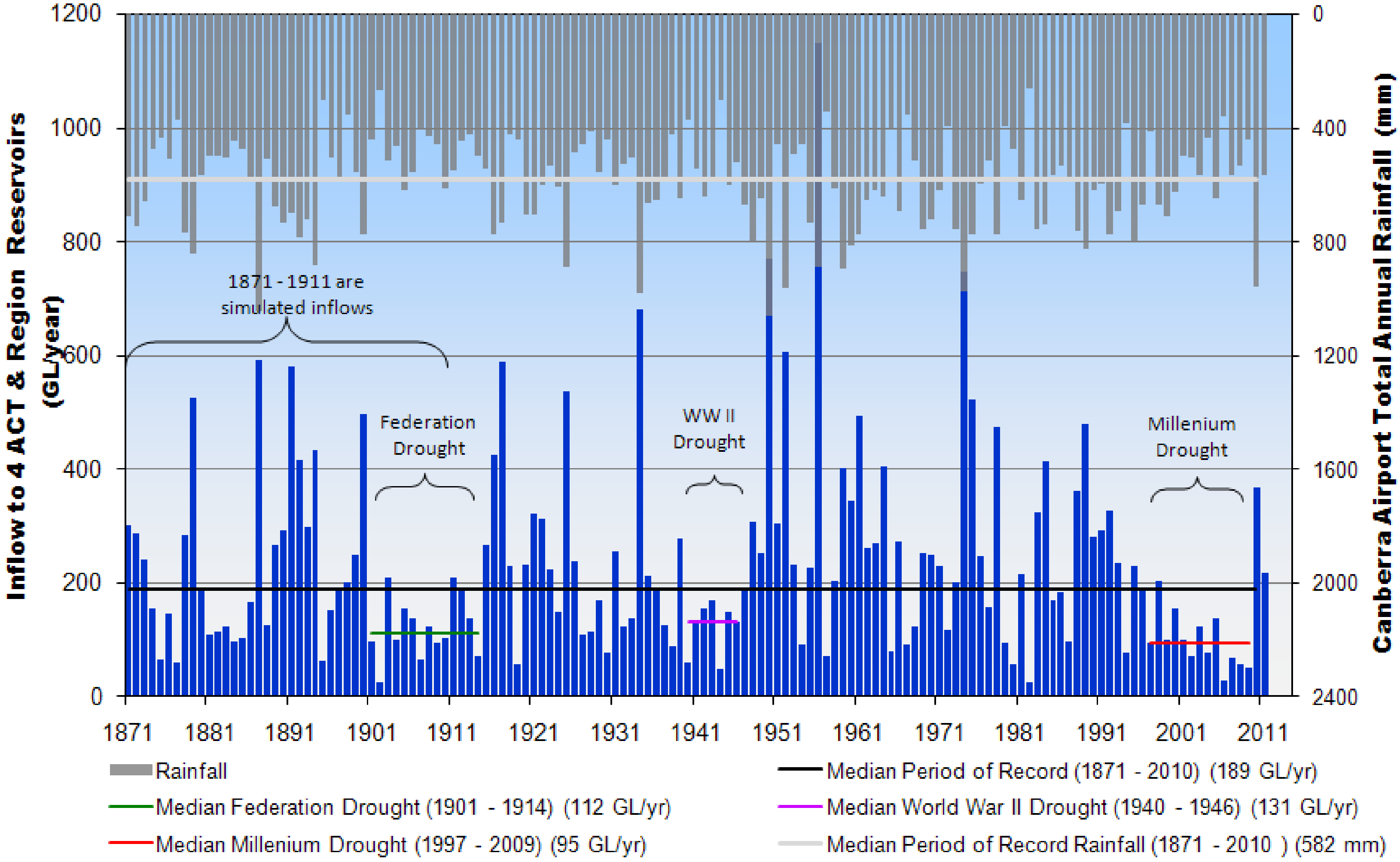

Figure 3-1: ACT Region Historic Rainfall and Median Four-Reservoir Inflow Record

The historic record is still modelled on occasion to examine the impacts of possible recurrence of past droughts. The historic record is not commonly used as it is based on the now questioned concept of climate stationarity. Climate stationarity being the long-held water resource planning premise that future climate will fluctuate within an unchanging envelope of variability defined by past climate.

3.2. Stochastic Climate Record

The historic record represents a relatively short period in the full climate history of the ACT region. It is quite likely that, due to natural climate variability, longer and more severe droughts occurred before the record keeping commenced in 1870. It is also possible for the same reason that longer and more severe droughts will occur in the future than have been observed to date.

To allow for this possibility, ACTEW developed a stochastic climate data set. The stochastic data is a sequence of synthetic climate generated from past climate observations using advanced statistical methods. ACTEW's stochastic climate generated in 2004 is based on the observed variability over the past 140 years and the mean of the 28-year period centred on 1990; with 1990 being the reference year for IPCC global warming projections. The median of the 28-year period was slightly wetter than the full historic record. This stochastic sequence is 10,000 years of possible future climate. It includes longer sequences of dry years than have occurred in the past and so contains more severe droughts than observed to date (SKM, 2004).

The right hand side of Figure 3-2 shows the model projected inflows for each year of this 2004 stochastic climate sequence Figure 3-2. The median of these 200 replicates is around 164 GL/yr; slightly lower than the annual median for the period of record. This difference is most likely due to inclusion of possible future bushfires in the model and the use of a modified Googong rainfall-runoff model to accommodate the unexpected decline in Queanbeyan River flows during extended low rainfall periods (this model underestimates flows before 1990).

This stochastic climate data is generally modelled as 50-year data sets (i.e. replicates) to give 200 equally possible model projected water security outcomes for the next 50-years.

3.3. CSIRO 2030 and 2070

From around 1996, ACTEW began to observe a decline in inflows. A similar but more marked decline had been observed in south-western Australia from around the mid-1970s, with a growing consensus that this decline was caused by climate change. Wary of a similar climate change impact, ACTEW sought advice from CSIRO in 2003 on future climate change for the ACT and region. CSIRO used a range of greenhouse gas (GHG) emission scenarios and Global Circulation Models (GCMs) to project the annual and seasonal rainfall and evaporation changes for ACT for the years 2030 and 2070 relative to 1990. The projections are forecasts of climate (i.e. an envelope of possible weather) at 2030 and 2070, not weather forecasts for these specific years.

The 2030 projections were based on three roughly equivalent GHG emission scenarios: the 2000 IPCC SRES A2, the earlier IS92a and 1% annual increase in CO_2 (The A2 scenario is an upper range greenhouse gas emissions scenario of independently operating, self-reliant nations, continuously increasing population, regionally oriented economic development, and more fragmented and slower technological change than other IPCC scenarios). Empirical scaling factors were created from 13 GCMs at a 100 km. grid scale. The 2070 scenario was based on simple extrapolation of the 2030 scenario (Suppiah & Whetton, 2003).

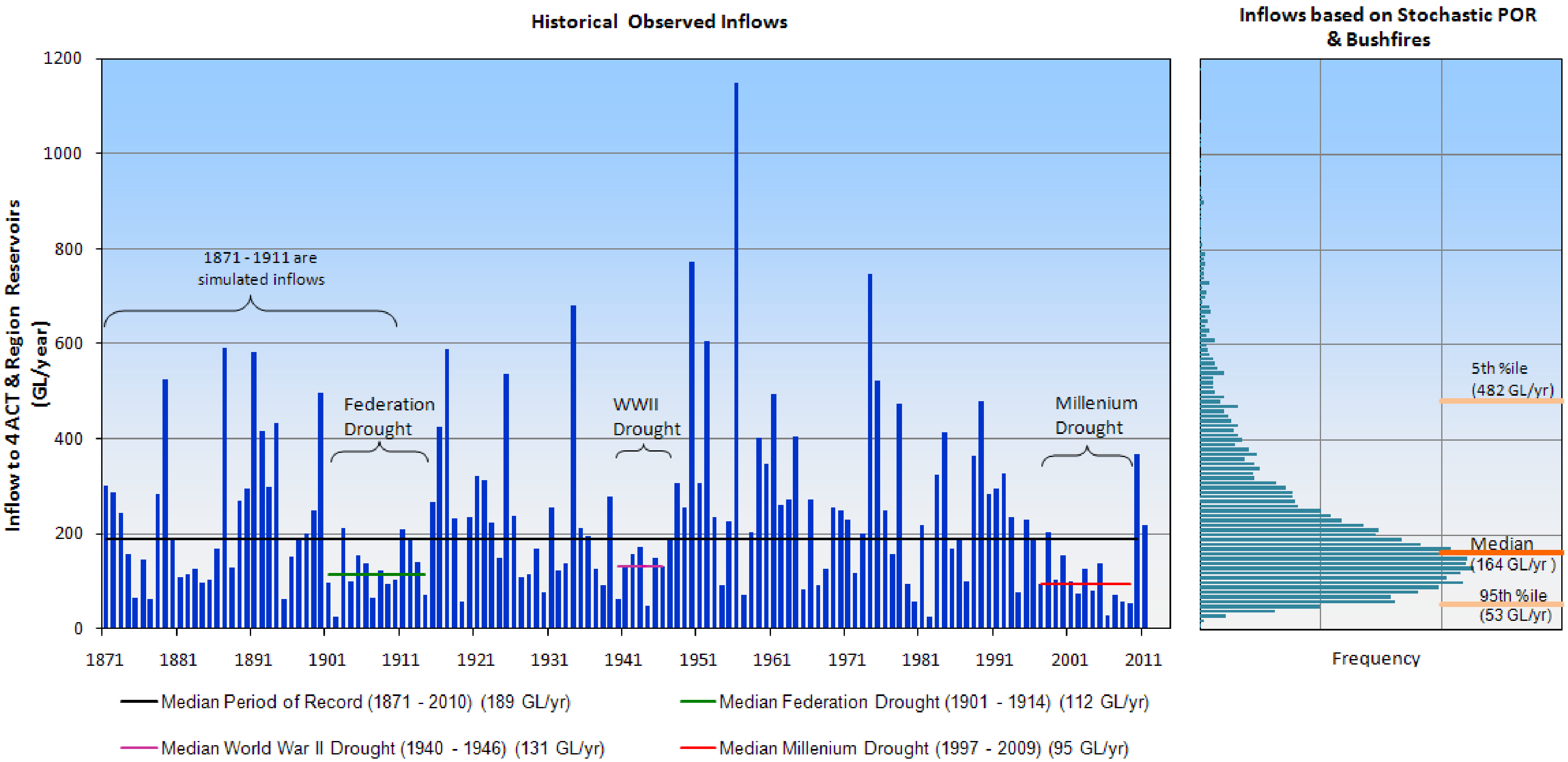

Figure 3-2: ACT region four-reservoir inflows showing Stochastic Climate Record (2004) annual inflows distribution

Figure 3-3 shows the range of CSIRO projected changes for 2030 relative to 1990. This should be interpreted as a range of projected changes taken from different GCMs rather than a probabilistic spread of projections. The 2030 annual rainfall was projected to range from a 2% increase to a 9% decrease; with evaporation similarly ranging from a 1.4% increase to a 9.1% increase.

Figure 3-3: CSIRO projected climate changes for 2030 (Suppiah & Whetton, 2003)

ACTEW elected to be prudent and created the CSIRO 2030 (2004) climate scenario by scaling the stochastic climate record (2004) to the worst case CSIRO projections of 9% annual rainfall reduction and a 9% annual evaporation changes. The percent changes were applied seasonally in proportion to the CSIRO seasonal projections. Again for reasons of prudence, and based on the ACT observed inflow decline and the south-western Australia experience, ACTEW assumed an immediate step change to CSIRO's projected climate for 2030.

Figure 3-4 shows that modelling the individual years of the CSIRO 2030 (2004) scenario reduces the median inflow of the stochastic climate scenario from 164 GL/year to 100 GL/year. The latter closely matches the 95 GL/yr median inflows observed during the Millennium Drought. The modelling of this climate change adjusted scenario also increases the projected frequency of severe droughts.

Mainly because of its close match to the observed Millennium Drought inflows, taken in combination with modelled bushfire impacts, the CSIRO 2030 (2004) climate scenario has become ACTEW's primary future water security planning scenario. The more severe 2070 projections are generally not used by ACTEW as they are less certain and lie beyond the current planning horizon.

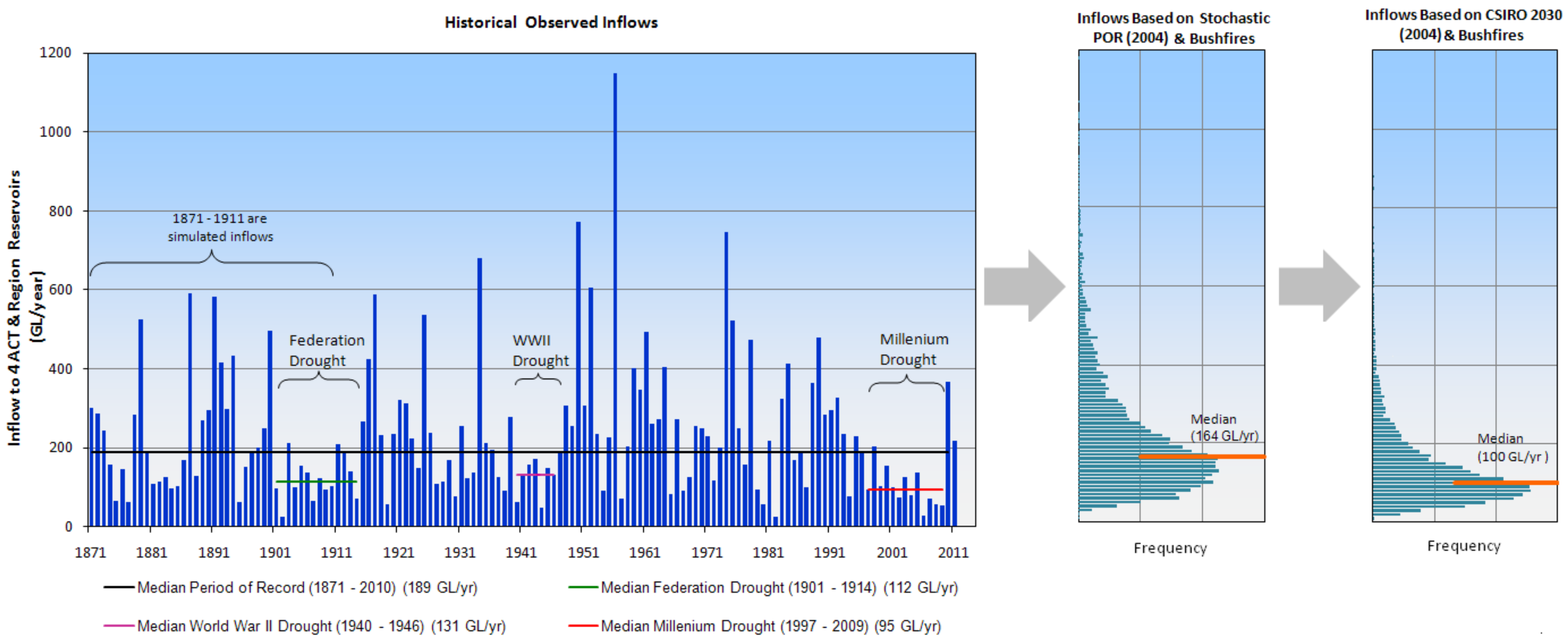

Figure 3-4: ACT Region Four-Reservoir Inflows Showing CSIRO 2030 (2004) Annual Inflows Distribution

4. Recent Climate Observations

This section looks at the ACT region's actual climate that has emerged in recent years. This emerged climate is compared to ACTEW's primary CSIRO 2030 (2004) climate scenario to assess the "skill" of this scenario in replicating actual climate.

4.1. Temperature and Rainfall

Figure 4-1 shows an upwards trend in the average annual temperature at Canberra Airport over recent years. This record is generally in line with recent observations of BOM and CSIRO (CSIRO/BOM, 2012) and the earlier observations of the IPCC (IPCC, 2007). This graph shows the periods of higher than average temperature are generally associated with periods of lower than average rainfall.

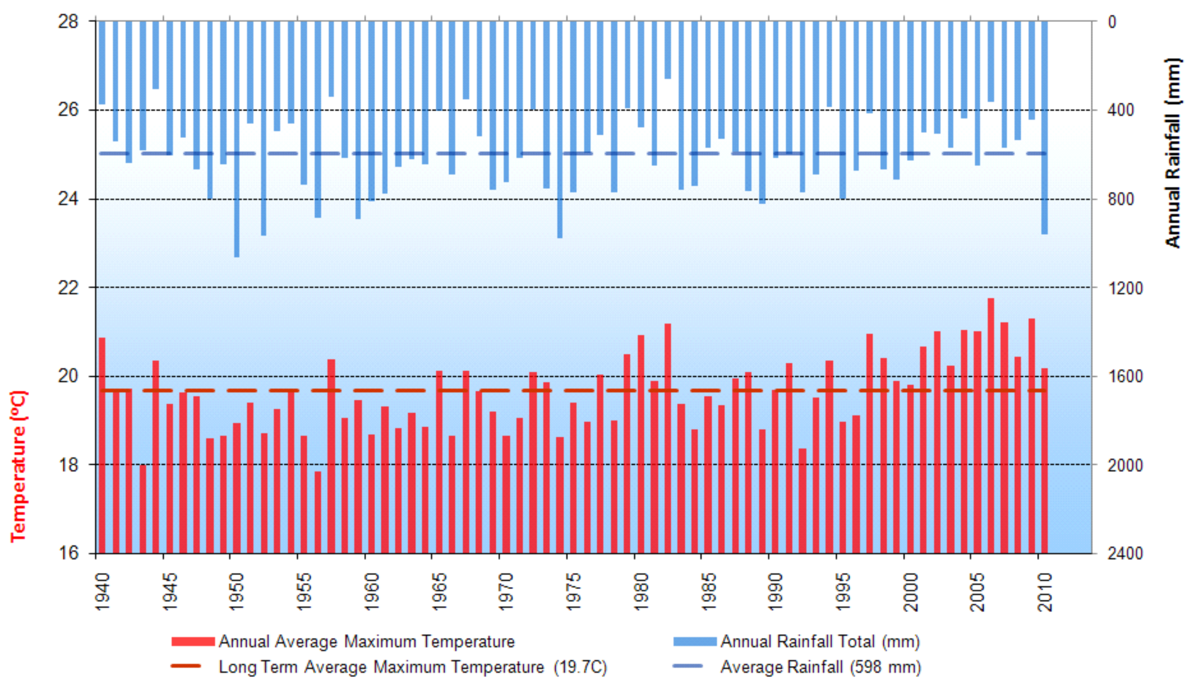

Figure 4-1: Canberra Airport Annual Temperatures and Rainfall Since 1940

4.2. Rainfall, Drought and Inflows

Figure 3-1 previously showed the annual rainfalls, four-dam inflows and the three periods of significant drought. The period since 1996 is particularly interesting as it includes the Millennium Drought and also the more recent very wet period (i.e. 2010 and 2011).

Table 4-1 shows the median annual rainfall and four-dam inflows for each of these periods of drought, and compares the reductions to the historic record up to 1996. This shows the rainfall reduction during the Millennium Drought was similar to the World War II Drought and much less than the Federation Drought. The inflow reductions however, were much higher during the Millennium Drought than previous droughts.

Table 4-1: ACT Region Rainfall And Stream Flow Reductions During Drought

Period	Median rainfall	Rainfall reduction	Median inflows	Inflow reduction
	(mm/yr)	(%)	(GL/yr)	(%)
Period of Record (1871 - 1996)	590	-	202	-
Federation Drought (1901 - 1914)	462 [a]	22%	112 [b]	45%
World War II Drought (1940 - 1946)	542	8%	131	35%
Millennium Drought (1997 - 2009)	535	9%	95	53%

[a] *Correlated rainfall and evaporation from Queanbeyan;*

[b] *Some uncertainty here as no records exist, inflows are from modelling (refer Advice to ACTEW: WA1011_014)*

This Millennium Drought observation contrasts with previous south-eastern Australian experience that the ratio of the observed rainfall reduction to streamflow reduction is generally around a factor of 2 to 3.5 (i.e. each 1% reduction in rainfall causes a 2 – 3.5% reduction in streamflow). Table 4-1 shows the ratio of the Millennium Drought rainfall reduction to ACTEW's inflow reduction is almost 6, much greater than in previous droughts.

Similar observations were made by the South Eastern Australian Climate Initiative (SEACI)[4]. SEACI's 2010 Synthesis Report noted a 13% rainfall decline in the southern Murray-Darling Basin (MDB) area over 1997 to 2006 resulted in a 44% decline in stream flows. By comparison, the stream flow reductions during the Federation Drought and World War II Drought were 27% and 23% respectively(CSIRO, 2010).

The 2010 SEACI report goes on to highlight the Millennium Drought was unprecedented compared to earlier droughts because:

- It was largely confined to the south-eastern of Australia
- It had lower year to year variability (i.e. a lack of wetter months and years), and
- The seasonal rainfall decline was greatest in autumn, followed by winter and spring.

SEACI's 2012 draft report suggests that during extended droughts some (low relief) catchments, such as the Queanbeyan River, show a disconnection between surface and groundwater. This, in combination with the annual variability and seasonality changes, provides an explanation for the observed magnification of streamflow reductions (CSIRO, 2012).

[4] SEACI was established in 2006 to investigating the causes and impacts of climate change and variability across south-eastern Australia, developing improved short-term predictions for hydrological and agricultural applications. It is collaboration between Bureau of Meteorology, CSIRO, Australian Government Department of Climate Change and Energy Efficiency, Murray–Darling Basin Authority, and Victorian Department of Sustainability and Environment; with CSIRO as the managing agency. ACTEW is an active participant in the Initiative.

4.3. Temporal Variation and Inflows

There is no readily apparent difference in the year-to-year variability of the 14-year Federation Drought, the 12-year Millennium Drought and the six-year long World War 2 Drought.

However Figure 4-2 and Figure 4-3 shows the observed rainfall seasonality in the Cotter and Googong catchments trends away from the relatively uniform historic seasonality towards higher summer[5] / spring rainfalls and lower autumn (and possibly winter) rainfalls during the Millennium Drought. This trend continues into the 2010 and 2011 wet years. This is consistent with SEACI's wider regional observations of "cooler month" rainfall reductions (CSIRO, 2010) (CSIRO, 2012). However, the split of seasons should be viewed with caution (e.g. a very high rainfall in the last few days of summer may skew the summer / autumn results, and given natural climate variability, could mask a significant autumn event arriving a few days early).

Any autumn and early winter rainfall reductions are significant as they will cause a reduction in stream flows. This is because the flows are highly dependent not just on rainfall but also on antecedent catchment wetness (from earlier rainfalls). Many consecutive years of low annual rainfall combined will lower groundwater base flows and streamflows. It is highly likely the Millennium Drought's 14 consecutive years of below median rainfall, in combination with the observed seasonal shift away from autumn rainfalls, caused the much decreased inflows described in Section 4.2.

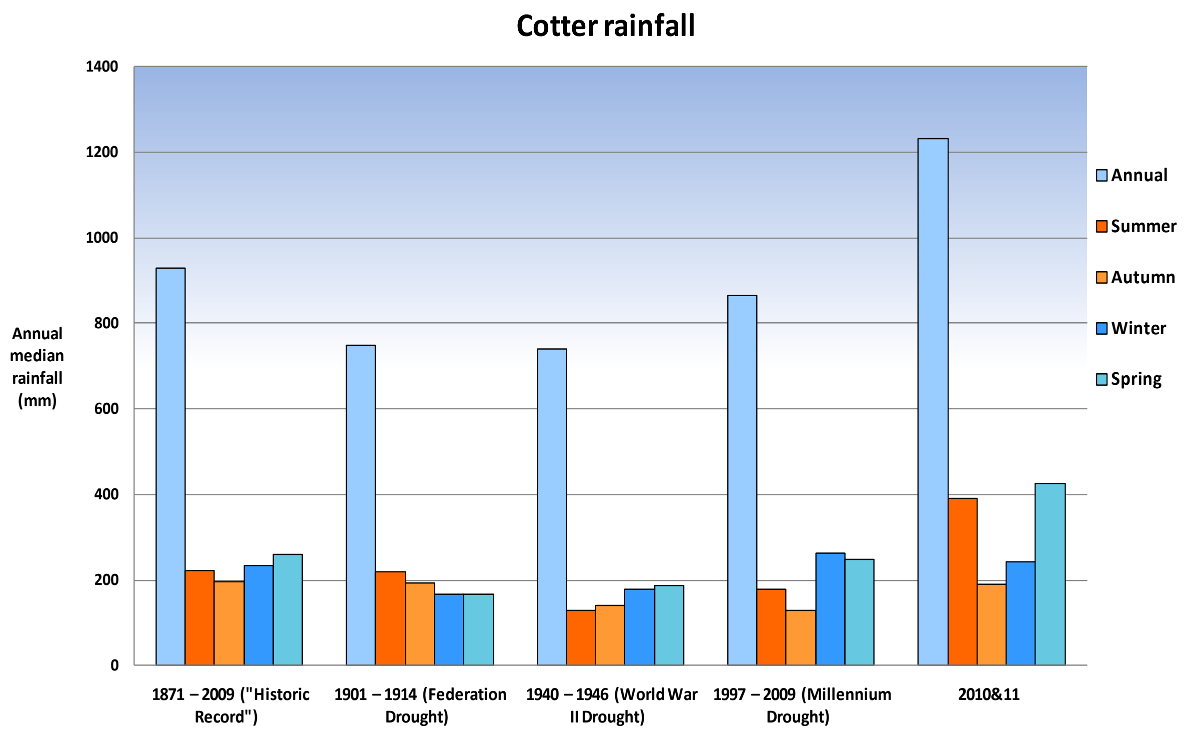

Figure 4-2: Annual and Seasonal Cotter Rainfall

[5] Summer being taken as December, January and February (DJF), and so on for each season.

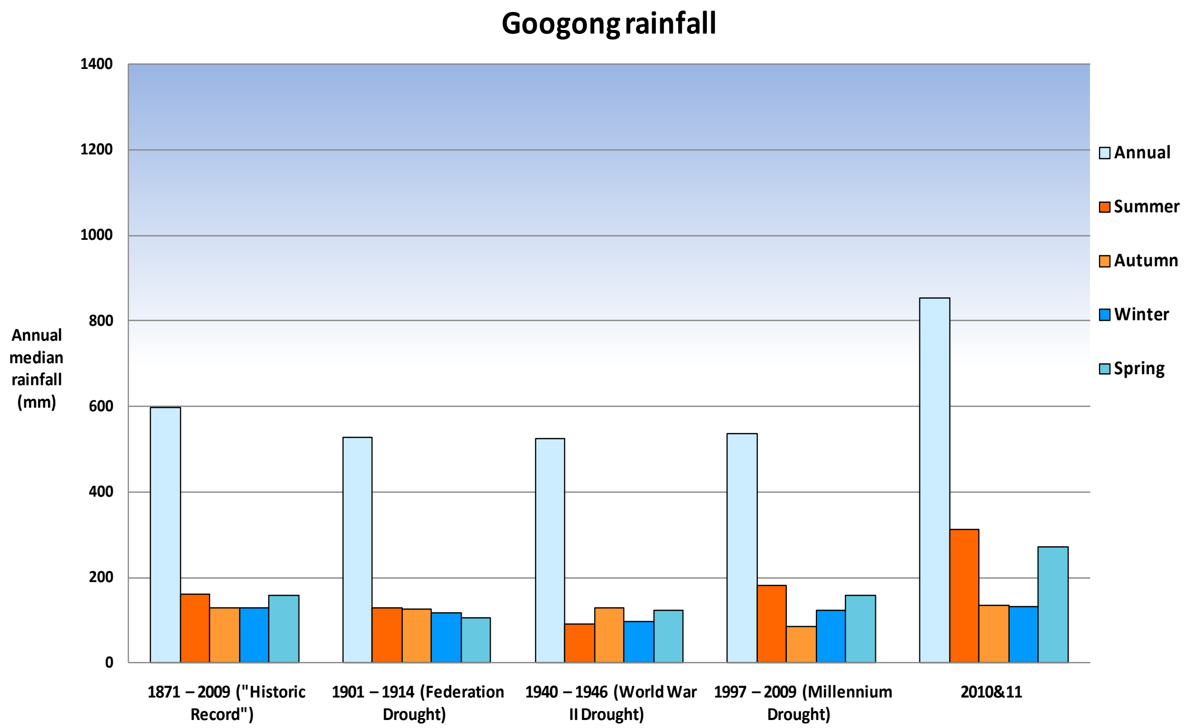

Figure 4-3: Annual and seasonal Googong rainfall

4.4. Spatial Variation and Inflows

Figure 4-4: and Figure 4-5 show the similar rainfall reductions observed in the Cotter and Queanbeyan catchments during the Millennium Drought. However, the slightly lower percentage rainfall reduction in Googong resulted in a much higher percent inflow reduction than in Cotter.

While still under debate, there appears some emerging consensus that runoff from less steep low rainfall catchments (like Googong) is more impacted in droughts due to some combination of the following:

- Low catchment soil moisture levels due to consecutive dry years and low autumn / early winter rainfalls (see Section 4.3)
- Reduction of base flows and increased capacity for moisture storage (in the unsaturated portion of soil profiles) due to low groundwater levels, and/or
- Increased percentage interception of reduced surface water flows due to farm dams and groundwater withdrawals (both increasing in number particularly in the rural residential areas of the Burra sub-catchment)

This suggests that the spatial distributions of climate change impacts are important to ACTEW's future projections of inflows, as the impacts of drought appear to vary from catchment to catchment. This is particularly so for the larger and flatter low rainfall Googong catchment.

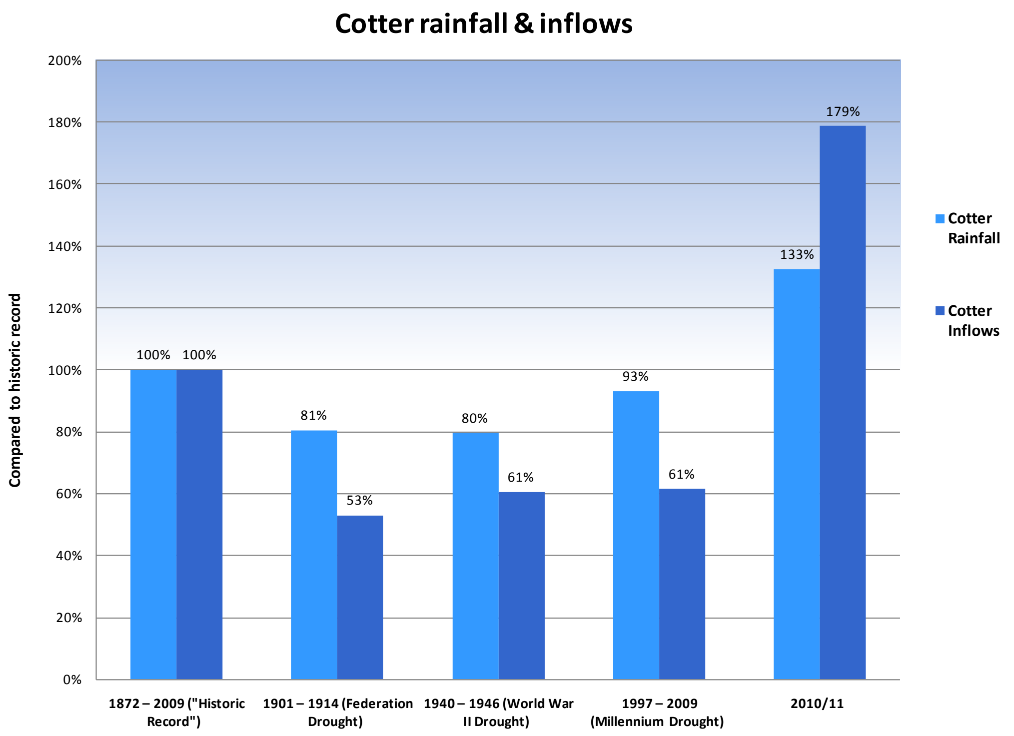

Figure 4-4: Cotter Catchment Rainfall and Inflows

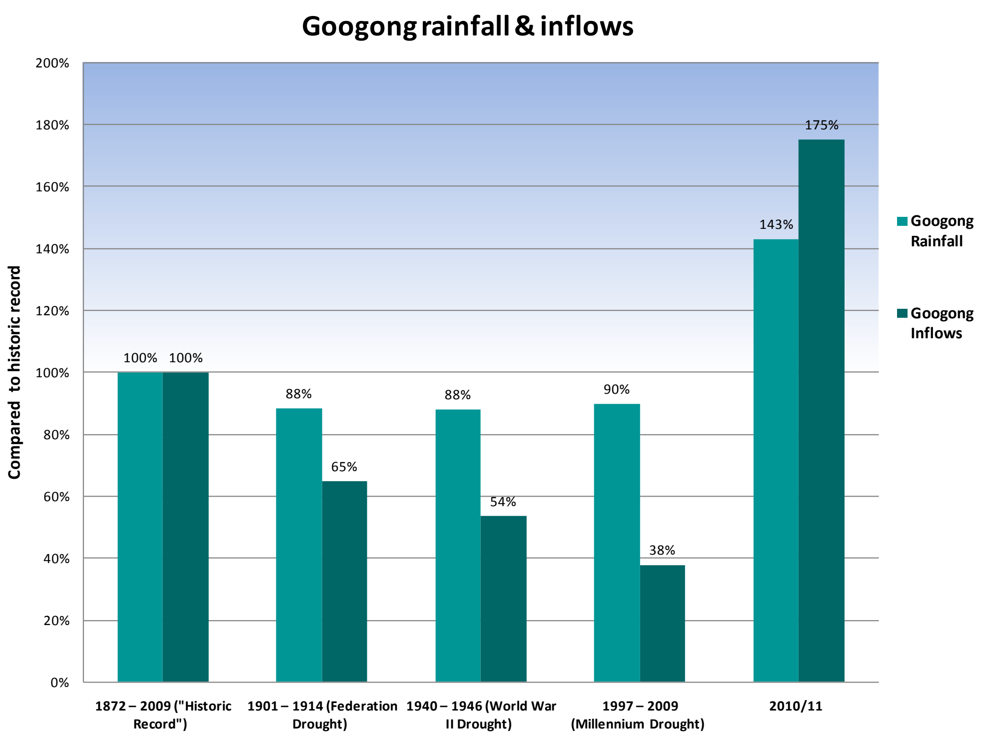

Figure 4-5: Googong Catchment Rainfall and Inflows

4.5. Observed climate compared to CSIRO's 2004 forecasts for 2030

Figure 4-6 compares the period 1997 to 2010 annual and seasonal rainfall and evaporation observed changes to CSIRO's 2004 forecasts for the year 2030. This shows the observed annual rainfall reduction during the Millennium Drought period is similar to the worst-case CSIRO projections for 2030.

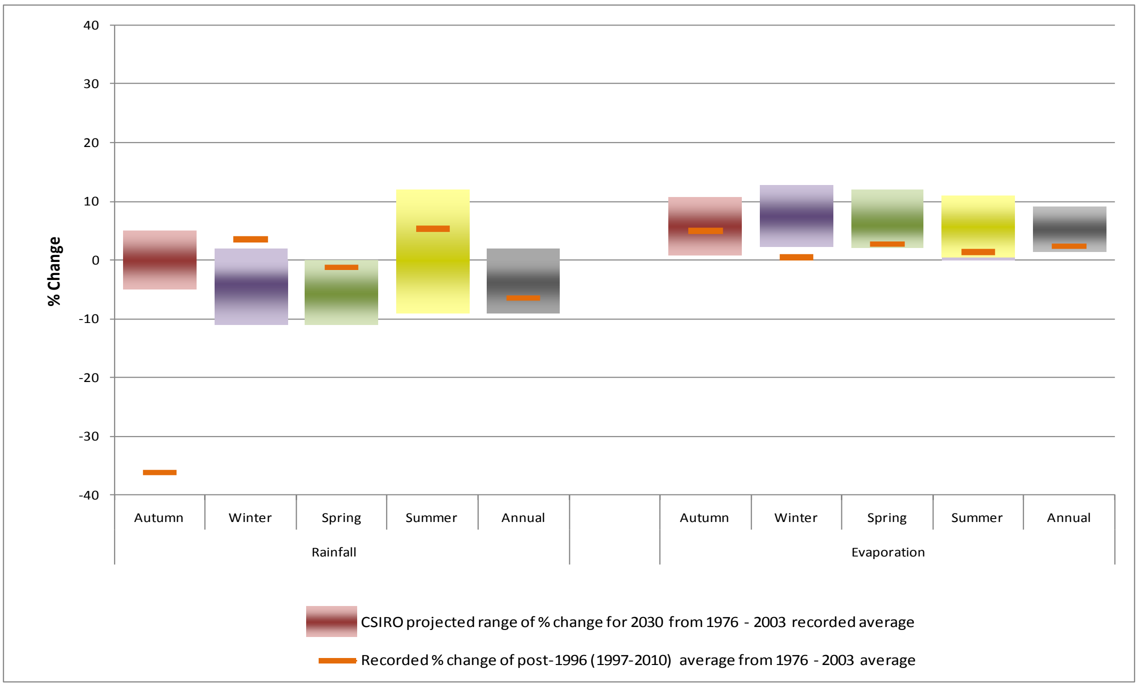

Figure 4-6: Post-1996 Change Compared to CSIRO's 2004 Forecasts for 2030

Except for the 36% autumn rainfall reduction compared to a CSIRO projected 3-4%, the seasonal Post-1996 observations values generally fit within, or are very close to, the CSIRO range of GCM projections. This is consistent with SEACI's findings that GCM's generally have poor skill in forecasting the observed autumn / winter rainfall reductions(CSIRO, 2010), however predictive skill of GCMs are continually being improved as global climate drivers are better understood.

5. Recent Climate Science

The understanding of global climate drivers has improved considerably since 2003, and the understanding of south-eastern Australia's climate is continuing to improve through the research of CSIRO, SEACI, BOM and others. However, the relatively limited historic climate record and natural climate variability, overlain with the climate impacts of global warming, means considerable uncertainty surrounding future climate still remains. This section outlines the current understandings relevant to the ACT region, and the implications for ACTEW's future water security planning.

5.1. Natural Climate Drivers

Figure 5-1 shows the primary large scale atmospheric circulation drivers of Australia climate.

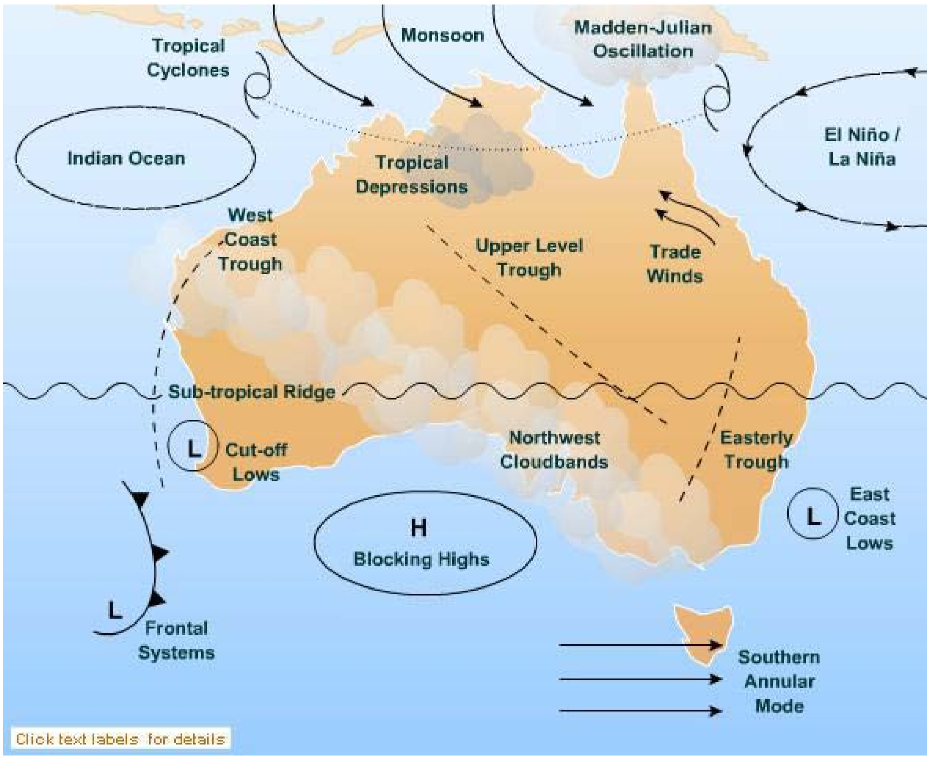

Figure 5-1: Major Climatic Features Affecting Australia (source: BoM)

In south-eastern Australia, CSIRO and BOM researchers have found the natural seasonal, intra-decadal and inter-decadal climate variations are primarily driven by:

- *El Niño/La Niña-Southern Oscillation (*ENSO) – this is the irregular variation of the surface temperature of the tropical eastern Pacific Ocean and the oscillation of air surface pressure in the tropical western Pacific. El Niño refers to the phase of extensive warming of the central and eastern tropical Pacific Ocean generally, but not always, associated with drier conditions across eastern Australia. The La Niña phase is generally associated with wetter conditions

- *Indian Ocean Dipole* (IOD) – is linked to the frequency of the rain bearing cloud bands across Australia, and
- *Southern Annular Mode* (SAM) – influences the strength and position of westerly winds in southern Australia.

5.2. The Millennium Drought and climate change drivers

SEACI have found the recent Millennium Drought resulted from a combination of natural climate drivers and an expansion of the topics pushing mid-latitude storms further south. SEACI's climate modelling shows that natural climate drivers alone do not explain the recently observed autumn and early winter rainfall reductions. Although the considerable interaction between natural and climate change drivers is not well understood at present, SEACI estimate that up to 80% of the recorded rainfall decline in south-eastern Australia is due to the increasing surface pressure in the Sub-tropical Ridge latitudes(CSIRO, 2010).

SEACI have also found when the GCMs are forced by global warming, they replicate the observed expansion of the *Hadley Cell* circulation system (see Figure 5-2). This expansion of the tropics and intensification of the Sub-Tropical Ridge[6] (STR) shifts westerly weather systems further to the south, and, as these systems are the dominant sources of the autumn-winter rainfalls across southern Australia, results in less cool season rainfall over southern Australia(CSIRO, 2010).

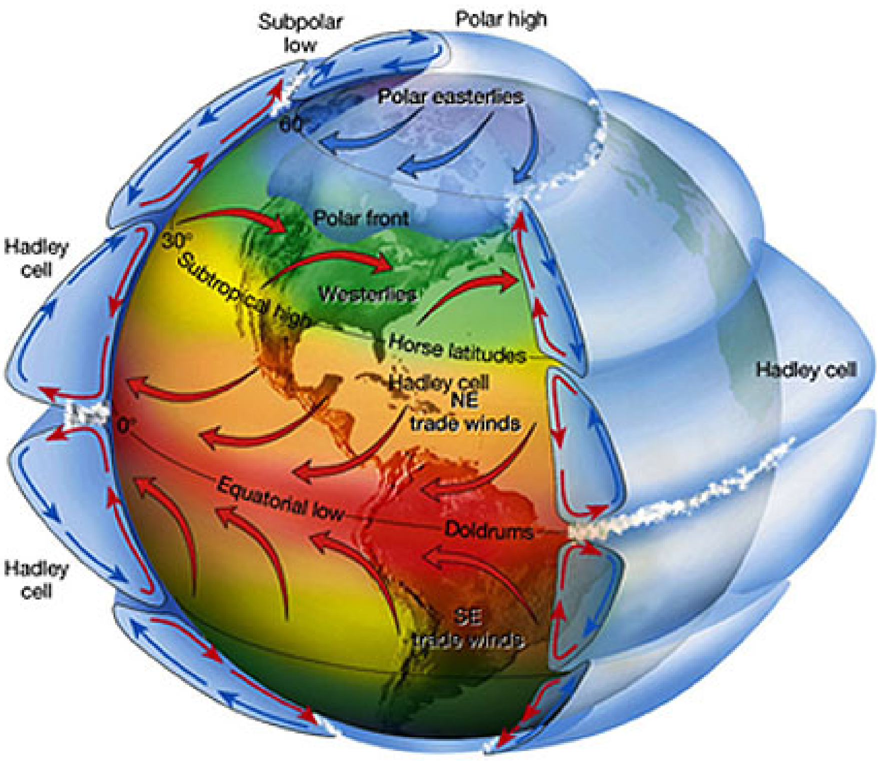

Figure 5-2: Large Scale Atmospheric Circulation (Source: SERC)

Monash University's Climate and Science experts also agree the decline in southern Australian rainfall in recent decades and autumn reductions are related to a trend towards a

[6] The subtropical ridge is a significant belt of high pressure situated around the latitude 30°S in the Southern Hemisphere.

more intense Sub Tropical Ridge, rather than a change in its latitude (Larsen S & Nicholls N, 2009).

This view is shared by the Australian Academy of Science researchers who believe it is possible for a climate shift to occur relatively abruptly as has occurred in the past:

> *"In southwest of Western Australia and the southeast coast, there is evidence of a systematic decline in rainfall in recent decades, …It is likely that these trends are related to (southward) shifts in pressure patterns over southern Australia, particularly the intensification of the subtropical high pressure belt."* (Australian Academy of Science, 2010)

5.3. The 2010 and 2011 Wet Years

SEACI also found the 2010 very wet conditions in south-eastern Australia resulted from a rare combination of natural wet phases of the ENSO, IOD and SAM natural climate drivers. The La Niña event was one of the strongest on record, and magnified by one of the most negative IOD of the past 50 years. In addition, SAM reached record positive values bringing in moist on-shore easterly winds. SEACI note that, even though this wet event is explained by natural variability, the persistent trend of STR intensification still caused below average rainfall to be recorded in autumn 2010, and this trend has continued into 2011 (SEACI, 2011).

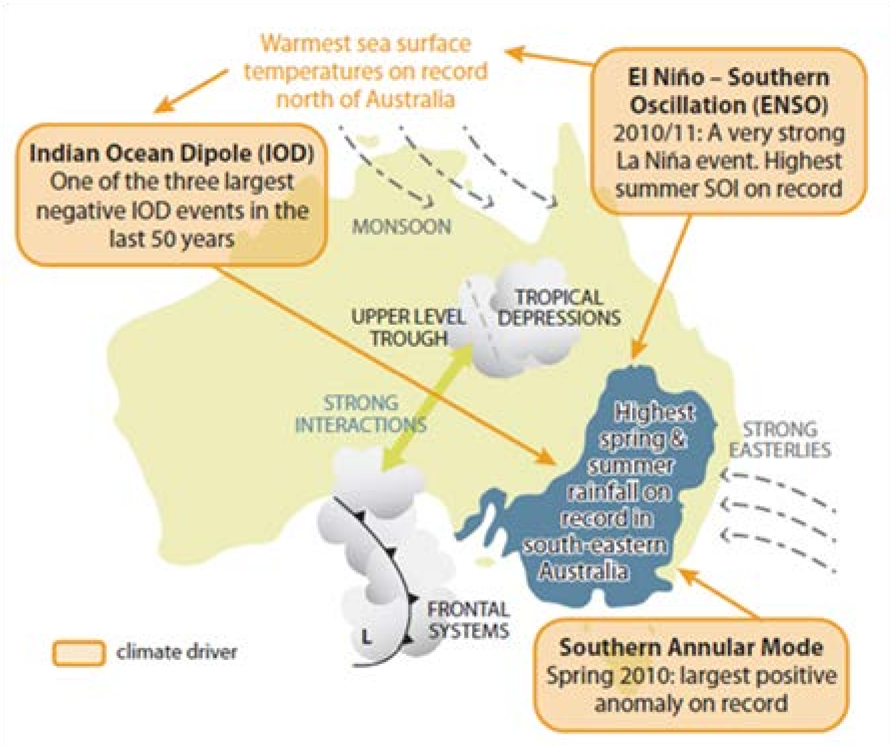

Figure 5-3: SE Australia 2010/11 wet climate drivers (source: SEACI 2011)

5.4. Observed changes are likely to persist

SEACI researchers note that although it is possible that natural climate variability may result in wetter conditions in the short-term, it is expected that south-eastern Australia's future climate will be drier and warmer than the long-term historical climate: "*it is possible that the current dry conditions may persist, and even possibly intensify, as warming is expected to continue"*(CSIRO, 2010).

It is now evident from a wide range of research that the global climate system is warming, and this situation will not be quickly reversed. It is reasonable to conclude that global warming induced climate changes, such as the reduction in cooler month rainfall and annual streamflows over south-eastern Australia, will most likely persist for the foreseeable future.

Along with the ACT Government (ACT Govt., 2011), ACTEW thinks it prudent to plan for a future ACT and region climate that will present:

- Higher temperatures
- Increased winds in the summer months
- Drier average seasonal conditions (especially in autumn)
- Increased frequency of extreme weather events including storms, and
- Increased risk of bushfires.

5.5. Future Climate Projections

5.5.1. IPCC Emissions Scenarios

The Intergovernmental Panel on Climate Change (IPCC) has developed several sets of greenhouse gas emissions scenarios over the past two decades. Figure 5-4 shows the current IPCC AR4 SRES GHG emissions scenarios and temperature projections.

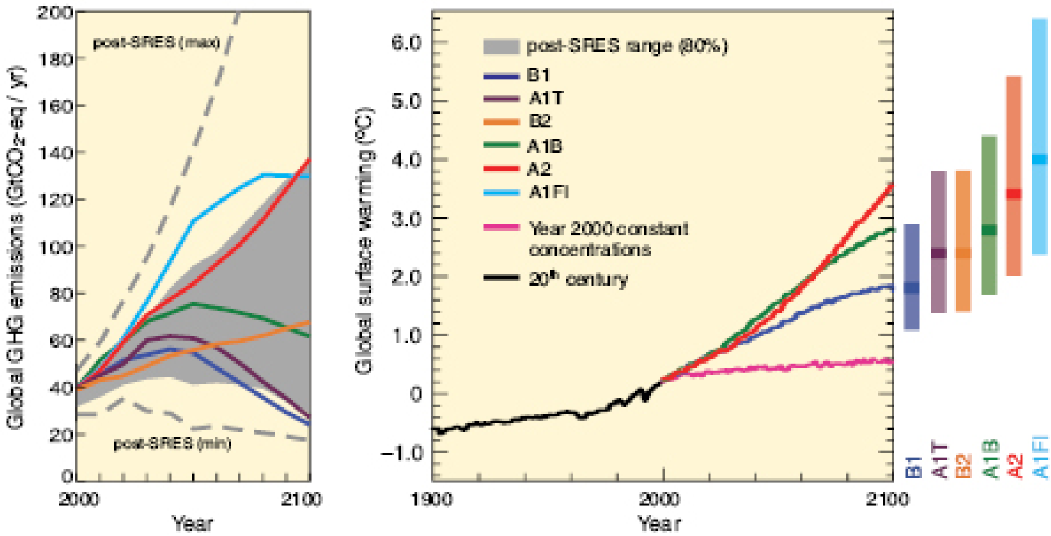

Figure 5-4: IPCC AR4 SRES GHG Emissions and Global Temperature Scenarios[7]

[7] Figure SPM.5. Left Panel: Global GHG emissions (in GtCO2-eq) in the absence of climate policies: six illustrative SRES marker scenarios (coloured lines) and the 80th percentile range of recent scenarios

At around 2030, the spread of emissions scenarios is less significant than the uncertainty arising from the GCM modelling. At around 2060, the spread of uncertainty becomes more significant.

New scenarios are created periodically to reflect advances in research, new data, and to support the increasing sophistication of integrated assessment and climate models. The IPCC decided in 2006 to catalyse the development of new scenarios by the research community and these would underpin its 5th Assessment Report scheduled for completion in 2013/14.

5.5.2. Global Climate Models

The range of results from the 23 available GCM's is a source of significant future uncertainty. Many studies, including by SEACI, have been undertaken on how to identify the best models for particular locations; however the study outcomes have generally been inconclusive and vary greatly on the parameters used for the assessment.

CSIRO/SEACI uses a set of 15 GCMs that all have readily available daily data outputs, and exclude those that show poor skill in projecting Australia's past climate. CSIRO/SEACI, like many others, do not weight individual model results; rather they consider all to GCM projections to be equally likely future climate scenarios. Some model outputs may cluster, however there is generally considered to be no "most likely" or more reliable result.

The IPCC AR5 due for release in 2013 may provide some guidance on the use of GCMs.

5.5.3. Downscaling

The low resolution of GCM outputs (> 100 km grid squares.) requires downscaling to incorporate important regional or catchment climate drivers and controls on rainfall such as local topography. A number of different methods are available, including the increasingly sophisticated empirical, statistical and dynamic methods and variants of each.

For most climate parameters, simple empirical scaling appears to produce reasonable mean results compared to dynamic downscaling; with daily and seasonal downscaling methods generally preferred over the constant scaling method (as it scales different rainfall amounts differently).

Dynamic downscaling using regional weather models may reduce the resolution down to around 10 km grid (see Section 5.5.5 NARCliM), but it requires exceptionally large computing capacities to run these models.

5.5.4. CSIRO/SEACI

The CSIRO *Climate change in Australia* web site is based upon international climate change research including conclusions from the IPCC's fourth assessment report. It also builds on CSIRO's climate research undertaken for the Australian region in recent years.

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published since SRES (post-SRES) (gray shaded area). Dashed lines show the full range of post-SRES scenarios. The emissions include CO2, CH4, N2O and F-gases. Right Panel: Solid lines are multi-model global averages of surface warming for scenarios A2, A1B and B1, shown as continuations of the 20th-century simulations. These projections also take into account emissions of short-lived GHGs and aerosols. The pink line is not a scenario, but is for Atmosphere-Ocean General Circulation Model (AOGCM) simulations where atmospheric concentrations are held constant at year 2000 values. The bars at the right of the figure indicate the best estimate (solid line within each bar) and the likely range assessed for the six SRES marker scenarios at 2090-2099. All temperatures are relative to the period 1980-1999.

The site provides projections for average climate in the years 2030, 2050 and 2070, taking into account consistency among GCMs. CSIRO notes the 50th percentile model result provides a “best estimate” (or more correctly termed a mid-range estimate) result, however natural climate variability means individual years will vary markedly from this estimate.

Figure 5-5 shows the CSIRO’s rainfall change projections are more strongly influenced by the emissions scenario as the projection period increases. All projections show drier conditions over the ACT region.

SEACI and other researchers are seeking to: improve long-term and seasonal hydro-climatic projections across south-eastern Australia, understand the impacts of climate variability and change on future water availability and river flow characteristics, and find ways to improve the understanding of runoff projections.

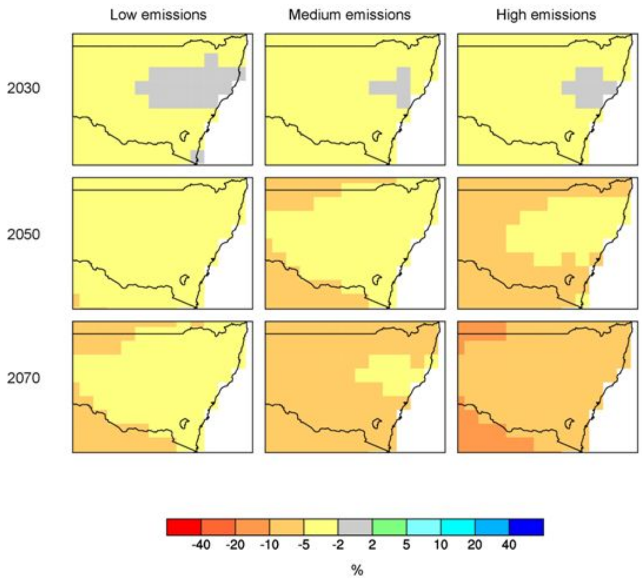

Figure 5-5: BOM Projected (50th Percentile) Rainfall Changes for NSW/ACT

(Notes: Low = B1 scenario, medium = A1B scenario, high = A1FI scenario;
Source: http://climatechangeinaustralia.com.au/nswactrain34.php accessed 10th Aug. 2012)

5.5.5. NARCliM

The NSW Office of Environment and Heritage (OEH) are working with the Climate Change Research Centre at the University of NSW to implement a NSW and ACT Regional Climate Modelling project (NARCliM). The objective of this project being to generate high resolution downscaled climate projections for New South Wales and ACT.

Project partners include Sydney Catchment Authority, ACT Government, Sydney Water Corporation, NSW Office of Water, Department of Primary Industries, Emergency Management NSW, Department of Transport and Hunter Water Corporation. Funding partners for this work include the ACT Govt., NSW Govt., Sydney Catchment Authority and Hunter Water (NSW OEH, 2011). ACTEW, through the ACT Government, is involved in the steering committee for this project.

Dynamical downscaling of climate projections will be modelled at a resolution of 10 km grid squares for the State of NSW and the ACT. The project aims to ensure data is accessible and useable. The project will use an ensemble of four GCMs and downscaling each of these with three different Regional Climate Models (RCMs). Three 20-year simulations will be performed with each GCM/RCM combination: one recent period (1990-2010) and two future periods (2020-2040 and 2060-80). The SRES A2 emission scenario will be used for future projections. The four GCMs that selected are: MIROC, ECHAM5, CCCMA and CSIRO mk3.5. More than 100 climate variables will be output from the model at three-hourly intervals; common surface variables will be hourly. The modelling is 10% complete at this time. Outputs are expected during 2013/2014, and will be based on the 2007 IPCC GCM outputs (and due for update during 2013/14) (NARCliM, 2012).

6. Future Climate Guidance

This section considers the policy and practice of national, regional and other similar organisations to examine what guidance is available to ACTEW for its development and use of future climate scenarios.

The policy guidance offered by the National Water Commission (NWC), Water Services Association of Australia (WSAA) and the ACT Government are considered, along with the practice of similar water utilities. National Water Commission

The NWC is responsible for driving progress towards the sustainable management and use of Australia's water resources. In 2008, the NWC noted water planning approaches varied from jurisdiction to jurisdiction; with individual plans generally being a function of state policy, legislation and customary practice developed over many years. NWC also made the observations that, in nearly all cases, future inflows were assumed to be a continuation of past patterns, and the Millennium Drought has brought to the fore the shortcomings of that approach. The NWC highlighted[8] the Victorian Central Region Sustainable Water Strategy (Central Region SWS) as the *"only practical application of the latest information on projected climate change."* (Hamstead M., 2008). The practical application of climate change scenarios is often not transparently reported, possibly as there are many other non-quantitative factors influencing water supply investment decision making.

The NWC's Raising National Water Standards Program has an objective to support water managers in the complex task of incorporating climate change into water supply and demand planning. To this end, *Waterlines Report 28 - Incorporating Climate Change in Water Allocation Planning"* provides some limited guidance and notes:

- the impacts of future climate change will be very complex and it is premature to make definitive statements about the levels of uncertainty in climate change assessments
- there is no consistently superior downscaling method, but it has frequently been demonstrated that the use of downscaling provides 'added value'
- projected changes in runoff and groundwater are subject to high levels of uncertainty
- there has been little consideration given to how impact assessments can be best used by water planners to make informed, robust decisions (Bates B., 2010).

Waterlines Report 41 – Integrated Resource Planning for Urban Water – Resource Papers specifically looks at the generation of climate change scenarios. The report notes that downscaling of GCMs provides the most comprehensive and physical based approach, however the application and calibration of statistical downscaling can be laborious and dynamic downscaling can be very computationally expensive. It notes that the simpler and cheaper empirical scaling has been used by CSIRO for its Murray-Darling Basin and Northern Australia Sustainable Yields projects (ISF, 2011). This is the same approach used by ACTEW in 2004. The report goes on to suggest future climate uncertainty should be addressed by selection of a set of climate change scenarios as per Table 6-1.

[8] Apparently of the water plans reviewed - ACTEW has made use of climate change scenarios since 2004.

Table 6-1: Climate and climate change scenarios - *source* (ISF, 2011)

Medium or "best estimate" climate change scenario	To represent the most likely climate change scenario for the supply–demand balance
Extreme wet and dry future climate change scenarios	To test high and low cases in the supply–demand balance to account for uncertainty in climate change projections
Worst case climate change scenario	To test adaptive planning, including readiness strategies and drought contingency plans

ACTEW Note: It is questionable whether the medium climate change scenario should be presented as the "best estimate" or "most likely"; as this is simply the mid-range output from a set of all equally likely GCM outputs.

6.1. ACT

There are currently no guidance documents (i.e. standards, code of practices or recommended methods) for selection of future climate scenarios in the ACT. ACTEW has presented its own approach in its 2005 Future Water Options study reports, its 2007 Water Security Recommendations and its Annual Review of Planning Variables reports published each year since 2005 (ACTEW, 2011).

To date, ACT Government agencies have adopted various approaches, although the ACT Government Environment and Sustainable Development Directorate is now working with the NSW Government on the development of the NARCliM regional climate model to provide an additional future climate projection resource for its decision making (see Section 5.5.5).

In 2010, ACT Government Independent Competition and Regulatory Commission (ICRC) suggested a "lack of clarity" around climate assumptions in its review of the Enlarged Cotter Dam. It stated an expectation that ACTEW would test its water security plans with low, medium and high climate change scenarios (ICRC, 2010). ACTEW considers its CSIRO 2030 (2004) climate scenario comprehensively covers these suggested scenarios, but notes the need to better convey this message. The ICRC has since applied ACTEW's CSIRO 2030 (2004) climate scenario for its review of secondary water use in the ACT[9], while similarly noting in the same review that a *"…richer and more flexible modelling of climate, should be a priority* (for ACTEW)" (ICRC, 2012).

[9] The principles of integrated resource planning require both water demand and supply-side investments are considered to identify the best balance usually at the least cost. The ACT Government has historically undertaken secondary water and demand-side planning, with ACTEW focussing mainly on primary supply-side planning. This approach by the ICRC represents the first use outside of ACTEW of a common future climate scenario to compare options on an equal basis and is to be encouraged.

6.2. Water Service Association of Australia

The Water Services Association of Australia (WSAA) is the peak industry body for the Australian urban water industry. While there is no specific guidance for its member utilities at this time, it has proposed a number of priority actions arising from its October 2010 Climate Change Adaptation workshop. These actions include:

- Preparation of a "roadmap" to provide clear research and policy direction on what is necessary to ensure essential water services are protected from climate change
- Development of a 'model business case' for investment (in infrastructure or a program) that incorporates a climate change adaptation perspective, and
- Develop a Climate Change Network for members to be informed and updated on relevant research and projects (WSAA, 2012).

6.3. Practices of Other Organisations

The approaches of peak agency, catchment managers and similar water supply managers provide an insight into current practices that may inform ACTEW's future approach.[10] The practices of each organisation are examined in relation to their:

- Relevance to ACTEW
- Outline of approach
- Method of addressing natural climate cyclic trends
- Climate baseline / timeframe / use of stochastic data
- Method of addressing climate change through selection of:
  - Global warming / emissions scenarios
  - Gcms
  - Scaling / downscaling method
- Method of addressing rare / high consequence severe drought periods
- Key outputs and reporting.

ACTEW may align its approach with those of peak regional / same catchment organisations or adopt more recent / state of art approaches. However, in addition to generally higher cost, there is a risk adopting advanced approaches may limit key stakeholders understanding and acceptance. ACTEW's objective is to achieve the best balance between the approaches of other regional organisations and the more advanced methods.

Table 6-2 and Table 6-3 summarise the different approaches of the peak agency / catchment management organisations, and other similar water supply agencies most relevant to ACTEW. The range of organisations being limited to those located within the same region or catchment and/or who apply relatively recent or "state of art" approaches.

[10] "best practices" provide a useful guide where no specific formal methodology is in place or the existing methodology does not sufficiently address the issue.

The Central Region SWS highlighted as good practice by the NWC adopts an adaptive management approach and looks at low, medium and high climate change scenarios. It assesses two different reservoir inflows scenarios: the first assumes a return to average inflows (past 50-100 years) with a gradual reduction due to medium climate change over the next 50 years; the second assumes a continuation of the low inflow conditions experienced over the previous 10 years. The latter scenario being more severe than anything experienced over the past 100 years (Victorian Govt. Dept. of Sustainability & Environment, 2006). The Central Region's approach informed the development of the *2011 Victorian Guidelines for the Development of a Water Supply Demand Strategy*; particularly its *"Return to Dry Conditions"* scenario. (Vic. Govt. Dept. of Sustainability & Environment, 2011).

Table 6-2: Practices of Peak Agency/Catchment Management Organisations

Relevance to ACTEW	*2008 / regional*	*2012 / peak catchment*	*Current / regional / state of art*	*2008 / regional*	*Current / regional / state of art*
Outline of approach	Examines 3 global warming scenarios and results of 15 GCMs to estimate % seasonal change in rainfall and PET per ^{o}C; modelled runoff for 45 scenarios; plus a recent climate scenario (i.e. 100 stochastic replicates 112 years long based mainly on 1997-2006).	Hydrologic modelling of Environmentally Sustainable Level of Take[11] in integrated river system modelling framework	Developing a regional climate model using Weather Research and Forecasting model to give future climate projections at a fine scale (10 km grid) for 12 GCM / RCM ensembles (i.e. 4 GCM's x 3 RCMs)	Estimates runoff for historic climate, and likely changes in 2030 based on GCM output	Estimates runoff for historic climate, and likely changes in 2030 based on GCM output e.g. calibrated and regionalised rainfall-runoff model (SimHyd)

[11] Sustainable Diversion Limits (SDLs) are the maximum long-term annual average quantities of water that can be taken on a sustainable basis from Basin water resources. Importantly, the SDL must reflect an Environmentally Sustainable Level of Take (ESLT). The Water Act defines an ESLT to mean the level at which water can be taken from a water resource which, if exceeded, would compromise:

- Key environmental assets of the water resource; or
- Key ecosystem functions of the water resource; or
- The productive base of the water resource; or
- Key environmental outcomes for the water resource.

Method: natural cyclic trends					
- Climate baseline / time period / stochastic data use	Historic 1895 to 2006; Stochastic for recent climate scenario only	Historic 1895 to 2009	1970 to 2010 (40 years)	Historic 1895 to 2006	Historic 1895 to 2006;
Method: climate change					
- Global warming scenarios	3 no. from IPCC AR4 for 2030: 1. Low / 0.45^{o}C (low end /10th %'ile of SRES B1) 2. Med.- 1^{o}C (ave.) 3. High - 1.6^{o}C (high end /90th %'ile of SRES A1T)	n.a.	IPCC AR4 SRES A2	IPCC AR4 SRES A1B (0.9 ^{o}C)	A1B scenario (0.9^{o}C)
- Global Climate Models	15 GCMs (of 23 due to availability of daily data) using SRES A1B to give % change per ^{o}C	n.a.	4 GCMs (from 23 by excluding 9 poor performing GCM's, then choosing 4 most independent with required data available)	15 GCMs (of 23 due to availability of daily data) using SRES A1B to give % change per ^{o}C	15 GCMs (of 23 due to availability of daily data) using SRES A1B to give % change per ^{o}C
- Scaling / downscaling method	Empirical scaling (seasonal and daily for rainfall and PET)	n.a.	Dynamic downscaling to 10 km grid using Regional Climate models (RCM's)	Empirical scaling (seasonal and daily for rainfall and PET)	Empirical scaling (seasonal and daily for rainfall and PET)

- Time step / seasonality	Daily	Daily	Sub-daily dependant on parameter; Seasonality changes from modelling of GCM/RCM ensembles	Daily	Daily
Method: rare but high consequence droughts					
- drought scenario	2nd driest of the 45 scenarios Recent climate: 100 by 112 years of stochastic data for recent (1997 to 2006)	n.a.	n.a.	n.a	n.a.
Output and reporting	1. Historic 2. Recent 3. Median GCM result for med. emission scenario 4 and 5. Uncertainty – extreme wet and drought (i.e. 2nd wettest and 2nd driest GCMs of high warming scenario)	Environmentally Sustainable Level of Take; Sustainable Diversion Limits	20 year model runs for each of 12 GCM/RCM ensemble for 3 time periods: 1. 1990 -2010 2. 2020-2040 3. 2060 -2080	Runoff estimates for historic climate and likely changes to runoff in 2030 (daily sequences of rainfall, APET and modelled runoff across NSW on a 5km grid, scaled to the results of 15 GCM's).	Runoff estimates for historic climate, and likely changes to runoff in 2030 based on 15 GCM's , daily sequences of rainfall, APET and modelled runoff across SE Australia on a 5km grid, scaled to the results of 15 GCM's

Notes	Scenarios include variants with future resource development (i.e. farm dams, commercial forestry and groundwater extraction); 5 km grid.	No climate change as: *"... average impact on water availability due to projected climate change is less than the climate variability to be expected in the life of the Basin Plan ... State Water Mgt. plans must demonstrate that they can accommodate a wide range of climate and water availability scenarios".*	Based at UNSW	This work uses the same method as the MDBSY projects future climate scenarios, but with different emission scenarios. It is believed to be the same as the SEACI Runoff Projections Work: 5 km grid	This work uses the same method as the MDBSY projects future climate scenarios, but with different emission scenarios. It is believed to be the same as the NSW Climate and Runoff projections
References	(Chiew F., 2008)	(MDBA, 2012)	(NSW OEH, 2011)	(Vaze, 2008)	(CSIRO, 2012) (Post, 2010)

Table 6-3: Practices of Similar Water Supply Managers

Relevance to ACTEW	*ongoing*	*2010*	*2012 / state of art*
Outline of approach	Models stochastic climate to identify average annual demand that can be supplied while meeting particular performance criteria.	Models long term performance of the water supply system using stochastic climate sequences.	Creates 114 year sequences of future rainfall and PET from 15 GCMs for 1 and 2^{o}C warming; takes account of seasonal and daily changes; to give future "wet", "medium" and "dry" runoff projections Also considers a "return to dry" scenario
Method: natural cyclic trends			
- Climate baseline / time period / stochastic data use	Historic (1898 -2008); Stochastic Data (based on historic)	Historic (1909 -2009) Stochastic data (based on historic)	Historic (1895 – 2008) from SILO Data Drill Stochastic Data may be considered for the return to dry scenario
Method: climate change			
- Global warming scenarios	IPCC SRES: A1, A2, B1, B2; IPCC 550 ppm CO_2 by 2150, IPCC 450 ppm CO_2 by 2090.	1. A2 (2030 and 2070) 2. B1 (2030 and 2070) 3. A1B (2030 and 2070)	Examines 1: IPCC A1B scenario: - 1.0^{o}C at 2030 - 2.0^{o}C at 2060
- Global Circulation Models	14 models (selected from 19, by eliminating poor performing models)	1 GCM (only 1 with suitable data available (CSIRO Mk3))	15 (of 23 due to availability of daily data)

- Scaling / downscaling method	Empirical scaling (10 % rainfall reduction applied)	Statistical Downscaling	Empirical scaling (seasonal and daily rainfall and PET)
- Time step / seasonality used	Monthly and Daily	Monthly	Daily data is used with Seasonal Scaling
Output and reporting	Stochastic climate data used to calculate yield (average annual demand that can be supplied while meeting particular performance criteria). Climate change scenario is used as a sensitivity test.	Stochastic climate used to calculate yield. Climate change scenarios have been used to indicate potential changes in supply and demand.	1. A table with scaling factors to apply to different catchments across Victoria for runoff, rainfall and PET for 2030 and 2060 for the Low, Med and High Climates 2.a methodology for producing a return to dry scenario.
Notes			Return to Dry scenario can use the seasonality of the Millennium Drought or the historic record, depending on scaling method chosen.
References	(Hunter Water, 2008); (SKM, 2008); (Hennessey, 2004)	(NOW, 2010b); (NOW, 2010a); (Sydney Catchment Authority, 2009); (SKM, 2011)	(Vic. Govt. Dept. of Sustainability & Environment, 2011)

7. Risks and Mitigations

The ACT Government's *Weathering the Change Draft Action Plan 2* highlights that climate change presents a significant risk to Canberra's urban water security (ACT Govt., 2011). Following this risk perspective, this section looks at the risks associated with the future climate scenarios currently used by ACTEW. Table 7-1 lists the significant risks identified and ranked in accord with ACTEW's Risk Management Framework.

7.1. Water Security Risks

The water security risks are twofold: (i) severe water shortages if future climate emerges drier than the future climate scenarios, and (ii) unnecessarily high water costs if the climate emerges wetter than projected.

Given a level of unavoidable future climate uncertainty will always exist, the water security risks can be mitigated, firstly, by reducing the uncertainty as much as is possible, and secondly, by managing the residual uncertainty through a combination of monitoring of the emerging climate, adaptive readiness planning, a high-level of resilience to a severe dry climate, and drought contingency planning. The latter action should include a program to inform and involve stakeholders with increasing frequency if climate begins to emerge more dry than expected.

7.2. Future Climate Scenario Risks

7.2.1. Managing Uncertainty

These risks all arise from future climate uncertainty; i.e. if future climate was predictable no significant risks would exist. Actions are proposed to limit the planning period as the longer the outlook the greater the uncertainty. Actions are also proposed to ensure ACTEW's climate scenarios better capture the natural intra- and inter-decadal cyclic trends. Further actions are proposed to incorporate the latest climate change projections.

Even though ACTEW's use of stochastic data gives a wide range of possible climate futures, a further set of "wet", "medium" and "dry" scenarios are proposed to meet the expectations of key stakeholders. The additional scenarios will be drawn from multiple GCM modelling of a medium to high global warming scenario. In combination with the current 200 stochastic outputs, this would give 600 possible futures. A fourth "severe drought" scenario is proposed to stress test ACTEW's water security plans against a repeat of Millennium Drought or similar low likelihood / high consequence drought years.

7.2.2. Managing Residual Risk

Given current understandings of future climate, there is no doubt some uncertainty will remain. Although not within the context of this report, the following provides an outline of the actions ACTEW propose to manage this residual uncertainty.

Adaptive readiness. This risk assessment is undertaken in the expectation ACTEW will fully implement the adaptive readiness strategy that forms the central pillar of its Urban Water Security Program. Any failure or substantial delay to implement this strategy over the coming years may expose ACTEW to additional risks arising from future climate uncertainty.

Supply resilience. Building supply system resilience is proposed as a risk management measure. In this context, resilience includes the following:

- A diverse range of independent water sources and demand management measures; such as accessing more reliable water catchments or less rainfall dependant sources, or implementing a range of unrelated but concurrent demand management measures .
- System interconnectivity to take advantage of any excesses in the system; such as gridding of water sources (the Cotter Googong bulk water transfer is one example of interconnectivity already in place)
- Planning flexibility; allowing implementation of the responses best suited to actual emerging futures
- Pre-set action triggers and agreements to progress certain options as and when required, and
- Pre-commitments to progress triggered actions; e.g. Funding in place, stakeholders support in place, planning approval.

Drought contingency plans. There is an expectation that parallel severe drought contingency plans will be prepared. Drought contingency plans comprise more short-term emergency response plans that will ensure that basic water needs for a community can be met for the duration of a very severe drought. The drought contingency plans include short-term fast responses which may differ from more sustainable longer-term options that may be difficult to implement quickly. Temporary water restrictions are an integral part of such plans.

There may be some commonality and overlap between longer-term adaptive readiness plans and drought contingency plans. For example, ACTEW's Tantangara Transfer option may be viewed as a longer-term water source or as a drought response measure in that its primary value arises from the deferral of severe levels of restrictions.

Table 7-1: ACTEW Future Climate/Future Climate Scenario Risks

Risk	Likelihood	Consequence	Rank	Proposed actions
Future water security level				
Frequent, long and severe water restrictions / supply fails **(i.e. supply inadequate for demand)**	Possible (future climate may emerge more dry than current planning scenarios)	Major / severe (excessive economic cost of time in restrictions / failure of water supply / damage to reputation)	High	Reduce uncertainty - as much as is possible Mange residual uncertainty - monitoring of emerging climate, adaptive readiness plans, high-level resilience to severe dry climate, drought contingency plans, inform and involve stakeholders
Pre-mature investment in supply augmentation / demand mgt. measures **(i.e. supply excessive for demand)**	Possible (future climate may emerge more wet than current planning scenarios)	Moderate (high cost of supply, environmental / social impacts of augmentations)	Medium	As above
Future climate scenario level				
Future climate scenarios do not adequately capture natural variability	Possible (CSIRO 2030 (2004) is based on 1871-2004 cycle and 28 year mean up to 2004, does not capture more recent cyclic trend of Millennium Drought and very wet 2010/11)	Moderate / major (under projection of flows leads to premature investment and higher than necessary water cost; over projection leads to excess time in restrictions, overdue investments and/or supply failure; either leads to damaged reputation)	Medium / high (monitoring required, control actions may be required)	Reduce uncertainty - update stochastic climate data to include recent cycles of drought (1997 to 2009) and extreme wet (2010/11); increase number of modelling replicates to provide greater resolution Manage residual uncertainty – as above

Risk	Likelihood	Consequence	Rank	Proposed actions
Future climate scenarios do not adequately capture spatial variability between catchments	Likely (based on limited climate record sites and GCM 200 km grid)	Moderate / major (as above)	High / very high (senior mgt monitoring required, control actions may be required)	Reduce uncertainty - update stochastic climate data to include data from additional sites in Upper Murrumbidgee catchment; increase climate change downscaling resolution Manage residual uncertainty – as above
Future climate scenarios do not adequately capture currently projected climate change	Likely (CSIRO 2030 (2004) is based on year 2000 emissions scenarios, questionable combination of different GCM seasonal forecasts, poorly replicates observed autumn reductions, and no catchment scale climate change adjustment)	Moderate / major (as above)	High / very high (as above)	Reduce uncertainty - minimise (within reason) planning timeframes; consider wet, medium and dry scenarios; daily and seasonal scaling of stochastic data; use regional climate downscaling (when available). increase climate change downscaling resolution Manage residual risk – as above
Future climate scenarios do not adequately capture possible future extreme droughts	Possible (from above, and limited examination of possible longer and more severe droughts than Millennium Drought)	Moderate / major (as above)	Medium / high (monitoring required, control actions may be required)	Reduce uncertainty - consider "severe drought" scenario and seasonal (empirical) scaling of stochastic data Manage residual risk – as above
Expectations of its key stakeholders not met	Almost certain (refer recent public ICRC comments)	Major (adverse stakeholder / media attention)	Very high (Prompt corrective action required)	Reduce uncertainty - adopt 3 climate scenarios; test plans against severe drought scenario Manage residual risk - as above

8. Future Climate Scenarios

ACTEW has developed four stochastic climate scenarios for use in future ACT water supply analysis. This approach will allow ACTEW to examine system performance under a range of possible climate futures. In addition to these scenarios, ACTEW will also analyse performance by modelling a repeat of observed conditions during the Millennium Drought. The use of multiple scenarios allows ACTEW to better quantify the full range of future climate uncertainty and align more closely with the expectations of key stakeholders.

The updated stochastic climate scenarios adopt recent climate change projections based on the IPCC Fourth Assessment Report, 2007. The update also uses climate change forecasts specific to each water supply catchment based on statistically downscaled global climate model output from the SEACI project.

8.1. Selection of Scenarios

The climate scenarios incorporate lessons from the Millennium Drought, viewed from the perspective of a relatively full water supply system following the breaking of the drought. The scenario planning approach is similar to that adopted in the *2011 Victorian Guidelines for the Development of a Water Supply Demand Strategy*(Vic. Govt. Dept. of Sustainability & Environment, 2011), which recommends adoption of low, medium, and high climate change scenarios along with a return to dry scenario based upon the Millennium Drought. ACTEW's proposed climate scenarios are:

- *Dry climate change*, stochastic data produced using outputs from the second driest of the 15 global climate models included in the SEACI project (the inmcm model has the second largest reduction in annual rainfall)
- *Medium climate change*, stochastic data produced using outputs from the median global climate model included in the SEACI project (the gfdl model has the median change in annual rainfall)
- *Wet climate change*, stochastic data produced using outputs from the second wettest of the 15 global climate models included in the SEACI project (the miroc model has the second largest increase in annual rainfall)
- *Last 20 Years*, stochastic data produced so that the seasonal means of rainfall in each catchment and evaporation are adjusted to match the means observed in the past 20 years from June 1993 to May 2013.
- *Repeat of the Millennium Drought*, where performance is tested using observed historical inflows from 1997-2009

Figure 8-1 demonstrates the selection of GCMs for the dry, medium and wet climate sequences from the SEACI output.

The Last 20 Years scenario is proposed as an alternative to the Global Climate Models used in the first three scenarios. Global Climate Models fail to predict the significant shift in autumn rainfall that has been observed in the past 20 years across South-Eastern Australia and may continue in the future. Basing future climate on recent observations provides a means of incorporating this shift into climate planning. This approach differs from the *2011 Victorian Guidelines*, in that this scenario includes the entirety of the past 20 years rather than focusing upon the drought period. ACTEW believes that stochastic data based purely upon the drought period would be overly conservative and difficult to justify following the recent higher inflow years. However, ACTEW will model performance with a repeat of historical inflows from the Millennium Drought as part of sensitivity analysis.

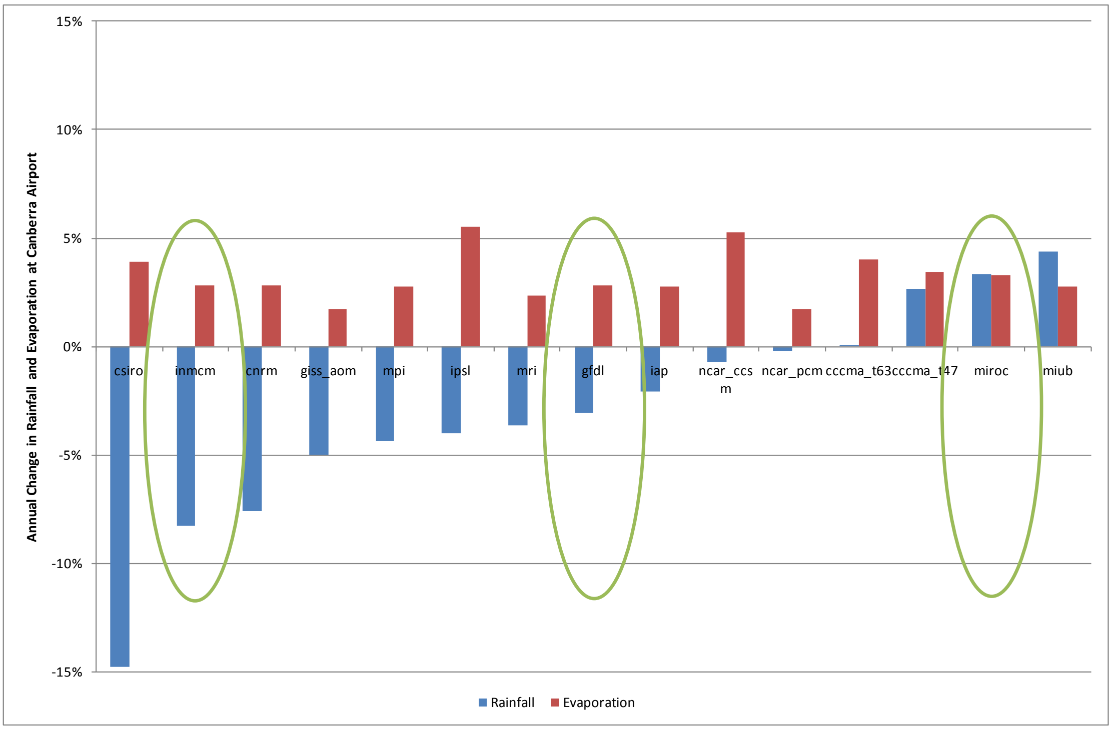

Figure 8-1: Selection of Global Climate Models for Dry, Medium and Wet Climate Scenarios

8.2. Stochastic Data Production

ACTEW engaged SKM to produce stochastic data for 12 rainfall sites in the Cotter, Queanbeyan and Murrumbidgee River catchments, plus rainfall and evaporation at Canberra Airport and Cooma evaporation. Investigations indicated that the most appropriate stochastic data generation technique for ACTEW was Empirical Mode Decomposition (EMD). This technique enables observed historical multi-year climate variability to be preserved in the stochastic data.

> *To ensure the preservation of multi-decadal climate characteristics in the data, a technique was used to separate out the short term (intra-decadal) and long term (inter-decadal) variability prior to stochastic generation. The technique is called Empirical Mode Decomposition and is used to identify the inherent high and low frequency signals within time series caused by drivers of hydroclimatic variability such as the El Nino/Southern Oscillation (ENSO).*(SKM, 2013)

SKM produced two stochastic data sequences reproducing the characteristics of the observed historical data, one based on the 1894 to 2012 observed record and the other based on the 1939 to 2012 period. There are pros and cons associated with each set: “While the longer data set includes the Federation Drought, the shorter data set may better represent climatic variability across the catchment as there is less reliance on infilled/extended data in the early part of the record”(SKM, 2013).

SKM then applied 4 climate change scenarios to the stochastic data. These were the dry, medium and wet SEACI output scenarios described above, plus a Millennium Drought scenario. The three SEACI scenarios were created by applying the seasonal rainfall and evaporation changes contained in the SEACI output at each site, while the Millennium Drought scenario was created by scaling the seasonal mean of the rainfall and evaporation data at each site in the stochastic data to match the observed data from the Millennium Drought. With the two baseline climate scenarios, this produced a total of ten stochastic climate scenarios (two historical and eight climate change). SKM also provided a template that allows ACTEW to easily create additional climate scenarios by specifying the seasonal changes in rainfall and evaporation at each site.

ACTEW has conducted hydrological modelling with all ten of these climate scenarios, using the process shown in Figure 8-2.

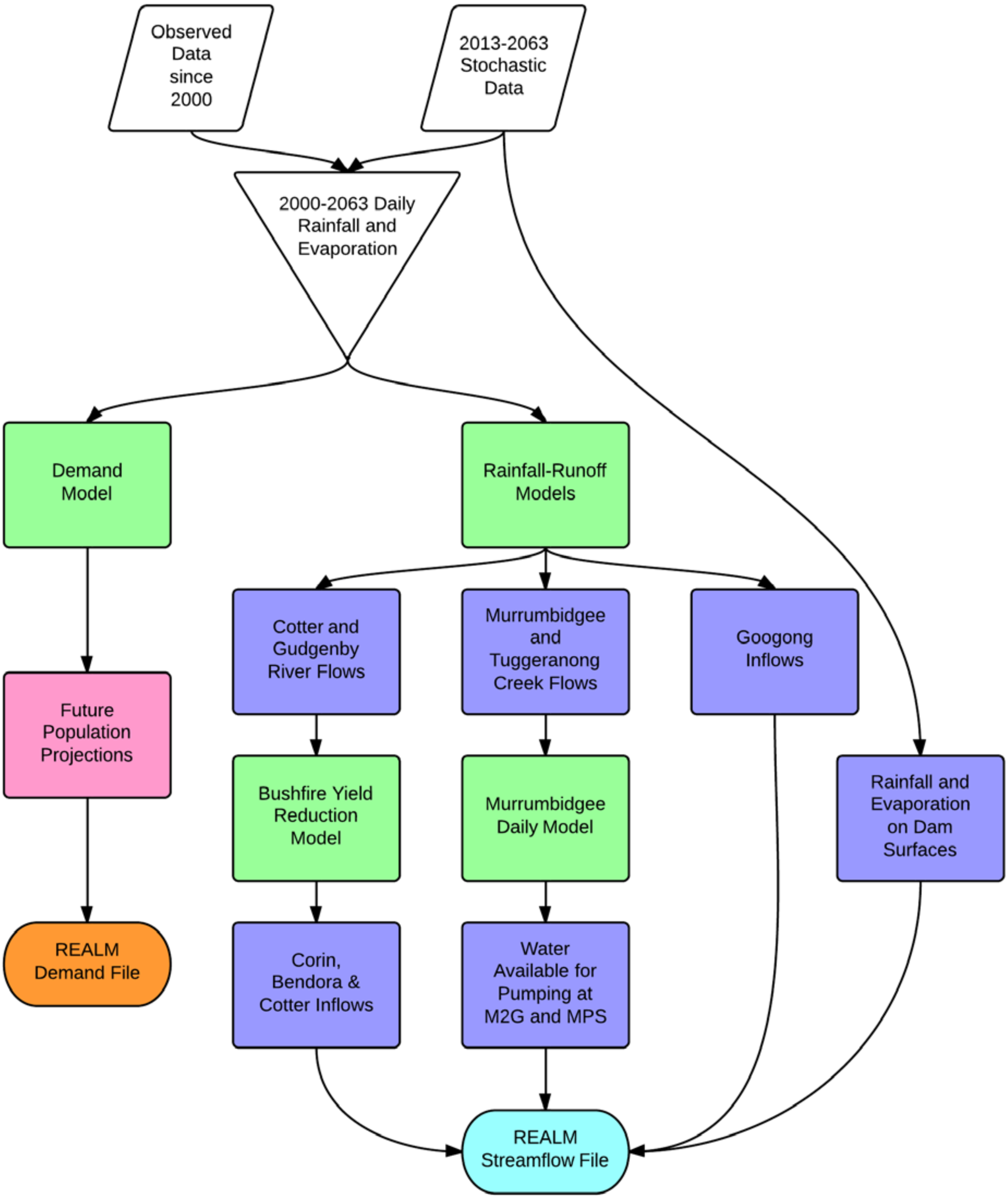

Figure 8-2: Process used to Generate REALM Water Resources Model Inputs

8.3. Scenario Rationalisation

An assessment of the results of the hydrological modelling found that the stochastic data based upon the longer period of record (1894-2012) is:

- Based on more data than the short sequences and includes the Federation Drought
- More conservative (lower inflows, higher probability of water restrictions)
- Better at preserving the spatial correlations between the Murrumbidgee River flows and dam inflows

Therefore, this report proposes that only the climate scenarios based upon the longer period of record are adopted. Further, as noted in this report, it is no longer reasonable to assume climate stationarity. ACTEW will not consider the no climate change scenario because ACTEW's ongoing policy is to include climate change in all water security planning(ACTEW , 2005)(ACTEW, 2007) and because the no climate change scenario is within the envelope of the three climate change scenarios from the SEACI output. As noted above, ACTEW will not include stochastic data based upon the Millennium Drought in future climate planning, but will instead directly model observed inflows during the Millennium Drought as a sensitivity test.

ACTEW used the template provided by SKM to generate a fourth stochastic climate scenario to accompany the dry, medium and wet scenarios. This scenario adjusts the seasonal means in the stochastic data to match the seasonal means observed at each site in the past 20 years. This stochastic data scenario maintains the variability of the entire historical record since 1894 while setting the mean values to more recent observations.

Figure 8-3 shows the range of inflows to ACT storages contained in the four stochastic data scenarios. The red dots show the average annual inflows, while the blue dots show the median annual inflow. The error bars show the variability of the annual inflow, shown here as 90% confidence limits.

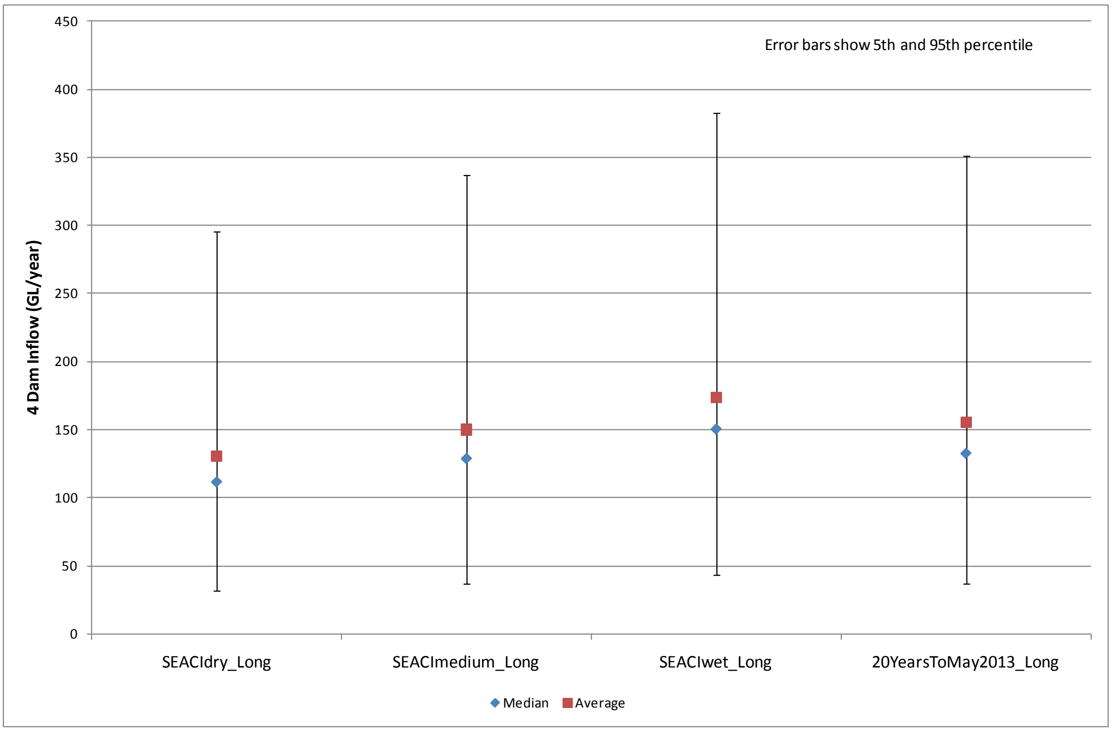

Figure 8-3: Range of Annual Inflows to ACT Water Supply Dams

8.4. Scenario Adoption

This report proposes the adoption of the five climate scenarios outlined in section 8.1. It is intended that all future water resources planning studies reported externally by ACTEW will examine and report on all five of these climate scenarios.

For many internal planning studies and investigations it may not be feasible to consider all five climate studies. In some cases it may be advantageous to develop strategies on the basis of a single climate scenario. Additional climates may be included for sensitivity analysis as necessary.

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