Queensland **the Smart State**

PRACTICAL ADAPTATION TO CLIMATE CHANGE IN REGIONAL NATURAL RESOURCE MANAGEMENT

Queensland Case Studies – Queensland Murray Darling Basin Report




Australian Greenhouse Office
Sinclair Knight Merz
Queensland Murray Darling Basin Committee
Desert Channels Queensland
Fitzroy Basin Association
South East Queensland Western Catchments

August 2007

FITZROY BASIN ASSOCIATION

desert channels
QUEENSLAND

healthy land
–OUR FUTURE
AN INTEGRATED REGIONAL NATURAL RESOURCE MANAGEMENT PLAN FOR THE WESTERN CATCHMENTS OF SOUTH-EAST QUEENSLAND

Queensland Murray Darling Committee Inc.

SINCLAIR KNIGHT MERZ
SKM

Australian Government
Department of the Environment and Heritage
Australian Greenhouse Office

Queensland Government
Climate Change Centre of Excellence
Department of Natural Resources and Water

PRACTICAL ADAPTATION TO CLIMATE CHANGE IN REGIONAL NATURAL RESOURCE MANAGEMENT

Investigator: Mr David Cobon

Queensland Climate Change Centre of Excellence
Department of Natural Resources and Water
PO Box 318
TOOWOOMBA Q 4350

Project No: EP08

Qld Case Studies – Report for QMDB Case Study – Climate Change Impacts on Water Resources of the Queensland Murray Darling Basin.

Authors:

Mr David Cobon, Principal Scientist, Climate Change Centre of Excellence, Toowoomba
Mr Nathan Toombs, Research Scientist, Climate Change Centre of Excellence, Toowoomba

Project Team:

Mr David Cobon, Principal Scientist, Climate Change Centre of Excellence, Toowoomba
Mr Nathan Toombs, Research Scientist, Climate Change Centre of Excellence, Toowoomba
Dr Xike Zhang, Research Scientist, Climate Change Centre of Excellence, Toowoomba
Mr Craig Johansen, Principal Scientist, Department of Natural Resources and Water, Indooroopilly

Project Partner Team:

Funding Co-ordinator	Paul Ryan, Australian Greenhouse Office
Project Leader	Craig Clifton, Sinclair Knight Merz
State Co-ordinator	Trica Gowdie, Queensland Murray Darling Basin Committee
Catchment Member	Michael Bent, Fitzroy Basin Association
Catchment Member	Steve Wilson, Desert Channels Queensland
Catchment Member	Dave Manning, South East Queensland Western Catchments
Reference Group Members	Paul Ryan, Craig Clifton, Roger Jones, David Poulter, Mirko Stauffacher, Geoff Park, John Francis, Trica Gowdie, David Cobon

Commencement Date: 1 July 2005 **Completion Date:** 30 June 2007

Cover: Water infrastructure (Coolmunda Dam, top left; MacIntyre Brook, top right; Glenlyon Dam, bottom left; Inglewood Weir, bottom right) in the Queensland Murray Darling Basin. Photos by David Cobon

Published by: Department of Natural Resources and Water, Queensland Climate Change Centre of Excellence, Toowoomba, 2007

Contents

Page

Figures

Page

Tables

Page

Executive Summary

A number of general circulation models (9) and greenhouse gas emission scenarios (4) were used to provide a range of projected temperature, evaporation and rainfall change to 2030. The wettest, driest and average climate scenarios for the region were used in hydrological models to assess changes in water flow for the MacIntyre Brook and Dumaresq River. Flows in the MacIntyre Brook were simulated using full water entitlement modelling, and flows in the Dumaresq River using crop demand modelling. Changes in climate and water flow were measured against a base period from 1961-1990.

Annual rainfall projections ranged from slightly wetter, to drier than the historical climate. Six of the nine models expressed an annual drying trend. Seasonally, changes are uncertain in DJF (December, January and February) and MJJ but are dominated by decreases in ASON. Increases in potential evaporation are much more certain.

The dry scenario for 2030 was associated with a mean temperature increase of 1.3°C, reduced annual rainfall of 6% and higher evaporation of 10%. The wet scenario for 2030 was associated with a mean temperature increase of 0.9°C, higher annual rainfall of 3% and higher evaporation of 2%.

Based on the set of scenarios, either increases or decreases in stream flow are possible for the MacIntyre Brook and Dumaresq River depending on which scenario is most closely associated with observed climate in the future. **The change in mean annual flow for the MacIntyre Brook ranged from approximately -25% to +9% by 2030. For the Dumaresq River the change in mean annual flow ranged from approximately -25% to +6% by 2030.**

For the MacIntyre Brook the average and dry scenarios were associated with a reduced frequency of daily flows for the mid-high (~5000 to 50 ML/d) and very low flow range (~5 to 0.1 ML/d) compared to the base. **Dry scenario mid-high flows were 7-35% lower than the base scenario and very low flows were 4-25% lower.** There was little difference in the frequency of daily flows (high or low) between the base and wet scenarios.

For the Dumaresq River the average and dry scenarios were also associated with a reduced frequency of daily flows and the wet scenario with higher flows compared to the base. **Dry scenario daily flows were 19-37% lower, and wet scenario flows 4-10% higher than the base scenario. The reduction in flows for the dry climate change scenario may have adverse environmental impacts downstream, and higher release of water during dry periods will place extra pressure on the water storage.** These impacts require further investigation.

For the MacIntyre Brook the 95-100 percentile daily flows for the dry scenario were 22-31% lower than the base scenario. These flows for the average scenario were 3-12% lower than the base, and for the wet scenario were 7-11% higher. The difference in simulated maximum daily flow between the base and dry scenario was approximately 23,200 ML/day.

For the Dumaresq River **the 95-100 percentile daily flows for the dry scenario were 19-25% lower than the base scenario.** For the wet scenario flows were from 5-8% higher compared to the base scenario. The difference in simulated maximum daily flow between the base and dry scenario was approximately 50,000 ML/day. These differences decreased as the percentile decreased e.g. by the 88th percentile the differences were <700 ML/day. **The reduction of very high flows in the dry and average scenarios could change vegetation downstream due to reduced inundation on the floodplains and the shorter duration of flood events.**

For the MacIntyre Brook **the annual on-allocation of water to irrigators maybe reduced by climate change. The dry scenario was associated with a greater risk of water allocations below**

10,000 ML/yr compared to the base scenario for irrigators between Inglewood and Whetstone Weirs. The **base scenario was associated with 83% reliability** of an annual on-allocation ≥10,000 ML, while the **dry scenario was associated with 66% reliability**. This could leave irrigators with significantly less water during dry periods. **The reduction of annual on-allocations for the dry scenario when irrigation water demands are high may reduce agricultural production.** Similar patterns were evident for other irrigators both upstream and downstream of this location. The wet and average scenarios were not apparently different to the base scenario.

For the Dumaresq River the annual on-allocation of water to irrigators in QLD for the dry climate change scenario was associated with a **reduction in water allocation reliability – the mean allocation was 12% lower**. Alternatively for irrigators in NSW the dry scenario was associated with more reliable allocations (mean allocation was 8% higher) within the 5000-10000 ML range, and less reliable allocations below 5000 ML, compared to the base scenario. **The wet scenario was not apparently different to the base scenario in either QLD or NSW.**

For the MacIntyre Brook the total area of crops planted did not change under climate change conditions because flows were simulated using full water entitlement modelling.

For QLD irrigators along the Dumaresq River the dry climate change scenario **was associated with a reduction in crop area – the mean was 28% lower.** This was driven by less rainfall (6%) and less water allocation which had a compounding influence on area of crops planted. For irrigators in NSW the dry scenario was associated with a mean reduction in crop area of 13% compared to the base scenario. **The wet scenario was not apparently different to the base scenario in either QLD or NSW.**

For the MacIntyre Brook the environmental flow required was 2 ML/day. Daily flows for Booba Sands showed 94% of the flows for the dry scenario were at least 2 ML/day. The base, wet and average scenarios had 96% to 97% of the flows being at least 2 ML/day. However the occurrence of long periods (5-40 days) of flow below 2 ML/day was higher in the dry scenario compared to base. For example, the chance of exceeding 10 days <2 ML/day was 18%, 11%, 10% and 7% for dry, average, base and wet scenarios respectively. There was a 5% chance that the period of below 2 ML/day flow lasted at least 14, 14, 17 and 22 days for the base, wet, average and dry scenarios respectively. The implications of this for environmental and natural systems need further investigation.

The environmental flow requirement for the Border Rivers was 100 ML/d at Mungundi. Daily flows downstream at the confluence of the MacIntyre Brook and Dumaresq River were below 100 ML/d 18% of the time for the base scenario, 24% of the time for the dry scenario, 20% of the time for the average scenario and 17% of the time for the wet scenario. The likely impacts of changes in flow due to climate change on environmental flows are unclear, as flows appear to be more affected by regulation. If climate change reduces water availability, allocations are likely to be more affected than environmental flows, as environmental flow requirements must be met before water is allocated. The dry scenario may force allocations to irrigators down in order to maintain environmental flows and provide for high security water users (e.g. town water supplies). This may force some irrigators to change their land use (e.g. use more of their land for grazing) which may alter the hydrology of the system.

The reduction of average flows for the dry and average climate change scenarios may lead to a reduction in the sediment load which may result in the decrease of particle deposition downstream. Increases/decreases in sediment load are associated with increases/decreases in the amount of nitrogen and phosphorous in streams. A decrease of nitrogen and phosphorous in streams may result in the decrease of blue-green algal blooms downstream, however the positive effects of this may be outweighed by the negative effects of reduced flows on the environment. These findings are supported by a general understanding of catchment process but more work is required to pinpoint the outcomes particular to this catchment.

The depth and exposed surface area of the water storages (Glenlyon dam - deep with relatively small surface area, and Coolmunda Dam – shallow with relatively high surface area) affects the amount of water lost to evaporation. Under climate change conditions building of deep on-farm storages will help reduce evaporation losses. The effects of wind on evaporation are not included in the models used in this study.

Other findings

For the MacIntyre Brook the mean duration of low daily flows (<2.2 ML/day) was not different (P>0.05) for all climate change scenarios. The apparent absence of change in the duration of low flows for the dry and average scenarios may be due to the fairly constant base-flow in the study region due to groundwater inflows, and releases from Coolmunda Dam. For the Dumaresq River, the longest simulated duration of low flows for the base scenario was 21 days. The maximum duration of low flows for the dry, average and wet climate change scenarios were of 30, 30 and 22 days respectively. The mean duration of low daily flows was not different (P>0.05) for all scenarios.

For the MacIntyre Brook the mean duration of high daily flows (>265 ML/day) was not different (P>0.05) for all scenarios. For the Dumaresq River, the longest simulated duration of high flows for the base scenario was 238 days. The maximum duration of high flows for the dry, average and wet scenarios were of 226, 236 and 239 days respectively. The mean duration of high daily flows was not different (P>0.05) for all scenarios.

For the MacIntyre Brook the mean annual frequency of low daily flows (<2.2 ML/day) was different (P<0.01) for the dry scenario compared to the base scenario. The average numbers of days of low flows per year for the base, wet, average and dry scenarios were 37, 36, 39 and 44 days respectively. For the Dumaresq River, the mean annual frequency of low daily flows was different (P<0.05) for the average and dry climate change scenarios compared to the base scenario. The average numbers of days of low flow per year for the base, wet, average and dry scenarios were 6, 6, 7 and 8 days respectively.

For the MacIntyre Brook the mean annual frequency of high daily flows (>265 ML/day) were different (P<0.01) for all scenarios compared to the base scenario. The average numbers of days of high flow per year for the base, wet, average and dry scenarios were 34, 37, 31 and 25 days respectively. For the Dumaresq River, the mean annual frequency of high daily flows was different (P<0.05) for all climate change scenarios compared to the base scenario. The average numbers of days of high flows per year for the base, wet, average and dry scenarios were 230, 236, 221 and 202 days respectively.

For Booba Sands on the MacIntyre Brook there was little apparent difference between the median duration of days where flow was below 2 ML/day for the average and dry scenarios (2 days), compared to the wet and base scenarios (1 day). The mean duration of low daily flows was 6, 5, 6 and 7 days for the base, wet, average and dry scenarios respectively. The increased duration of flows below 2 ML/day for Booba Sands, especially in the case of the dry scenario, could lead to the drying of the river bed, reducing the speed of water order deliveries, and to the inhibition of the migration of fish species in the river system.

1 Project overview

The project involved seven regional natural resource management (NRM) organisations - including the Queensland Murray-Darling Basin Committee (QMDC) – and the Queensland Department of Natural Resources and Water. It was coordinated by Sinclair Knight Merz.

The project has two main objectives, as follows:

1. improve understanding of the implications of climate change for regional NRM
2. develop tools and processes that help regional NRM organisations incorporate climate change impacts, adaptations and vulnerability into their planning processes.

The project was divided into three main stages:

Stage A. This stage identified components of participating region's natural resource system that were more vulnerable to climate change. The key steps were to develop the 'conceptual mapping' workshop process, conduct a literature review to document climate change projections, impacts and adaptive mechanisms for each participating region and then to run 'conceptual mapping' workshops in each of these regions.

Stage B. This stage completed a series of regional case studies which explored climate change impacts on one or a small number of components of the natural resource system that were more vulnerable to climate change. The case studies were designed to provide more objective information on climate change impacts and vulnerability and will be used to support analysis of how regional NRM processes can incorporate climate change considerations. Results of the case study for QMDC are reported here and will be used by each of the participating NRM regions to complete Stage C.

Stage C. The final stage, in which lessons from the case study will be used to help develop tools and processes (e.g. thinking models, numerical models, workshop processes, modifications to risk assessment processes) that enable regional NRM organisations to incorporate climate change into their planning, priority setting and implementation. A series of workshops will be held in each state to receive feedback on the tools and processes developed or identified through the project.

2 Objectives of the case study

Early work in this project (Stage A) completed a review of literature and assessment of the likely impacts of climate change in Queensland Murray Darling Basin (QMDB) (Perkins and Clarkson 2005), and is available from the Queensland Murray Darling Committee in Toowoomba. A conceptual mapping workshop was held in Toowoomba (September 2005) to help the community better understand the drivers, pressures and impacts of climate change, and to plan the responses that maybe useful to prepare for climate change (Stage A). During this process a number of key issues in the region were identified related to climate change (Clifton and Turner 2005). This report provides a scientific assessment (Stage B) of one key issue in the region, namely; under climate change conditions for 2030 identify changes in:

1. Regional rainfall, temperature and evaporation
2. Surface flow for the MacIntyre Brook and Dumaresq sub-systems and the capacity to meet the irrigation needs of broad acre agriculture
3. Demand driven land use to meet the needs of environmental allocations for the MacIntyre Brook and Dumaresq sub-systems
4. River health for the MacIntyre Brook and Dumaresq sub-systems (qualitative assessment).

3 Queensland Murray Darling Basin

The Queensland Murray Darling Basin (QMDB) has an area of 260,000 km^2 (Figure 1). This is approximately 15% of the area of Queensland and 25% of the Murray-Darling Basin. The major primary industries are agriculture, oil and natural gas production, and timber production. The predominant land use is the grazing (89% of total area), cropping (5%), State forests and timber reserves (4%) and national parks and protected areas (2%). Major water resources in the region include the Bulloo, Maranoa, Balonne, Paroo, MacIntyre and Warrego Rivers, the Great Artesian Basin, aquifers, wetlands and water storages.

Associated with these water resources are both private and public infrastructure, including Beardmore Dam and weirs, and on-farm irrigation water storage. The economic stability of the regions has grown to rely heavily on access to and utilisation of these resources, both for agriculture and urban water supply. Due to the climatic variability of the regions, the water resources are known to be unreliable. Such unreliability has prompted the development of dams, weirs and other water storages to reduce the impact of water scarcity.

The region contains some of the most productive soils in Australia, which underpin the regional agricultural economy including irrigated horticulture in the Granite Belt and around St George, irrigated cotton cropping on the MacIntyre and Balonne floodplains, dryland cropping in the Moonie, Border Rivers and Maranoa-Balonne catchments and grazing enterprises across the region. The variety of soils also determines vegetation type and contributes to biodiversity. The inherent environmental value of rivers, streams and water bodies is reflected by the strong dependence of species on water resources as refuges during adverse climatic conditions reliance (e.g. water birds, fish, invertebrates).

Land use varies between the seven main catchments: the Condamine-Balonne is dominated by dryland and irrigated cropping, intensive livestock production, forestry and grazing; the main land uses in the Border Rivers catchment are grazing and dryland and irrigated cropping; extensive grazing is the dominant land use in the Warrego, Paroo, Bulloo, Nebine-Mungallala and Maranoa catchments.

Significant issues for water resources management in the QMDB are the equitable allocation of water resources, including water for the environment, water quality and determination of flows for event-based management. Large increases in surface water diversions took place between 1988 and 1994. For the Border Rivers, diversions increased by 187%, mainly for the expansion of irrigated cotton. Full utilisation of existing water licences is likely to significantly reduce flows into NSW, over-bank flooding and beneficial inundation on the floodplains. Water Allocation and Management Plans and Resource Condition Targets have been designed to address these important issues, however they currently make no provision for the impacts of climate change. As such it is important that the impacts of climate change on water flows are assessed so that relevant provisions in the plans can be made. This case study examines the impact of climate change on water availability in the MacIntyre Brook and Dumareq sub-systems of the Border Rivers catchment.

The five river health indicators developed for the QMDC are 1) Hydrology – flow volume, timing of flow, duration of flood events 2) Biology – macro invertebrates and fish, species diversity and number 3) Water quality – total dissolved solids, total nitrogen, total phosphorus and water temperature 4) Riparian zone – vegetation species, structure and cover and 5) Channel flow – geomorphology, flows and particle deposition. Floodplain, wetland and aquatic ecosystems may be at risk from alterations to flow regimes due to climate change and harvesting of overland flows.

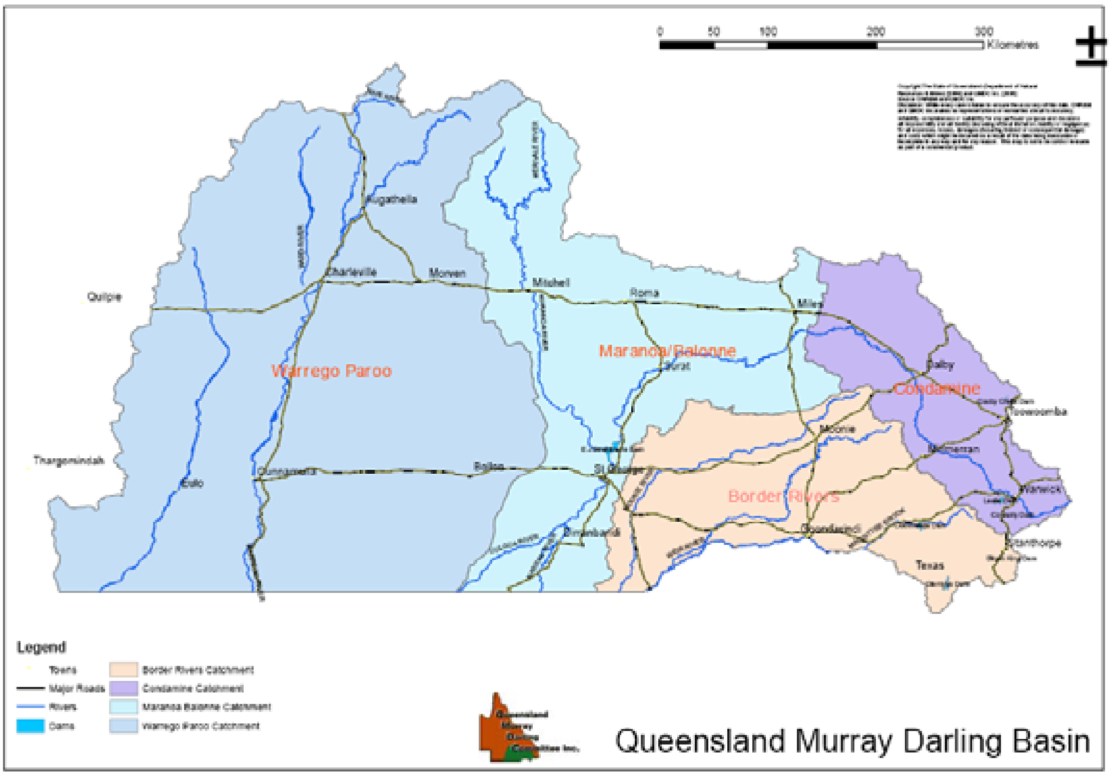


Figure 1. The Queensland Murray Darling Basin (QMDB). The river systems studied in this report are the MacIntyre Brook and Dumaresq River which exist within the Border Rivers catchment.

4 The climate change scenarios

4.1 UNCERTAININY IN CLIMATE CHANGE

Three major climate-related uncertainties were considered by this study. The first two are global uncertainties, which include the future emission rates of greenhouse gases and the sensitivity of the climate system's response to the radiative balance altered by these gases. Both uncertainties are shown in Figure 2, which shows the range in global warming to 2100, based on the Special Report on Emission Scenarios (SRES; Nakiçenovic *et al.*, 2000) and Inter Governmental Panel on Climate Change (IPCC, 2001). The dark grey shading shows emission-related uncertainties, where all the SRES scenarios have been applied to models at constant 2.5°C climate sensitivity. The light grey envelope shows the uncertainty due to climate sensitivity ranging from 1.5–4.5°C (measured as the warming seen in an atmospheric climate model when pre-industrial CO_2 is doubled). These uncertainties contribute about equally to the range of warming in 2100.

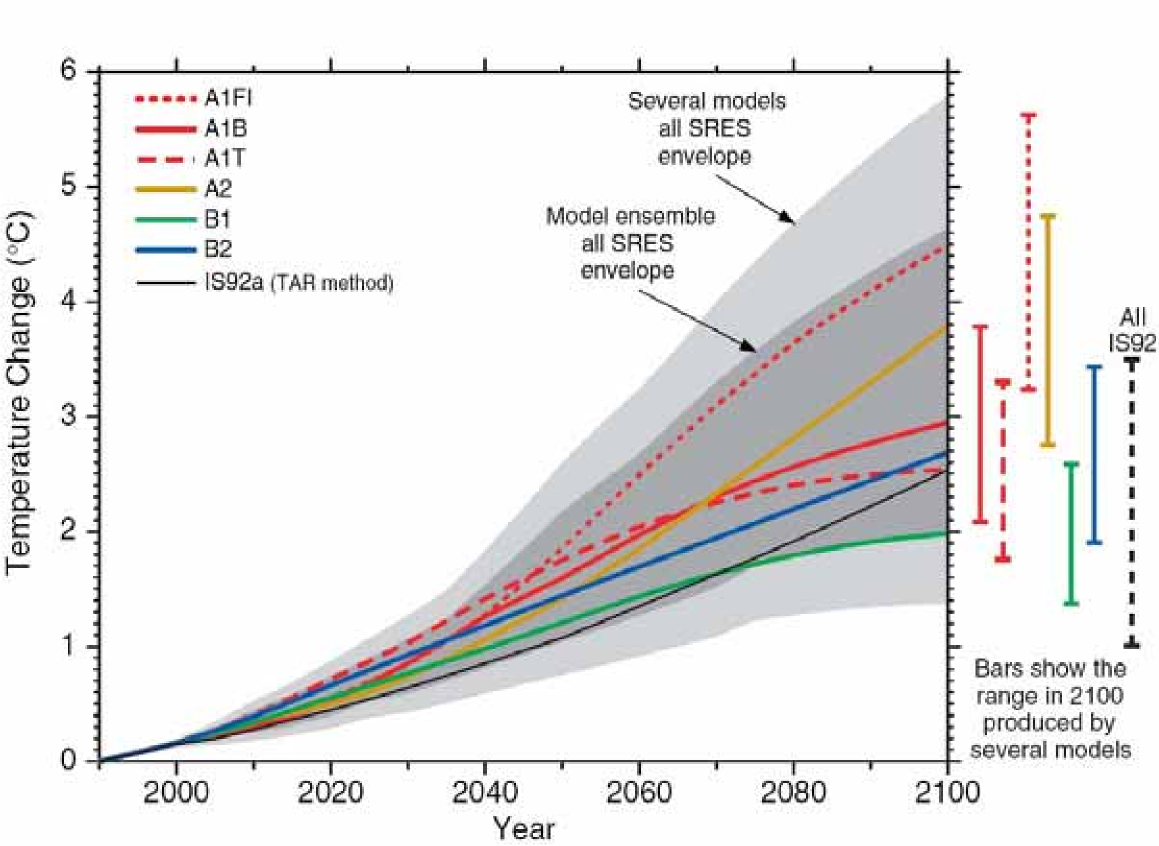


Figure 2. Global mean temperature projections for the six illustrative SRES scenarios using a simple climate model tuned to a number of complex models with a range of climate sensitivities. Also for comparison, following the same method, results are shown for IS92a. The darker shading represents the envelope of the full set of thirty-five SRES scenarios using the average of the models results. The lighter shading is the envelope based on all seven model projections (from IPCC, 2001).

The third major uncertainty is regional, described by changes to mean monthly rainfall and potential evaporation. To capture the ranges of these regional changes, we use projections from a range of international GCMs, as well as GCMs and Regional Climate Models (RCMs) developed by CSIRO.

Projections of regional climate change and model performance in simulating Queensland's climate have been described by Cai *et al.* (2003). Here, we have access to a similar suite of climate model results as summarised in Cai *et al.* (2003). They investigated the ability of the models to simulate sea level pressure, temperature and rainfall, discarding the four poorest-performing models from subsequent analysis. The models used for this study are summarised in Table 1.

Table 1. Climate model simulations analysed in this report. The non-CSIRO simulations may be found at the IPCC Data Distribution Centre (http://ipcc-ddc.cru.uea.ac.uk/). Note that DARLAM125 and CC50 are regional climate models

Centre	Model	Emissions Scenarios post-1990 (historical forcing prior to 1990)	Years	Horizontal resolution (km)
CSIRIO, Aust	CC50	SRES A2	1961-2100	50
CSIRO, Aust	Mark2	IS92a	1881–2100	~400
CSRIO, Aust	Mark 3	SRES A2	1961-2100	~200
CSIRO, Aust	DARLAM125	IS92a	1961–2100	125
Canadian CC	CCCM1	IS92a	1961–2100	~400
DKRZ Germany	ECHAM4	IS92a	1990–2100	~300
Hadley Centre, UK	HadCM3	IS92a	1861–2099	~400
NCAR	NCAR	IS92a	1960-2099	~500
Hadley Centre, UK	HadCM3	SRES A1T	1950–2099	~400

Note: The HadCM3, ECHAM4 and CC50 Models were run for both medium and high climate sensitivities, all other models were run with medium climate sensitivity.

In the region surrounding the Queensland Murray Darling Basin, annual rainfall projections range from slightly wetter, to much drier than the historical climate of the past century. Regional temperature increases inland at rates slightly greater than the global average, with the high-resolution models showing the steepest gradient away from the coast. Ranges of change are shown in Cai *et al.* (2003). Potential evaporation increase in most cases, with increases greatest when coinciding with significant rainfall decreases.

4.2 CLIMATE CHANGE PATTERNS

Patterns of climate change calculated as percentage change per degree of global warming were created for monthly changes in rainfall and point potential evaporation from a range of models. In OzClim, these are linearly interpolated onto a 0.25° grid (the simplest form of downscaling). Changes are averaged for a specific area.

Area average changes for the Border Rivers catchment are shown in Table 2. All the models show increases in potential point evaporation, however increasing rainfall usually results in lesser increases in potential evaporation, an outcome that is physically consistent with having generally cloudier conditions in a situation where rainfall increases. This will produce a "double jeopardy" situation if mean rainfall decreases because this will be accompanied by relatively larger increases in potential evaporation.

Table 2. Changes in annual rainfall and point potential evaporation for the Border Rivers catchment of the Queensland Murray Darling Basin, simulated by the models in Table 1, expressed as a percentage change per degree of global warming

Model	Rainfall	Point Potential Evaporation
CCCM1	-0.91	4.86
DARLAM125	1.87	4.67
NCAR	0.48	5.37
MARK2	-1.88	5.32
ECHAM4	3.65	2.98
HADCM3 - IS92A	-4.38	9.72
HADCM3 - A1T	-4.34	9.64
CC50	-6.21	10.67
MARK3	-0.45	7.70

Seasonal changes are shown in Figure 3 where the mean monthly change for both rainfall and potential evaporation per degree of global warming is shown with the upper and lower extremes. Changes in potential evaporation are much more certain, always increasing and showing a slight inverse relationship with rainfall, with deviations of only few percent per degree of global warming between models.

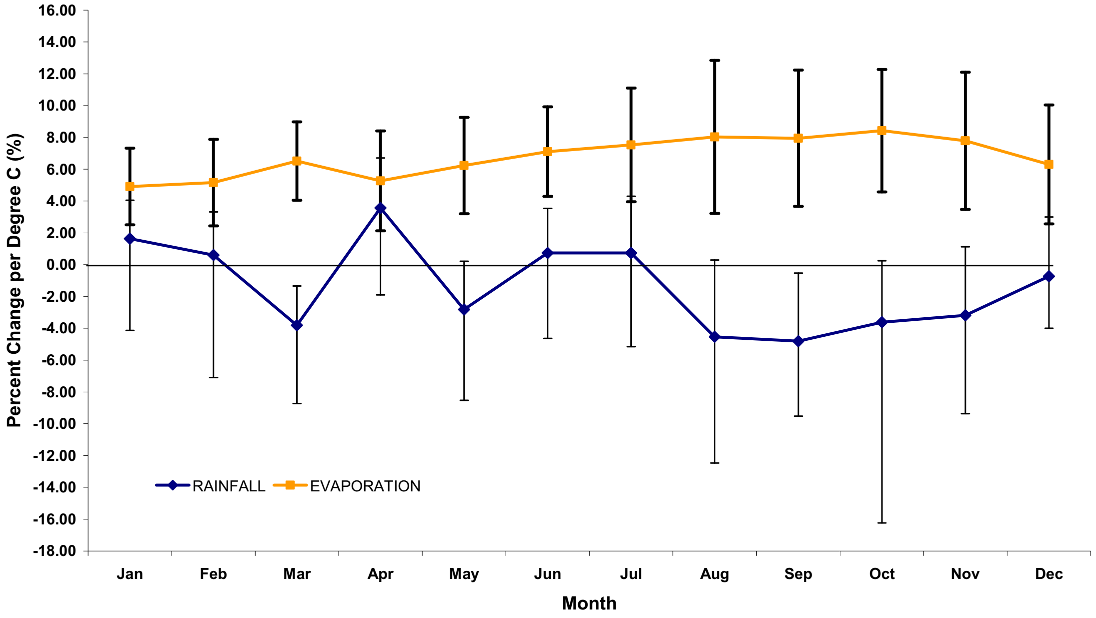
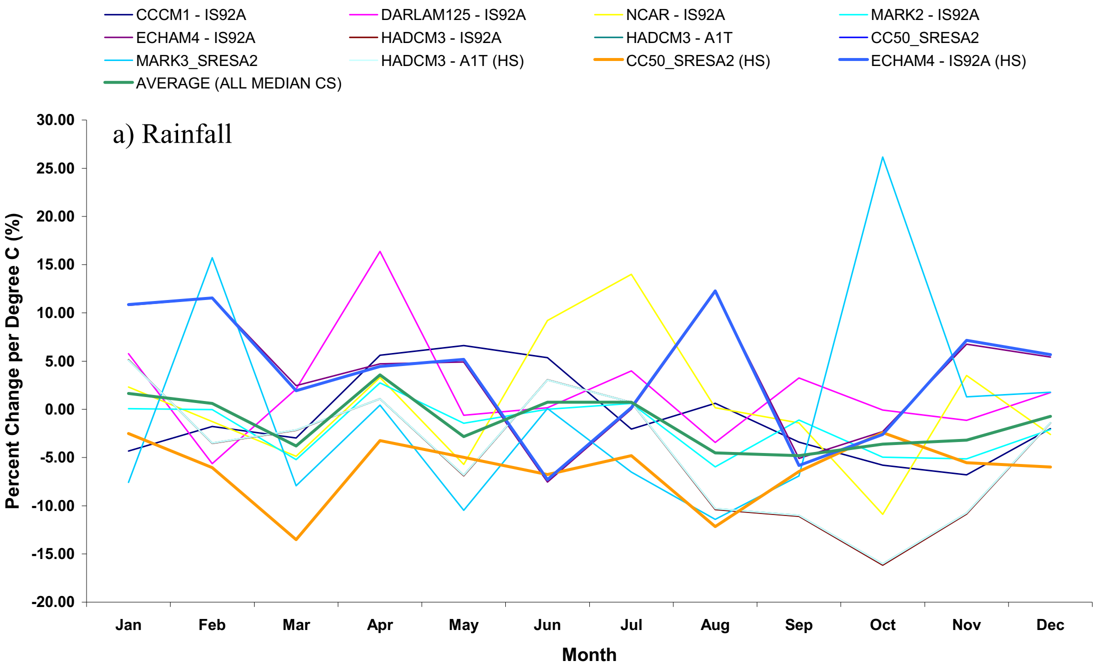


Figure 3. Average monthly percentage change in rainfall and potential evaporation for the Border Rivers catchment of the Queensland Murray Darling Basin (see Table 4 for the 9 locations) per degree of global warming using the nine climate models and emissions scenarios with medium sensitivity shown in Table 1 with one standard deviation.



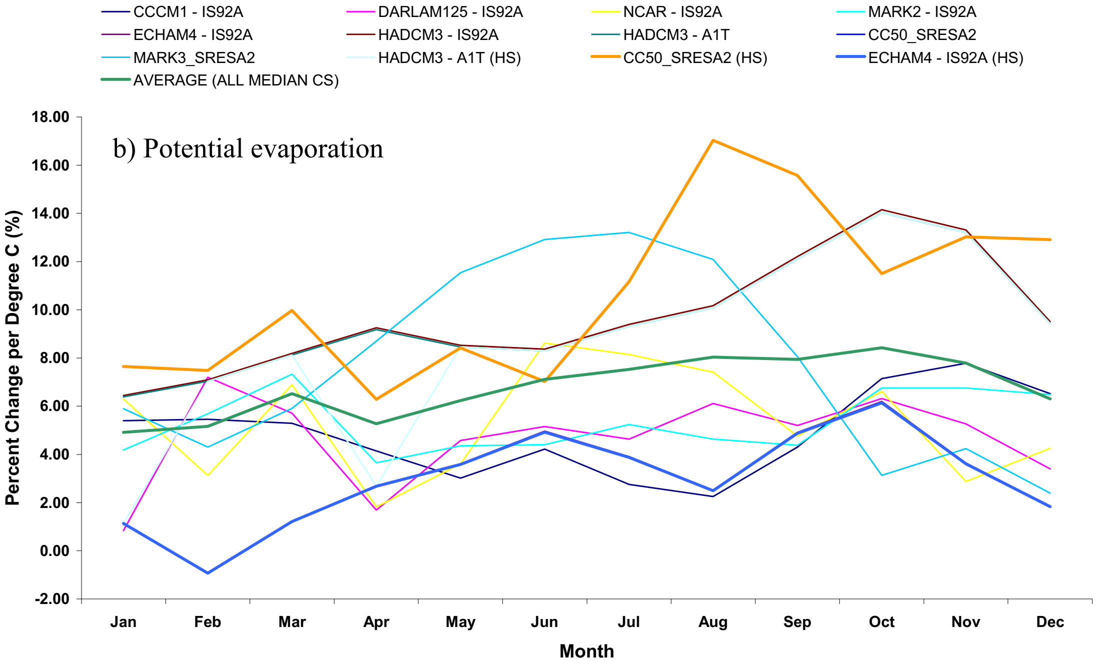


Figure 4. Average monthly percentage change in a) rainfall and b) potential evaporation for the Border Rivers catchment of the Queensland Murray Darling Basin (see Table 4 for the 9 locations) per degree of global warming for the nine climate models shown in Table 1 at medium (MS) and high sensitivity (HS).

4.3 CLIMATE CHANGE SCENARIOS

This report presents the range of possible changes provided by dry, wet and average climate change scenarios for the Border Rivers catchment in 2030. This range combines the range of global warming from IPCC (2001) and the climate change patterns in Table 2. These provide an initial set of estimates for possible hydrological change and set the scene for a risk analysis of possible changes to water resources in the catchment.

The three scenarios are:

- A dry climate change scenario where global warming follows the SRES A2 greenhouse gas scenario in 2030 forced by high climate sensitivity with regional rainfall and potential evaporation changes expressed by the CC50 RCM.
- An average climate change scenario where global warming follows the average of all the climate models used in this analysis (all with median climate sensitivity).
- A wet climate change scenario where global warming follows the IS92a greenhouse gas scenario in 2030 forced by high climate sensitivity, with regional rainfall and potential evaporation changes expressed by the German ECHAM4 GCM.

These simulations represent most of the possible ranges of change in average climate over the Border Rivers catchment of the Queensland Murray Darling Basin by 2030. Note that the dry and wet climate scenarios are both forced by high climate sensitivity. This is because in locations where either increases or decreases in rainfall are possible, the more the globe warms, the larger these accompanying regional changes will become. Therefore, if we wish to look at the extremes of possible changes in catchment response to climate change, then both the wet and dry scenarios will utilise the higher extreme of plausible global warming.

These scenarios are summarised in Table 3. Note that the SRES A2 greenhouse gas scenario contributes to the highest warming in 2030.

Table 3. Dry, average and wet climate change scenarios for 2030 for the Border Rivers catchment of the Queensland Murray Darling Basin

Scenario	Dry	Average	Wet
Global warming scenario	SRES A2	Average of All	IS92a
GCM	CC50	Average of All	ECHAM4
Global mean warming (°C)	0.92	Average of All	0.78
Regional minimum temperature change (°C)	1.2	Average of All	0.9
Regional maximum temperature change (°C)	1.5	Average of All	0.9
Regional mean temperature change (°C)	1.3	Average of All	0.9
Change in annual rainfall (%)	-5.7	-1.1	2.8
Change in annual potential evaporation (%)	9.8	4.0	2.3

5 Model construction and calibration

5.1 GENERAL CIRCULATION MODELS

The overall approach was to perturb historical records of climate variables required to run various models using a series of climate change scenarios for 2030. The aim of this study was to represent the range of uncertainty displayed by a number of climate models rather than attempt to develop precise scenarios from individual models.

The projections of percent changes in regional climate variables were extracted from CSIRO's OzClim database and from the CSIRO Consultancy Report on climate change in Queensland (Cai *et al.* 2003). The OzClim database includes different emission scenarios and global circulation models. The projections from a range of international General Circulation Models (GCM's), and Regional Climate Models (RCMs) were used (Table 1). This set of nine models includes some of the models that were used by CSIRO in its recent studies of the Burnett and Fitzroy region (Durack *et al.* 2005) and represent a broad range of climate change scenarios.

The multiple series of climate variables for 2030 climate were run through the Integrated Quantity Quality Model (IQQM) to produce output that was conditioned on 2030 climate.

5.2 PERTURBING HISTORICAL DATA

The locations of climate stations within the Border Rivers catchment of the Queensland Murray Darling Basin (Figure 1) close to the MacIntyre River were chosen for the extraction of climate change factors using Ozclim. The stations that were chosen are shown in Table 4.

Table 4. Climate stations together with their latitudes and longitudes for which climate change factors were obtained from OzClim

Name	Latitude	Longitude
Inglewood Post Office	-28.41	151.08
Bonshaw Post Office	-29.05	151.28
Coolatai	-29.25	150.75
Boggabilla Post Office	-28.60	150.36
Boomi Post Office	-28.72	149.58
Mungindi Post Office	-28.98	148.99
Wallangra Station	-29.24	150.89
Pindari Dam	-29.39	151.24
Texas Post Office	-28.85	151.17

These stations covered a large area of the catchment and represented a range of climate change factors over the region. Ozclim was used to obtain climate change maps for rainfall and evaporation, for each of the models and scenarios listed in Table 1 and for all months. Each OzClim map was imported into ArcGIS and the points of the climate stations were overlayed. The climate change factors for rainfall and evaporation for each location and month were recorded and imported into a spreadsheet. This process was carried out for all the models and scenarios listed in Table 1.

The average monthly climate change factors for rainfall and evaporation across the Border Rivers catchment were calculated by taking the average across all stations for each month, for each climate model and scenario. These factors were graphed for each model and scenario (Figure 4) to help choose the three models for the wet, average and dry scenarios of climate change. The models for these scenarios were chosen by graphing the monthly climate change factors for rainfall and evaporation divided by the change in global warming for each of the models and scenarios listed in Table 1. The overall factors for summer, the dry season, and the calendar year for each of the models and scenarios were used to select the wet, average and dry climate change scenarios.

The wet scenario was represented by the ECHAM4 model with IS92a emissions warming at high climate sensitivity and the dry scenario by the CC50 model with SRES A2 emissions warming at high climate sensitivity. The model for the average scenario was chosen to be the average of the factors for all of the climate models and scenarios in Table 1. The average of the factors of all of the climate models produced climate change factors that were midway between the wet and dry scenarios in most cases, and especially for evaporation (see Figure 4 and Table 5).

5.3 OVERVIEW OF SACRAMENTO RAINFALL-RUNOFF MODEL

System inflows are the total measure of surface runoff and base-flow feeding into streamflow in the Border Rivers catchment. This was carried out using the Sacramento rainfall-runoff model, which is incorporated into the Integrated Quantity Quality Model (IQQM).

The Sacramento rainfall-runoff model has been used in previous climate change studies where IQQM has been perturbed according to a range of climate scenarios (e.g. O'Neill *et al.* 2004). The Sacramento model is a physically based lumped parameter rainfall-runoff model (Burnash *et al.* 1973). The processes represented in the model include; percolation, soil moisture storage, drainage and evapotranspiration. The soil mantle is divided into a number of storages at two levels. Upper-level stores are related to surface runoff and interflow, whereas baseflow depends on lower-level stores. Streamflows are determined based on the interaction between the soil moisture quantities in these stores and precipitation. Sixteen parameters define these stores and the associated flow characteristics, of which ten have the most significant effect on calibration. The values for all sixteen parameters are derived based on calibration with observed streamflows. Burnash *et al.* (1973) describe storage details, their interactions, procedures and guidelines for initial parameter estimations.

5.4 MODEL SET-UP AND CALIBRATION – MACINTYRE BROOK

The IQQM and Sacramento rainfall-runoff models were previously configured and calibrated for the MacIntyre Brook sub-system of the Border Rivers catchment by the Queensland Department of Natural Resources (Cooke 1999). Flows in the MacIntyre Brook were simulated using full water entitlement modelling. The sub-system covers 10% of the overall Border Rivers catchment area. This calibration was based on records of historic streamflow, historic rainfall and Class-A pan evaporation for the period 1987-1996. From the calibrated model a daily streamflow model (IQQM Version 6.73.4) was developed for the period 01/01/1890 to 31/12/1996.

The MacIntyre Brook catchment has its outlet at the Dumaresq River and has its own irrigation scheme with regulated water supplied from the Coolmunda Dam and five weirs downstream of the dam (Figure 5). One IQQM model was used to cover the study area. The model was divided into four sub-areas. Historical rainfall and evaporation files (for each sub-area) were perturbed using monthly climate change factors for the dry, average and wet climate change scenarios using a macro in Microsoft Excel.

The total area of crops planted by irrigators was determined in accordance with IQQM. QL4a were irrigators between Coolmunda Dam and Inglewood Weir, QL4b between Inglewood and Whetstone Weirs, QL4c between Whetstone and Ben Dor Weirs and QL4d between Ben Dor and Sunnygirl Weirs. The total area of crops planted was simulated using IQQM.

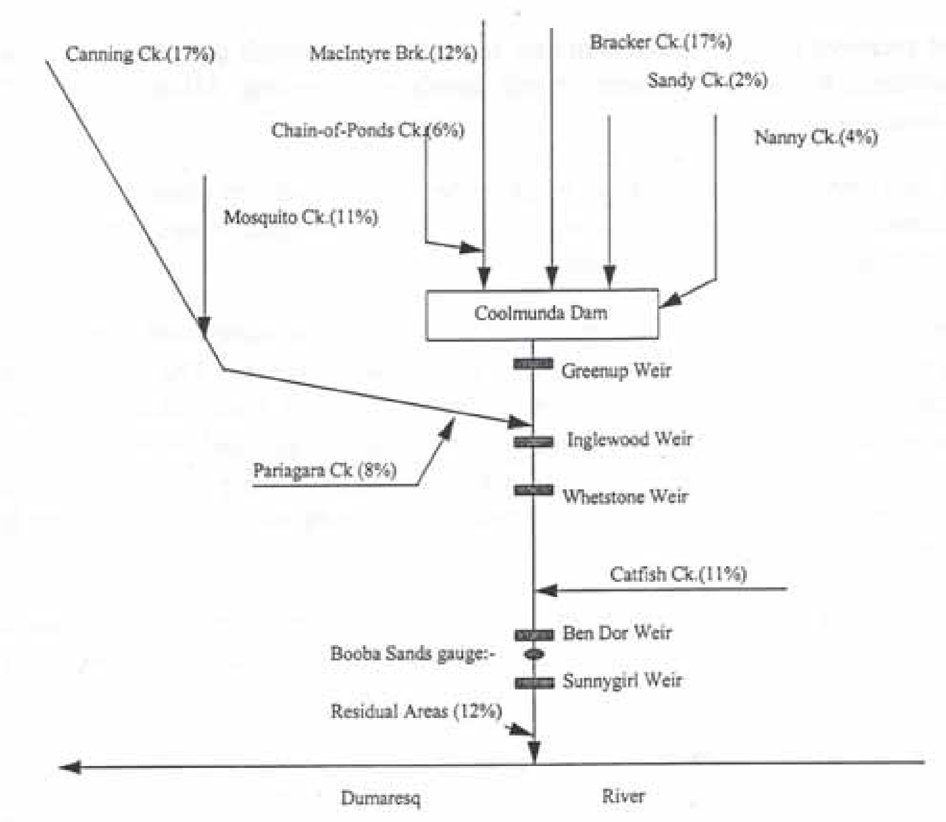


Figure 5. Schematic of the MacIntyre Brook showing percentage of the catchment drained by each watercourse at its outlet.

Sacramento models for each of the four sub-areas were run using historical rainfall and evaporation then rerun using the modified rainfall and evaporation files to produce simulated historical runoff and runoff for each scenario. These runs produced inflows for the IQQM model for each of the four sub-areas for each of the climate change scenarios. Some of these inflows were then multiplied by scaling factors in order to derive residual inflows for each of the climate change scenarios. Groundwater inflows were not modified as these only represented a small fraction of the total flow. The modified flows (for climate change) were then obtained at Inglewood and at the end of system (EOS) (junction of the MacIntyre Brook and Dumaresq Rivers) by running IQQM with the modified inflows and factored rainfall and evaporation files as input.

5.5 MODEL SET-UP AND CALIBRATION – DUMARESQ RIVER

The IQQM and Sacramento rainfall-runoff models were previously configured and calibrated for the Border Rivers catchment by the Queensland and NSW Department of Natural Resources. Flows in the Dumaresq River were simulated using crop demand modelling. The adopted period for flow calibration was 01/01/1985 to 31/12/1996. The section of the Dumaresq River chosen for this study covered the first three reaches and the beginning of the fourth reach of the Border Rivers catchment, which extended from Glenlyon Dam to a ‘dummy node’ just before the confluence of the Dumaresq and MacIntyre Brook Rivers. Reach 1 ran from Glenlyon Dam to the Roseneath gauge, reach 2 ran from Roseneath gauge to the Bonshaw gauge, reach 3 ran from Bonshaw gauge to the Mauro gauge and reach 4a ran from Mauro gauge to the junction of the Dumaresq River and Macintyre Brook. Each reach (except reach 1) contained irrigators from both Queensland and New South Wales. These irrigators produce a range of crops including summer and winter cereals, vegetables and lucerne. Some irrigators also grew pasture for cattle grazing. A schematic of the Dumaresq system can be seen in Figure 6.

Historical rainfall and evaporation files for this region were perturbed using monthly climate change factors for the dry, average and wet climate change scenarios using a macro in Microsoft Excel. Sacramento models were then run using historical rainfall and evaporation, then rerun using the modified rainfall and evaporation files to produce simulated historical runoff and runoff for each scenario. These runs produced inflows for the IQQM model for each of the climate change scenarios. The modified flows (for climate change) were then obtained for a dummy node just before the junction of the Dumaresq River and MacIntyre Brook (called the EOS node in this report) by running IQQM with the modified inflows and factored rainfall and evaporation files as input. Other flows, such as releases from Glenlyon Dam and the flow at Bonshaw Weir were also obtained for the base scenario and each of the climate change scenarios. Groundwater inflows were not modified as these only represented a small fraction of the total flow.

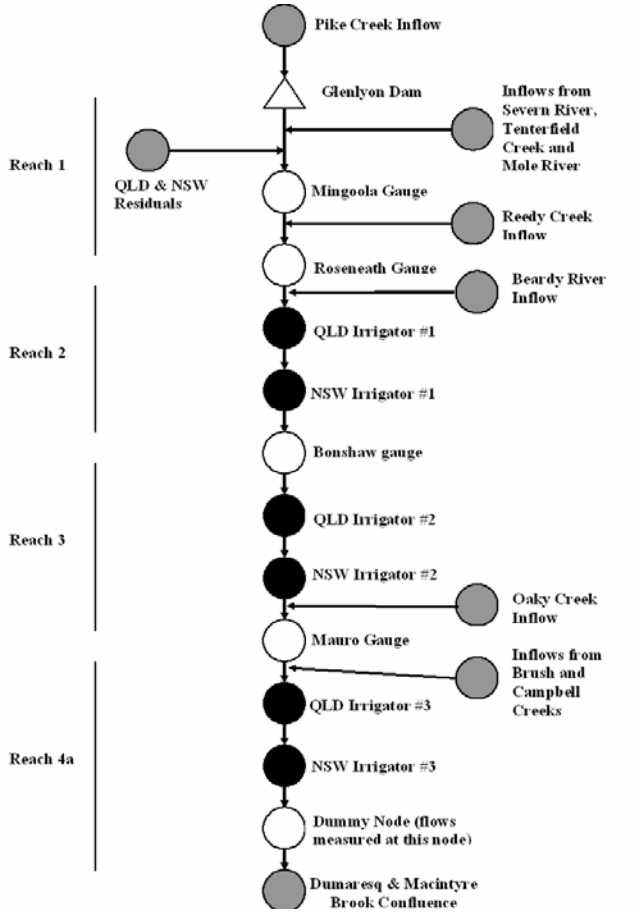


Figure 6. Schematic of the Dumaresq River showing major inflows and irrigators.

5.6 APPLICATION OF THE CLIMATE CHANGE FACTORS

Base data for the MacIntyre Brook was comprised of 30 years of daily data from 1961 to 1990 for 12 rainfall and 4 evaporation stations. Base data for the Dumaresq River was comprised of 30 years of daily data from 1961 to 1990 for 12 rainfall and 9 evaporation stations. Percentage changes derived from OzClim for precipitation and evaporation for each month of 2030, were multiplied with the base data for the MacIntyre Brook and Dumaresq. The monthly changes for rainfall and potential evaporation in percentage change per degree of global warming from each of the climate models are shown in Figure 4. The climate change factors that were used to modify the base data for precipitation and evaporation for the MacIntyre Brook and Dumaresq River systems are shown in Table 5.

Table 5. Climate change factors (% change from base scenario) for the dry, average and wet scenarios for 2030 over the Border Rivers catchment

Variable	Scenario	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Rainfall	**Wet**	8.5	9.0	1.5	3.5	4.0	-5.7	0.1	9.6	-4.5	-2.0	5.6	4.4
	Average	1.0	0.4	-2.7	2.0	-2.2	0.4	0.2	-3.5	-3.6	-2.4	-2.4	-0.5
	Dry	-2.3	-5.6	-12.4	-3.0	-4.6	-6.2	-4.4	-11.2	-5.9	-2.2	-5.1	-5.5
Evaporation	**Wet**	0.9	-0.7	0.9	2.1	2.8	3.8	3.0	1.9	3.8	4.8	2.8	1.4
	Average	3.3	3.4	4.3	3.7	4.3	4.8	5.1	5.5	5.5	5.7	5.3	4.3
	Dry	7.0	6.9	9.2	5.8	7.7	6.5	10.3	15.7	14.3	10.6	12.0	11.9

5.7 GENERATION OF MODIFIED SYSTEM FLOWS

IQQM was run to calculate the streamflow under normal conditions, and then rerun using the modified climate files to obtain the flows for the wet, average and dry climate change scenarios.

6 Results of impact assessment – MacIntyre Brook

6.1 ANNUAL FLOW CHANGES

The results show that based on the set of scenarios, either increases or decreases in stream flow are possible for the MacIntyre Brook. **The change in mean annual flow ranged from -25% to +9% by 2030 at the MacIntyre Brook EOS** (Table 6). Figure 7 shows the mean annual flows at the EOS node for the base scenario and each of the climate change scenarios.

Table 6. Changes in mean annual stream flow for the MacIntyre Brook EOS for the dry, average and wet climate change scenarios in 2030

Scenario	Dry	Average	Wet
Global warming scenario	SRES A2	Average of All	IS92a
GCM	CC50	Average of All	ECHAM4
Global mean warming (°C)	0.92	Average of All	0.78
Regional minimum temperature change (°C)	1.2	Average of All	0.9
Regional maximum temperature change (°C)	1.5	Average of All	0.9
Regional mean temperature change (°C)	1.3	Average of All	0.9
Change in annual rainfall (%)	-5.7	-1.1	2.8
Change in annual potential evaporation (%)	9.8	4.0	2.3
Change in annual streamflow at MacIntyre Brook EOS (%)	-24.9	-8.5	+9.2

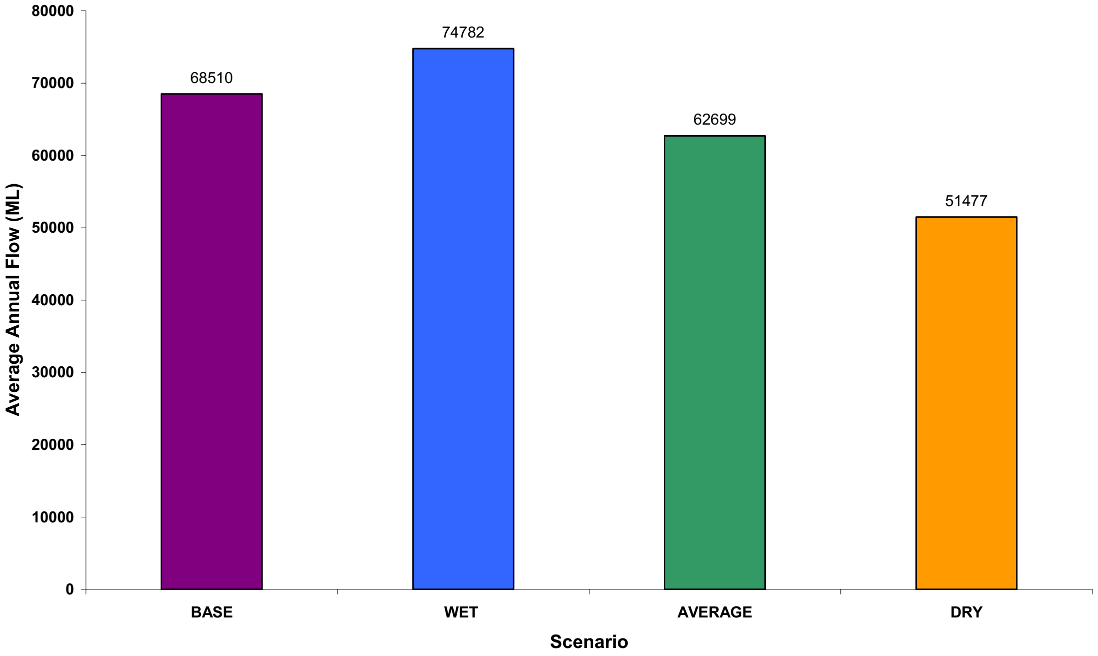


Figure 7. Mean annual streamflow for the MacIntyre Brook EOS for the base scenario and the dry, average and wet climate change scenarios in 2030.

6.2 MONTHLY AND SEASONAL FLOW CHANGES

The highest average monthly flows occurred in February for the wet scenario at the EOS. However, the base and wet scenarios had similar mean flows in most months (May-November) which were higher than the average and dry scenarios (Figure 8). These patterns were consistent with those at Inglewood (Appendix 2).

The highest average seasonal flows occurred in summer and autumn at the EOS. The wet scenario had higher flows than the base scenario in summer and autumn, but flows were similar for both scenarios in winter and spring (Appendix 3). The average and dry scenarios had lower flows in all seasons than the base scenario. Seasonal flows for Inglewood showed a similar pattern (Appendix 3). The 12 month moving average flow at the EOS was highest for the wet and base scenarios, followed by the average and then dry scenario (Figure 9).

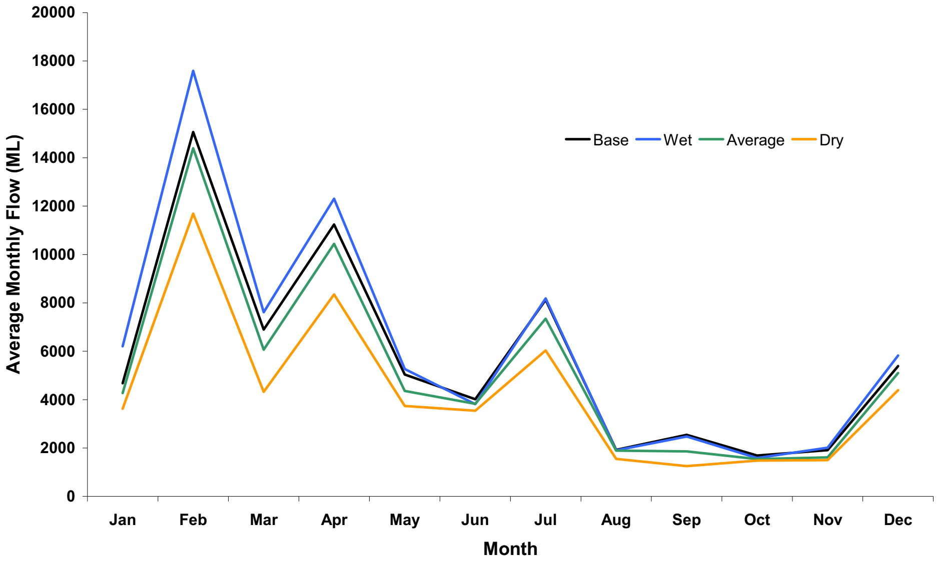


Figure 8. Simulated average monthly flow at the MacIntyre Brook EOS for the base scenario and the dry, average and wet climate change scenarios in 2030.

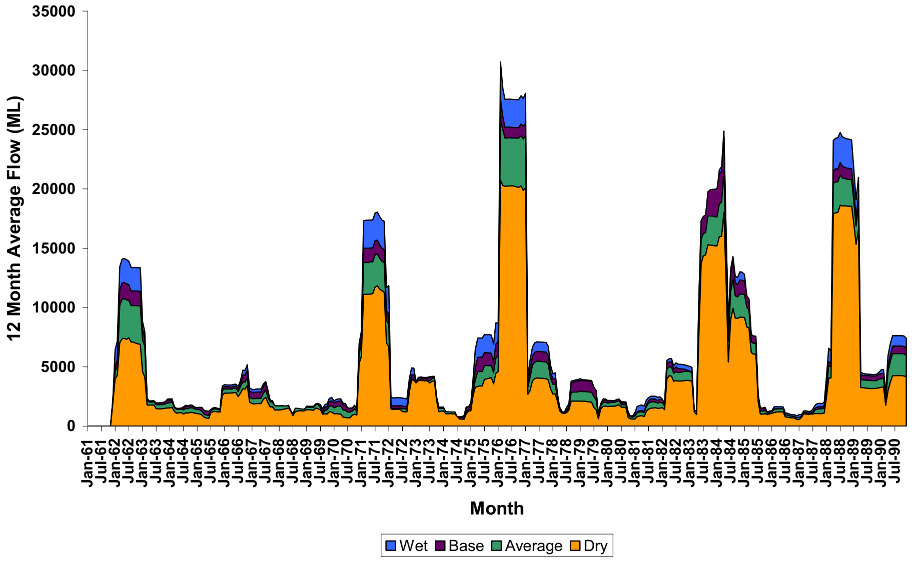


Figure 9. Simulated 12 month moving average flows at the MacIntyre Brook EOS for the base scenario and the dry, average and wet climate change scenarios in 2030.

6.3 DAILY FLOW CHANGES

The average and dry scenarios were associated with reduced EOS flows for the mid-high (>20 ML/d) and very low flow ranges (0.1-5.0 ML/d) compared to base (Figure 10). **Dry (average) scenario mid-high flows were 7-35% (2-16%) lower than the base scenario and very low flows were 4-25% (2-8%) lower (Appendix 12).** There was little apparent difference in EOS daily flows (high and low) between the base and wet scenarios (Figure 10). The flow range from 5 to 20 ML/d did not appear different between all scenarios. Daily flow at Inglewood is shown in Appendix 1.

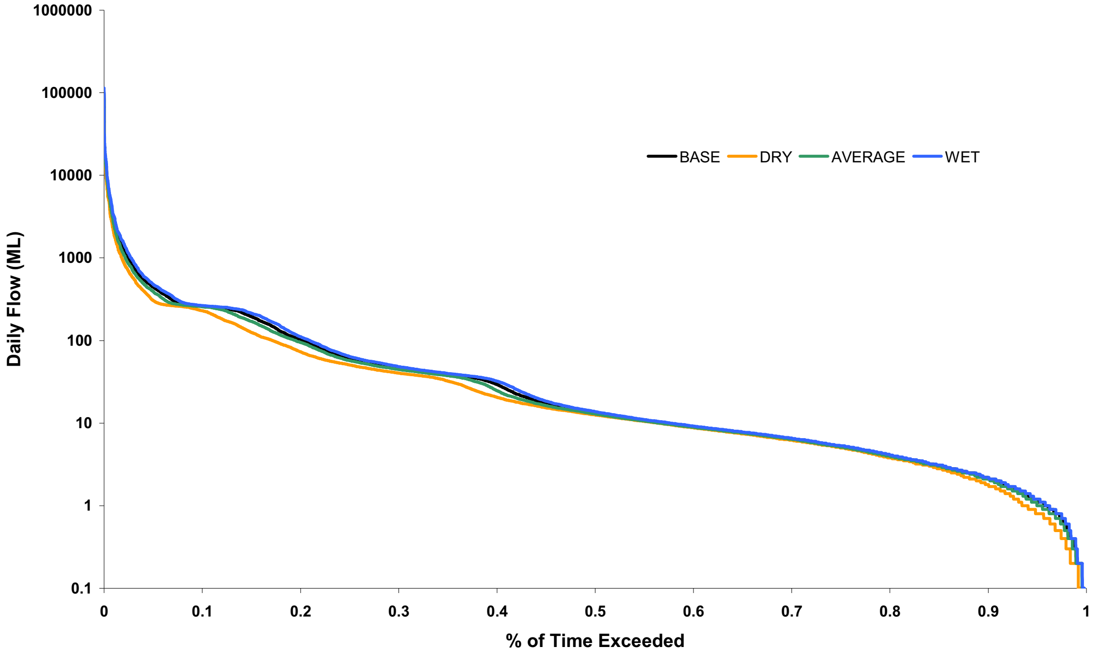


Figure 10. Daily flow exceedance curves for the base scenario and the dry, average and wet climate change scenarios for the MacIntyre Brook EOS in 2030.

The maximum daily flow for the dry scenario was 22% lower than the base scenario and the wet scenario was 11% higher (Appendix 12). The difference in simulated maximum daily flow between the base and dry scenario was 23,200 ML/day. The extent of this difference decreased as the percentile decreased,and for the 88th percentile the difference between the base and dry scenario was <100 ML/day.

The reduction in mid-high flows for the dry climate change scenario may have adverse environmental impacts downstream, and the reduction in very low flows an adverse local impact on land and aquatic ecosystems. These impacts require further investigation. The wet climate change scenario provided small increases in daily flow compared to base, but against the uncertainty associated with the modelling process these apparent differences are minor and probably insignificant.

6.4 LOW FLOWS

6.4.1 Frequency of low flows

The mean annual frequency of low daily flows (<2.2 ML/day) at the MacIntyre Brook EOS was higher ($P<0.05$, paired t test) for the dry scenario compared to the base scenario (Figure 11). The wet and average scenarios were not different to the base scenario. The average numbers of days of low flows per year for the base, wet, average and dry scenarios were 37, 36, 39 and 44 days respectively.

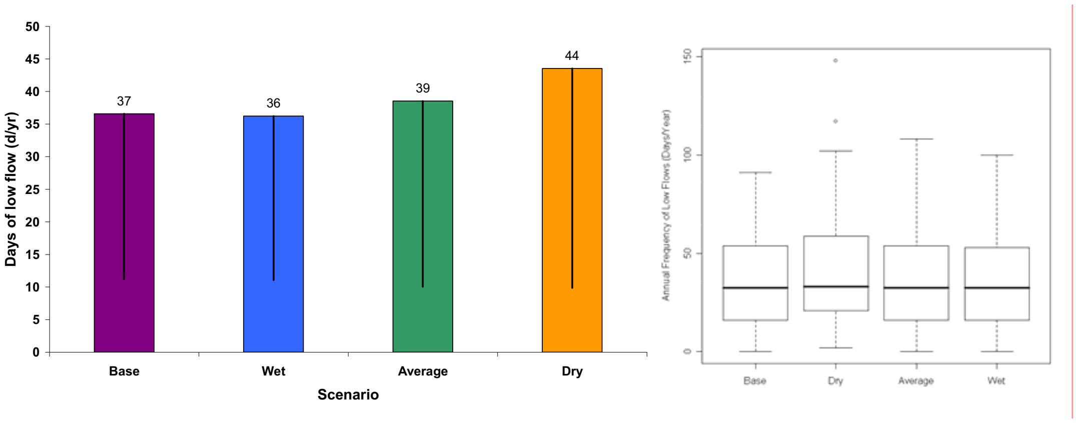


Figure 11. a) Mean number of days per year with low flows (-SD) and b) boxplot of low flow days per year for the base, dry, average and wet scenarios in 2030.

6.4.2 Duration of low flows

The longest simulated duration of low flows (<2.2 ML/day) for the MacIntyre Brook EOS for the base scenario was 61 days (Table 7). The longest duration of low flows for the dry, average and wet scenarios were 76, 71 and 58 days respectively.

The mean duration of low daily flows (<2.2 ML/day) was 8 days for the base scenario. There was no difference (P>0.05, t test) from the base scenario for all scenarios.

The absence of a difference in low flow duration might be attributed to the relatively constant base-flow that occurs in this region due to groundwater inflows, and releases from Coolmunda Dam into the MacIntyre Brook. Frequency plots of the duration of low flows are shown in Appendix 5.

Table 7. Duration of lows flows for the MacIntyre Brook EOS for the base scenario and the wet, average and dry climate change scenarios

Probability of exceeding	Duration of low flow (days)			
(%)	Base	Wet	Average	Dry
0	61	58	71	76
0.2	11	11	13	15
0.4	6	6	6	7
0.6	2	2	2	2
0.8	1	1	1	2

The median duration of low flows was 4 days for the base, wet, average and dry scenarios (Figure 12b).

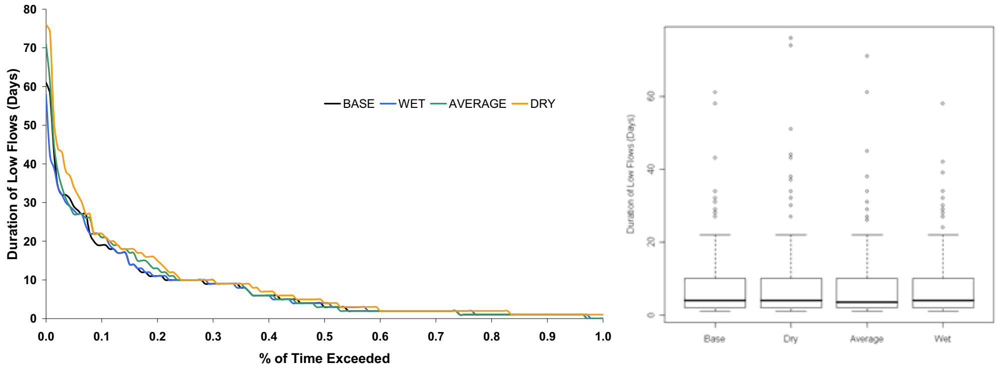


Figure 12. a) Chance of exceeding duration of low flows (<2.2 ML/day) and b) boxplot of duration of low flows for the MacIntyre Brook EOS for base scenario and the wet, average and dry climate change scenarios in 2030.

6.5 HIGH FLOWS

6.5.1 Frequency of high flows

The mean annual frequency of high daily flows (>265 ML/day) for the MacIntyre Brook EOS was lower for the dry and average (P<0.01, paired t test) scenarios, and higher for the wet (P<0.01, paired t test) scenario compared to the base (Figure 13). The average numbers of days of high flows per year for the base, wet, average and dry scenarios were 34, 37, 31 and 25 days respectively.

6.5.2 Duration of high flows

The longest simulated duration of high flows (>265 ML/day) for the MacIntyre Brook EOS for the base scenario was 47 days. The longest duration of high flows for the dry, average and wet scenarios were 42, 46 and 46 days respectively.

The mean duration of high daily flows (>265 ML/day) was 11 days for the base scenario. There was no difference (P>0.05, t test) from the base scenario for all scenarios. Figure 13a shows the POE curves for the duration of high flows for the base scenario and the three climate change scenarios.

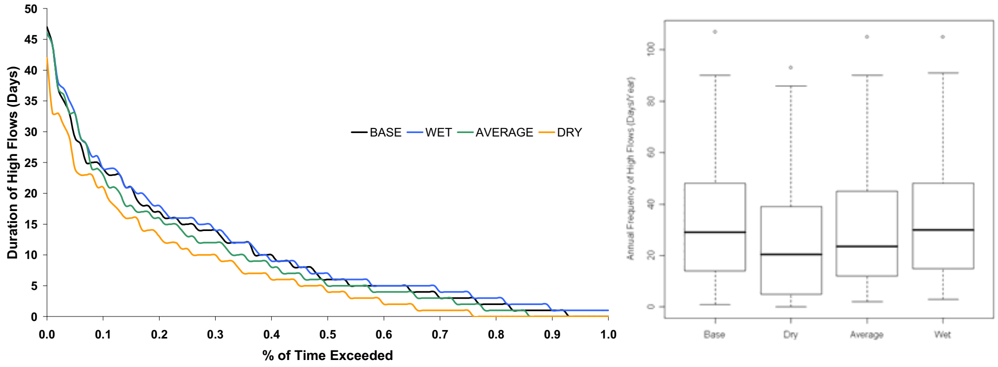


Figure 13. a) Chance of exceeding duration of flows >265 ML/d and b) number of days per annum of flows >265 ML/d for the MacIntyre Brook EOS for the base scenario and the wet, average and dry climate change scenarios in 2030.

6.6 ANNUAL ON-ALLOCATION OF WATER TO IRRIGATORS

The annual on-allocation of water to irrigators occurs at the start of the water year (1st October) and is calculated based on the amount of water available in storage after environmental flows and high security allocations (e.g. town water supplies) are removed. Figure 14 shows the reliability of annual on-allocations for irrigators between the Inglewood and Whetstone Weirs. **The dry scenario was associated with a significant increase in risk of on-allocations below 10,000 ML/yr compared to the base scenario. The wet scenario was associated with less risk compared to the base scenario.** For the dry scenario, only 66% of annual on-allocations were 10,000 ML or above, whereas 83% of annual on-allocations were 10,000 ML/yr or above for the base scenario. This could leave irrigators with significantly less water during dry periods. Similar findings occurred for irrigators upstream of Inglewood Weir, between Whetstone and Ben Dor Weirs and between Ben Dor and Sunnygirl Weirs (Appendix 4A).

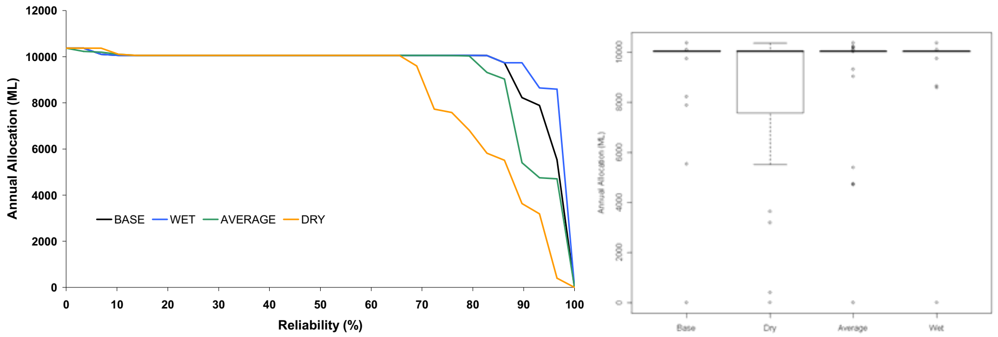


Figure 14. a) Reliability of annual on-allocation of water for irrigators between Inglewood and Whetstone Weirs and b) boxplots of annual on-allocation of water to irrigators between Inglewood and Whetstone Weirs for the base scenario and the three climate change scenarios.

6.7 AREA OF CROPS PLANTED

The total area of crops planted on the MacIntyre Brook did not change under climate change conditions (Appendix 4b) because flows were simulated using full water entitlement modelling. Using this approach the full water entitlement is used by irrigators each year, because unused allocations cannot be carried over into the next water year. Under these circumstances the area of crops planted, along any reach, did not change under climate change conditions.

6.8 ENVIRONMENTAL FLOWS

The environmental flow required for the MacIntyre Brook has been defined as maintenance of 2 ML/day at Booba Sands (Cooke 1999). This flow was designed to keep the river bed wet for speedy water order deliveries and maintain river flow down to the Dumaresq River junction, for fish passage.

Daily flows for Booba Sands showed 94% of the flows for the dry scenario were above the environmental flow of 2 ML/day (Appendix 1). The base, wet and average scenarios had 96-97% of flows above 2 ML/day. There was separation between the distributions for the average and dry scenarios from the base and wet scenarios (between which there was little difference) (Figure 15). **The dry scenario was associated with a longer duration of sub-environmental flows of 5-10 days compared to the base scenario. There was little difference between the base and wet scenarios.**

The occurrence of long periods (5-40 days) of flow below 2 ML/day was higher in the dry scenario compared to the base scenario (Figure 15). For example, the chance of exceeding 10 days

<2 ML/day was 18%, 11%, 10% and 7% for the dry, average, base and wet scenarios respectively. There was a 5% chance that the period of below 2 ML/day flow lasted at least 14, 14, 17 and 22 days for the base, wet, average and dry scenarios respectively.

There was little apparent difference between the median duration of days where flow was below 2 ML/day for the average and dry scenarios (2 days), compared to the wet and base scenarios (1 day). The mean duration of flows below 2 ML/day was 6, 5, 6 and 7 days for the base, wet, average and dry scenarios respectively.

The longer duration of flows below 2 ML/day could lead to more drying of the river bed, reduced speed of water order deliveries and inhibition of migration of fish species in the river system. The practical significance of these findings on aquatic and land ecosystems needs some interpretation from water managers, water users, ecologists and other people with a practical understanding of the system.

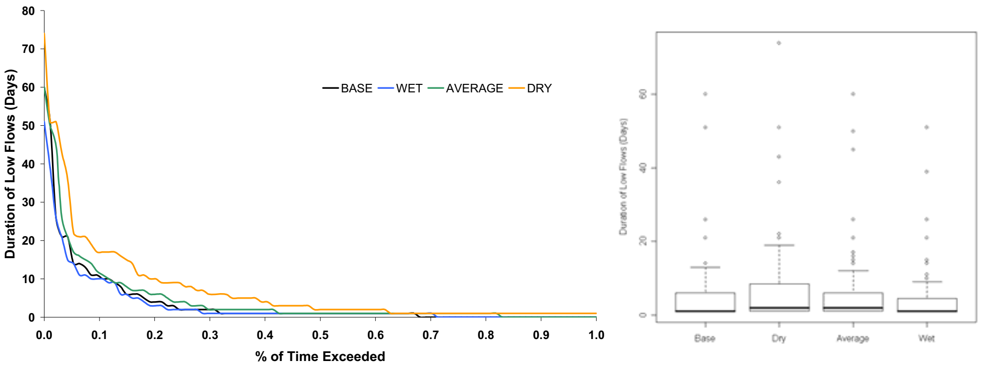


Figure 15. a) Chance of exceeding duration of low flows (<2 ML/day) and b) boxplot of duration of low flows at Booba Sands of the MacIntyre Brook for the base scenario and the wet, average and dry climate change scenarios in 2030.

7 Results of impact assessment – Dumaresq River

7.1 ANNUAL FLOW CHANGES

The results show that based on the set of scenarios, either increases or decreases in stream flow is possible for the Dumaresq River. **The change in mean annual flow ranged from -25% to +6% by 2030 at the Dumaresq River EOS** (Table 8). Figure 16 shows the mean annual flows for the Dumaresq River EOS for the base scenario and each of the climate change scenarios.

Table 8. Changes in mean annual stream flow for the Dumaresq River EOS for the dry, average and wet climate change scenarios in 2030

Scenario	Dry	Average	Wet
Global warming scenario	SRES A2	Average of All	IS92a
GCM	CC50	Average of All	ECHAM4
Global mean warming (°C)	0.92	Average of All	0.78
Regional minimum temperature change (°C)	1.2	Average of All	0.9
Regional maximum temperature change (°C)	1.5	Average of All	0.9
Regional mean temperature change (°C)	1.3	Average of All	0.9
Change in annual rainfall (%)	-5.7	-1.1	2.8
Change in annual potential evaporation (%)	9.8	4.0	2.3
Change in annual streamflow at Dumaresq River EOS (%)	-24.8	-9.6	+5.8

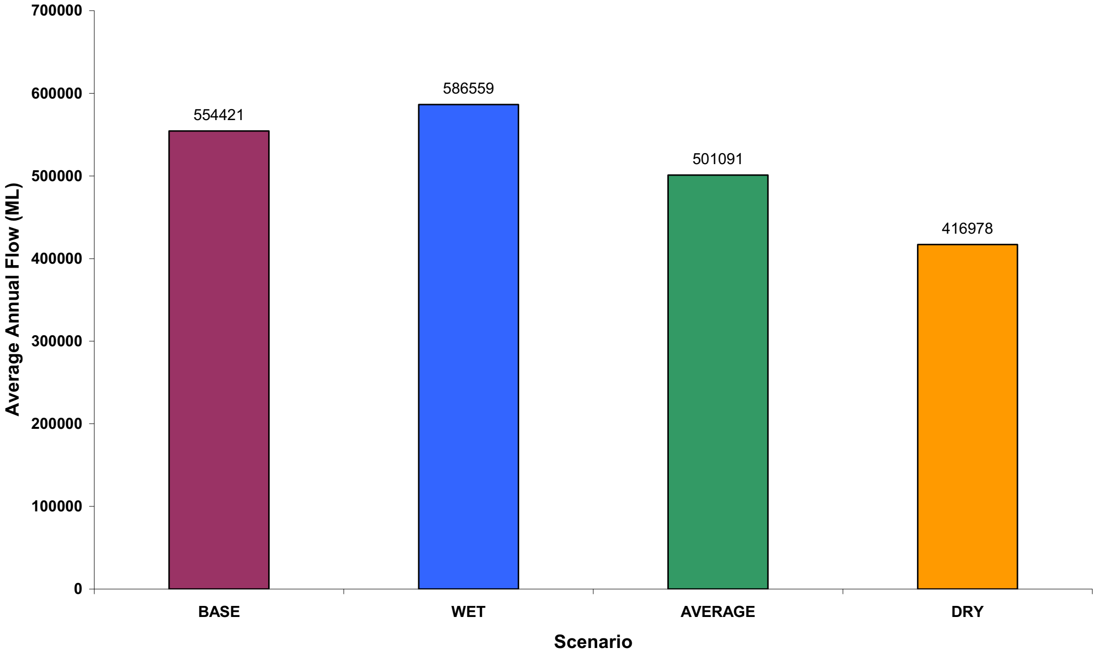


Figure 16. Mean annual streamflow for the Dumaresq River EOS for the base scenario and the dry, average and wet climate change scenarios in 2030.

7.2 MONTHLY AND SEASONAL FLOW CHANGES

The wet scenario was associated with higher average monthly EOS flows during the wet season (December to May) (Figure 17) but similar EOS flows during most of the dry season (i.e. June to November) compared to the base scenario. However during the dry season the wet scenario was associated with higher water releases from Glenlyon Dam (Appendix 7). **The dry scenario was associated with lower water availability in Glenlyon Dam, lower water releases and lower flows than the base scenario in all months.**

Seasonal flows for the wet scenario were higher than the base scenario in summer and autumn and similar in winter and spring (Appendix 8). The dry scenario flows were lower than the base scenario in all seasons. The 12 month moving average flows show slightly higher average flows for the wet scenario and lower flows for the dry scenario, compared to the base scenario (Figure 18).

The 12 month moving average releases from Glenlyon Dam for the wet scenario showed higher and extended periods of release (Appendix 7). Seasonal releases from Glenlyon Dam were higher for the wet scenario in spring, and lower for the dry scenario in all seasons, compared to the base scenario (Appendix 8).

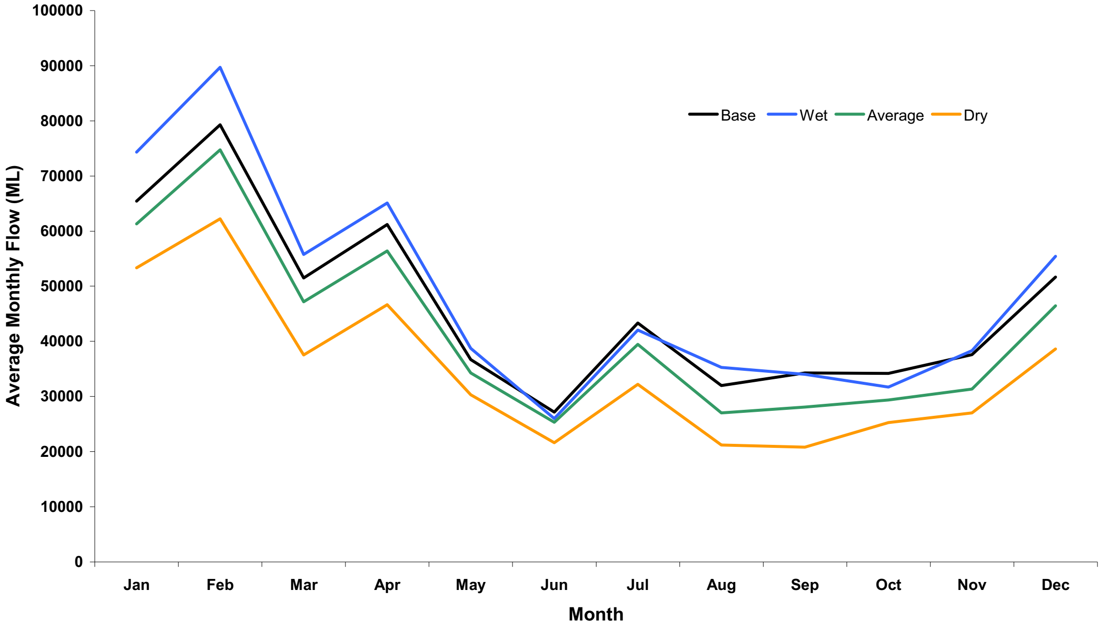


Figure 17. Simulated average monthly flow for the Dumaresq River EOS for the base scenario and the dry, average and wet climate change scenarios in 2030.

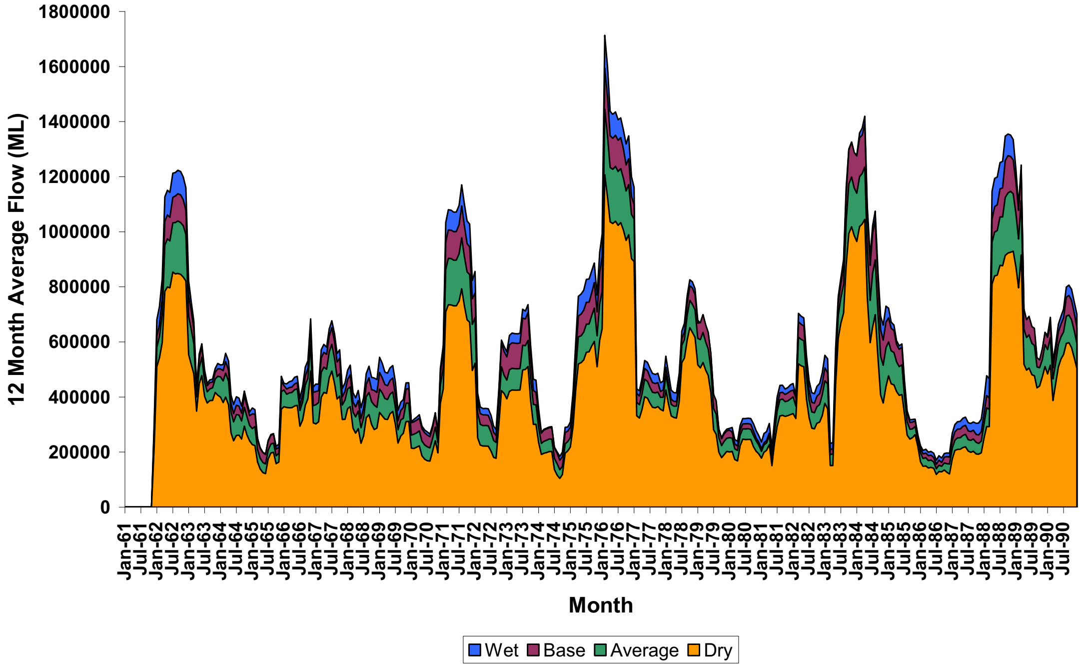


Figure 18. Simulated 12 month moving average flows at the Dumaresq River EOS for the base scenario and the dry, average and wet climate change scenarios in 2030.

7.3 DAILY FLOW CHANGES

The dry scenario was associated with lower EOS daily flows, and the wet scenario with higher flows compared to the base scenario. **Dry scenario daily flows were 19-37% lower, and wet scenario flows 4-10% higher, than the base scenario** (Figure 19, Appendix 12). The average scenario daily flows were 3-16% lower compared to the base scenario.

Daily releases from Glenlyon Dam show all releases for the wet scenario to be higher than the base scenario, the high releases (>10 ML/d) for the dry scenario to be lower than the base scenario, but the low releases (<10 ML/d) for the dry scenario to be higher than the base scenario (Appendix 6). During dry conditions for the dry scenario more water is released to maintain environmental flows (Intergovernmental Agreement 2006-2007 for 100 ML/d at Mungundi).

The reduction in flows for the dry climate change scenario may have adverse environmental impacts downstream, and higher release of water during dry periods will place extra pressure on the water storage. These impacts require further investigation.

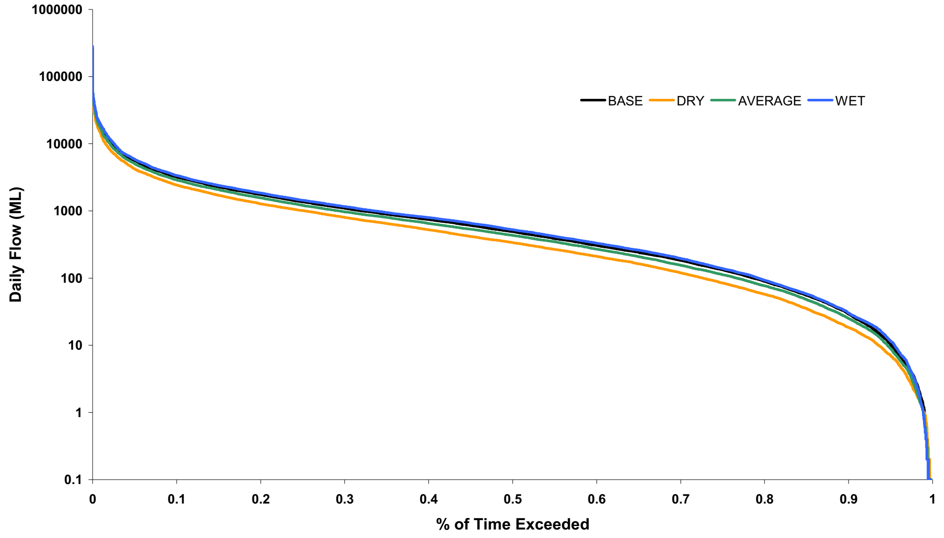


Figure 19. Daily flow exceedance curves for the base scenario and the dry, average and wet climate change scenarios for the Dumaresq River EOS in 2030.

The maximum daily flow for the dry scenario was 19% lower than the base scenario, and that for the wet scenario was 8% higher (Appendix 12). The difference in simulated maximum daily flows between the base and dry scenario was approximately 50,000 ML/day. The extent of this difference decreased as the percentile decreased, and by the 88th percentile the difference between the base and dry scenarios was < 700 ML/day.

7.4 LOW FLOWS

7.4.1 Frequency of low flows

The mean annual frequency of low daily flows (<2.2 ML/day) at the Dumaresq River EOS was different ($P<0.05$, paired t test) for the average and dry climate change scenarios compared to the base scenario (Figure 20). The average numbers of days of low flows per year for the base, wet, average and dry scenarios were 6, 6, 7 and 8 days respectively. Boxplots for each of the scenarios (Figure 20b) showed that the dry scenario had the highest upper-quartile range. The median for each of the scenarios was zero (Figure 20b).

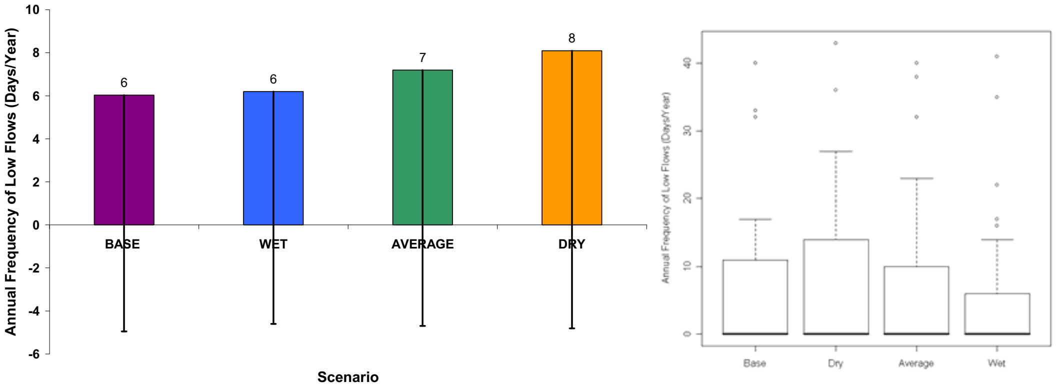


Figure 20. a) Mean number of days per year with low flows (-SD) and b) boxplot of low flow days per year for the base, dry, average and wet scenarios in 2030.

7.4.2 Duration of low flows

The longest simulated duration of low flows (<2.2 ML/day) was 21 days for the Dumaresq River EOS for the base scenario (Table 9). The longest duration of low flows for the dry, average and wet scenarios were of 30, 30 and 22 days respectively.

The mean duration of low daily flows (<2.2 ML/day) was 6 days for the base scenario. There was no difference (P>0.05, t test) from the base scenario for all climate change scenarios.

Frequency plots of the duration of low flows are shown in Appendix 11.

Table 9. Duration of lows flows at the Dumaresq River EOS for the base scenario and the wet, average and dry climate change scenarios

Probability of exceeding (%)	Duration of low flow (days)			
	Base	Wet	Average	Dry
0	21	22	30	30
0.2	8	8	9	10
0.4	5	7	6	6
0.6	4	4	5	4
0.8	2	2	2	2

The median duration of low flows was 5, 6, 6 and 6 days respectively for the base, wet, average and dry scenarios (Figure 21b).

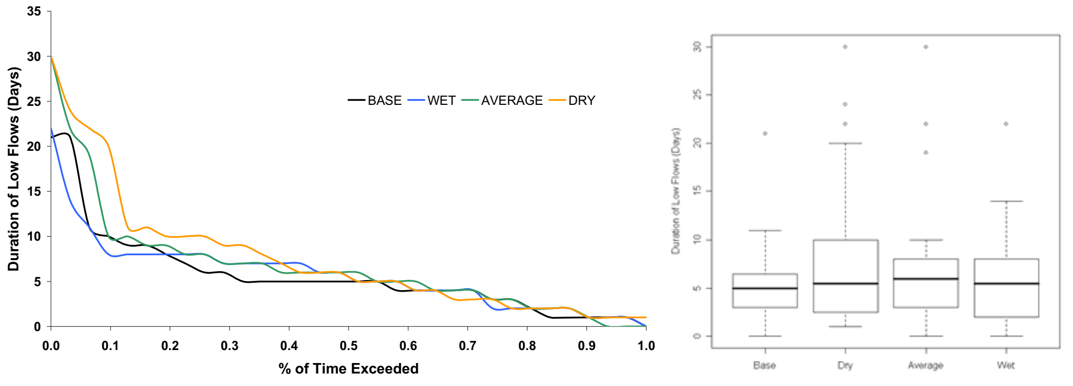


Figure 21. a) Chance of exceeding duration of low flows and b) boxplot of duration of low flows at the Dumaresq River EOS for the base scenario and the wet, average and dry climate change scenarios in 2030.

7.5 HIGH FLOWS

7.5.1 Frequency of high flows

The mean annual frequency of high daily flows (>265 ML/day) for the Dumaresq River EOS was different (P<0.01, paired t test) for all climate change scenarios compared to the base scenario (Figure 22b). The average numbers of days of high flows per year for the base, wet, average and dry scenarios were 230, 236, 221 and 202 days respectively. The median frequencies of high flows for the base, wet, average and dry scenarios were 226, 230, 214 and 200 days respectively (Figure 22b).

7.5.2 Duration of high flows

The longest simulated duration of high flows (>265 ML/day) was 238 days for the Dumaresq River EOS for the base scenario. The longest duration of high flows for the dry, average and wet scenarios were 226, 236 and 239 days respectively.

The mean duration of high daily flows (>265 ML/day) was 40 days for the base scenario. There was no difference (P>0.05, t test) from the base scenario for all climate change scenarios. Figure 22a shows the POE curves for the duration of high flows for the base scenario and the three climate change scenarios.

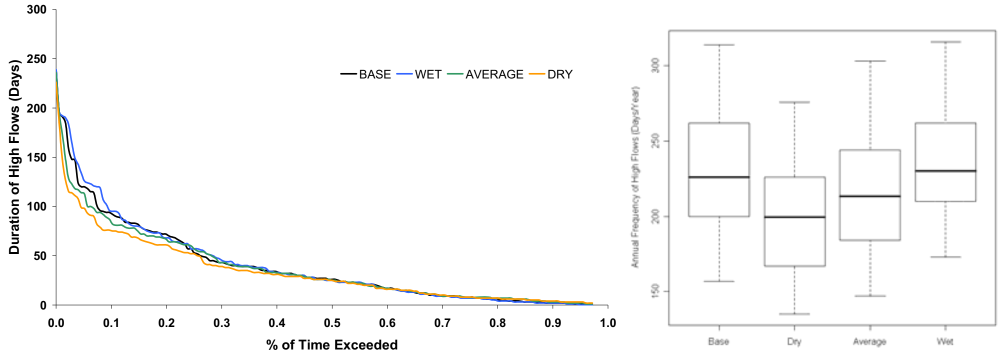


Figure 22. a) Chance of exceeding duration of flows >265 ML/d and b) number of days per annum of flows >265 ML/d at the Dumaresq River EOS for the base scenario and the wet, average and dry climate change scenarios in 2030.

7.6 ANNUAL ON-ALLOCATION OF WATER TO IRRIGATORS

The annual on-allocation of water to irrigators occurs at the start of the water year (1st October) and is calculated based on the amount of water available in storage after environmental flows and high security allocations (e.g. town water supplies) are removed. **For irrigators in QLD the dry climate change scenario was associated with a reduction in water on-allocation reliability – the mean allocation was 12% lower** (Table 10, Figure 23; base scenario mean allocation was 3660 ML). Alternatively for irrigators in NSW the dry scenario was associated with more reliable allocations (mean allocation was 8% higher) within the 5000-10000 ML range, and less reliable allocations below 5000 ML, compared to the base scenario (Table 10, Figure 24; base scenario mean allocation was 5280 ML). **The wet scenario was not apparently different to the base scenario in either QLD or NSW.**

The apparent higher reliability of on-allocations for NSW irrigators for the dry scenario (not in QLD) compared to the base scenario, was likely to be associated with greater certainty and flexibility of the on-allocation process for NSW compared to QLD irrigators along the Dumaresq River. NSW irrigators have greater capacity to use more water than QLD irrigators (for less risk), and under conditions of greater water need (e.g. dry scenario) and high allocations (i.e. adequate storage levels) NSW irrigators use more water which was associated with higher reliability of allocation following rainfall, storage inflows and refill. For the dry scenario when storage levels and allocations were lower (<5000 ML) there was less flexibility in water on-allocation for NSW irrigators, which reduced capacity to use water and was associated with lower allocations compared to the base scenario.

Table 10. Mean annual water on-allocations for QLD and NSW irrigators along the Dumaresq River for the base scenario and percentage change from the base for the dry, average and wet climate change scenarios

State	Reach of river	Mean allocation for base scenario (ML)	Dry scenario (% change)	Average scenario (% change)	Wet scenario (% change)
QLD	Glenlyon to MacIntyre Brook confluence	3660	-12	-2	2
	Glenlyon to Bonshaw	1660	-14	-2	4
	Bonshaw to Mauro	1410	-10	0	2
	Mauro to MacIntyre Brook confluence	590	-12	-3	-7
NSW	Glenlyon to MacIntyre Brook confluence	5280	8	7	0
	Glenlyon to Bonshaw	2390	17	13	0
	Bonshaw to Mauro	2750	0	1	1
	Mauro to MacIntyre Brook	140	8	2	-7

The impact of climate change on the mean annual water on-allocation for different reaches of the river was similar for QLD irrigators but varied for NSW irrigators (Table 10, Appendix 9). The dry scenario was associated with a mean reduction in on-allocation of 14% for QLD irrigators on the reach between Glenlyon Dam and Bonshaw Weir, 10% for the reach from Bonshaw Weir to Mauro gauge, and 12% for the reach from Mauro gauge to the MacIntyre Brook confluence. The climate change scenarios did not appear to change the mean annual on-allocation for NSW irrigators between Bonshaw Weir and Mauro gauge from the base scenario. However the dry scenario was associated with mean annual on-allocation increases of 17% for NSW irrigators between Glenlyon Dam and Bonshaw Weir, and 8% for NSW irrigators between Mauro gauge and the MacIntyre Brook confluence.

The security of water on-allocations for NSW irrigators along the Dumaresq River is improved because irrigators downstream of the Dumaresq River have access to allocations from Pindari Dam as well as Glenlyon Dam, which places less pressure on the water allocations of NSW irrigators along the Dumaresq River. QLD irrigators downstream of the Dumaresq River have allocations from Glenlyon Dam only and as such are more likely to use water from Glenlyon Dam than their NSW counterparts. This helps explain why annual on-allocations of water are less reliable for Queensland irrigators, and why NSW irrigators can receive higher annual on-allocations for the dry climate scenario compared to the base scenario. The variable allocations for this region are a factor that was absent for the Macintyre-Brook River study, where there was one water supply (Coolmunda Dam) and the demand of irrigators was constant.

The demand for water by irrigators downstream of Glenlyon Dam for the wet scenario was higher in the dry season (August - December), and lower in the wet season (January - February), compared to the base scenario. This reflects improved rain-fed soil moisture during the dry season with the opportunity to plant crops with some extra use of irrigation water. During the wet season the higher rain-fed soil moisture reduces demand for water for the wet scenario.

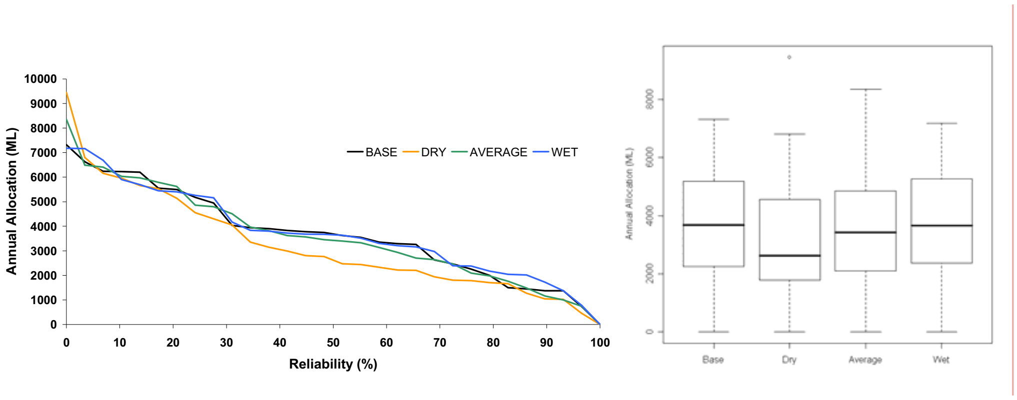


Figure 23. a) POE graph of reliability of annual on-allocation of water for all Queensland irrigators and b) boxplots of reliability of annual on-allocation of water for all Queensland irrigators.

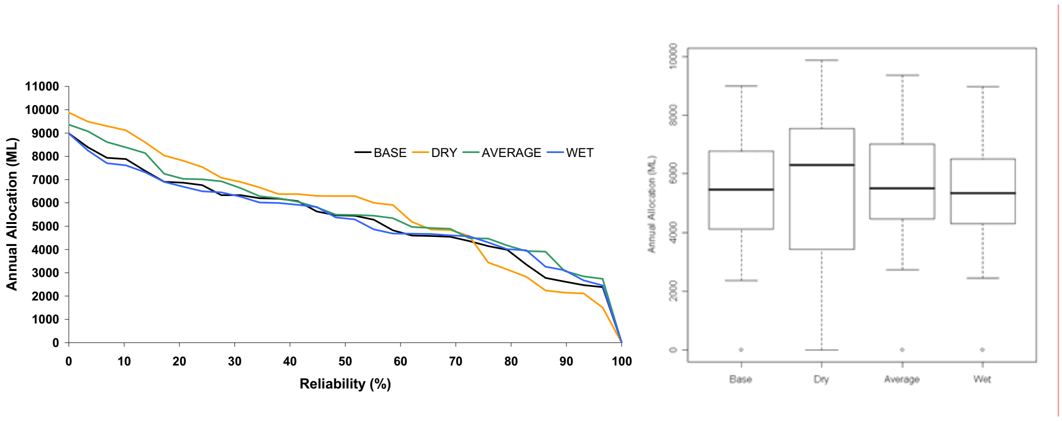


Figure 24. a) POE graph of reliability of annual on-allocation of water for all NSW irrigators and b) boxplots of reliability of annual on-allocation of water for all NSW irrigators.

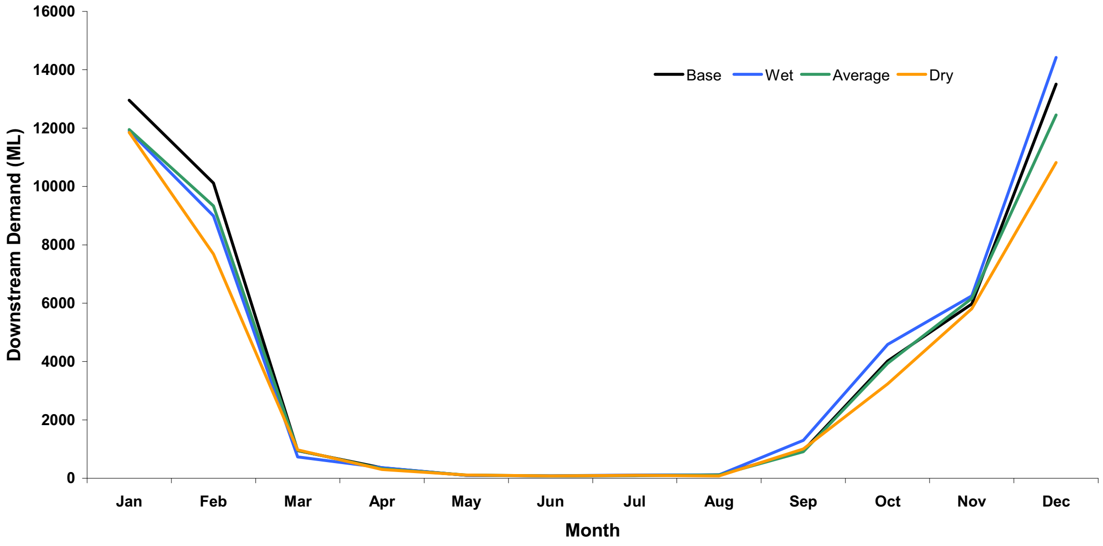


Figure 25. Downstream demand for all irrigators below Glenlyon Dam (including downstream of the Dumaresq EOS) for the base scenario and the three climate change scenarios.

7.7 AREA OF CROPS PLANTED

The dry climate change scenario produces less rainfall (6%) and less water allocation which has a compounding influence on area of crops planted. **For irrigators in QLD the dry climate change scenario was associated with a reduction in crop area – the mean was 28% lower** (Table 11, Figure 26; base scenario crop area was 2070 ha). For irrigators in NSW the dry scenario was associated with a mean reduction in crop area of 13% compared to the base scenario (Table 11, Figure 27; base scenario crop area was 1490 ha). **The wet scenario was not apparently different to the base scenario in either QLD or NSW.**

The dry climate change scenario was associated with a reduction in crop area for QLD irrigators along each reach of the Dumaresq River. Total area of crops planted by all irrigators and for the Queensland and NSW irrigators along each reach of the Dumaresq River is shown in Appendix 10.

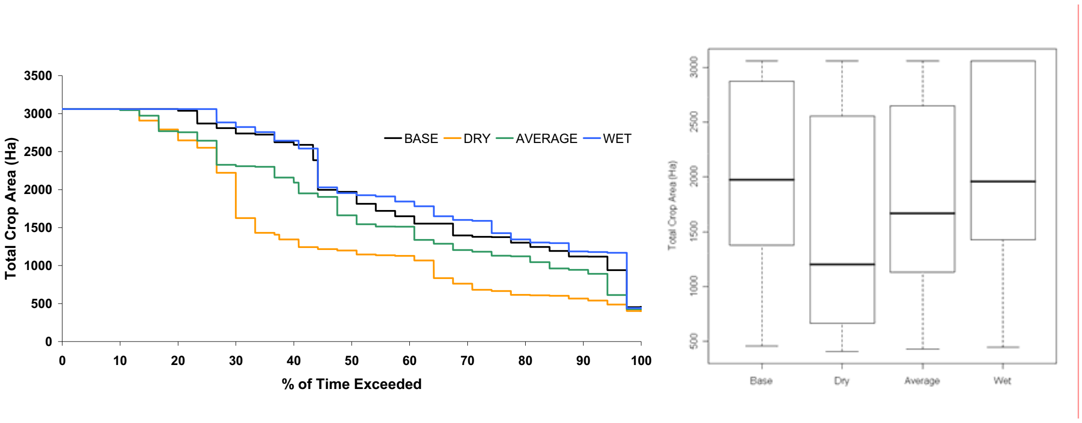


Figure 26. a) POE graph of total crop area planted for all Queensland irrigators and b) boxplots of total crop area planted for all Queensland irrigators.

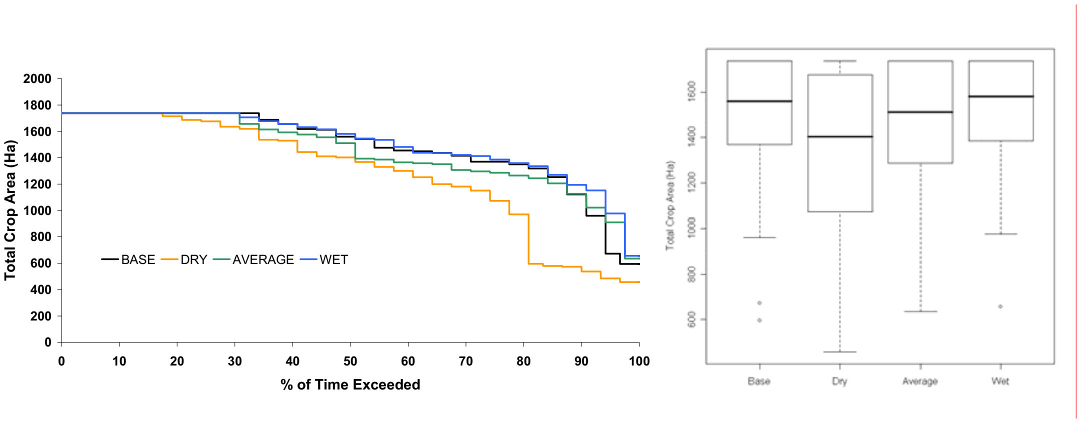


Figure 27. a) POE graph of total crop area planted for all NSW irrigators and b) boxplots of total crop area planted for all NSW irrigators.

Table 11. Mean simulated crop areas for QLD and NSW irrigators along the Dumaresq River for the base scenario and percentage change from the base for the dry, average and wet climate change scenarios

State	Reach of river	Mean crop area for base scenario (ha)	Dry scenario (% change)	Average scenario (% change)	Wet scenario (% change)
QLD	Glenlyon to MacIntyre Brook confluence	2070	-28	-11	4
	Glenlyon to Bonshaw	660	-28	-12	4
	Bonshaw to Mauro	910	-32	-14	3
	Mauro to MacIntyre Brook confluence	490	-20	-5	5
NSW	Glenlyon to MacIntyre Brook confluence	1490	-13	-2	2
	Glenlyon to Bonshaw	790	-9	2	2
	Bonshaw to Mauro	640	-19	-7	2
	Mauro to MacIntyre Brook	55	0	0	0

7.8 ENVIRONMENTAL FLOWS

The environmental flow requirement for the Border Rivers is shown in the Intergovernmental Agreement (Addendum to Bulk Water Sharing Plan for 2006-07) as 100 ML/d at Mungundi. Daily flows downstream at the confluence of the MacIntyre Brook and Dumaresq rivers are below 100 ML/Day 18% of the time for the base scenario, 24% of the time for the dry scenario, 20% of the time for the average scenario and 17% of the time for the wet scenario.

The likely impacts of changes in flow due to climate change on environmental flows are unclear as flows appear to be more affected by regulation. If climate change reduces water availability, allocations are likely to be more affected than environmental flows, as environmental flow requirements must be met before water is allocated.

8 Conclusions and Recommendations

8.1 SUMMARY OF RISK ANALYSIS

In this study we have assessed the likelihood of changes to mean annual flow by perturbing input data to the MacIntyre Brook and Dumaresq Integrated Quality Quantity Models according to quantified ranges of climate change for 2030. These ranges incorporate the range of global warming according to the IPCC Third Assessment Report (IPCC, 2001) and regional changes in rainfall and potential evaporation encompassing the results from nine different climate models. The methods used are primarily designed to manage uncertainty and its impact on processes impacting on water supply. Other aspects of uncertainty within the water cycle, such as land use change, or demand change, have not been addressed.

Annual rainfall projections ranged from slightly wetter, to drier than the historical climate. Six of the nine models expressed an annual drying trend. Seasonally, changes are uncertain in DJF

(December, January and February) and MJJ but are dominated by decreases in ASON. Increases in potential evaporation are much more certain.

The dry scenario for 2030 was associated with a mean temperature increase of 1.3°C, reduced annual rainfall of 6% and higher evaporation of 10%. The wet scenario for 2030 was associated with a mean temperature increase of 0.9°C, higher annual rainfall of 3% and higher evaporation of 2%.

Based on the set of scenarios, either increases or decreases in stream flow are possible for the MacIntyre Brook and Dumaresq rivers depending on which scenario is most closely associated with observed climate in the future. **The change in mean annual flow for the MacIntyre Brook ranged from approximately -25% to +9% by 2030. For the Dumaresq River the change in mean annual flow ranged from approximately -25% to +6% by 2030.**

For the MacIntyre Brook the average and dry scenarios were associated with a reduced frequency of daily flows for the mid-high (~5000 to 50 ML/d) and very low flow range (~5 to 0.1 ML/d) compared to the base scenario. **Dry scenario mid-high flows were 7-35% lower than the base scenario and very low flows were 4-25% lower.** There was little difference in the frequency of daily flows (high or low) between the base and wet scenarios.

For the Dumaresq River the average and dry scenarios were also associated with a reduced frequency of daily flows, and the wet scenario with higher flows compared to the base. **Dry scenario daily flows were 19-37% lower, and wet scenario flows 4-10% higher than the base scenario. The reduction in flows for the dry climate change scenario may have adverse environmental impacts downstream, and higher release of water during dry periods will place extra pressure on the water storage.** These impacts require further investigation.

For the MacIntyre Brook the 95-100 percentile daily flows for the dry scenario were 22-31% lower than the base scenario. These flows for the average scenario were 3-12% lower than the base, and for the wet scenario were 7-11% higher. The difference in simulated maximum daily flow between the base and dry scenario was approximately 23,200 ML/day.

For the Dumaresq River **the 95-100 percentile daily flows for the dry scenario were 19-25% lower than the base scenario.** For the wet scenario flows were from 5-8% higher compared to the base scenario. The difference in simulated maximum daily flow between the base and dry scenarios was approximately 50,000 ML/day. These differences decreased as the percentile decreased e.g. by the 88th percentile the differences were <700 ML/day. **The reduction of very high flows in the dry and average scenarios could change vegetation downstream due to reduced inundation on the floodplains and the shorter duration of flood events.**

For the MacIntyre Brook **the annual on-allocation of water to irrigators maybe reduced by climate change. The dry scenario was associated with greater risk of water allocations below 10,000 ML/yr compared to the base scenario, for irrigators between Inglewood and Whetstone Weirs.** The **base scenario was associated with 83% reliability** of an annual on-allocation ≥10,000 ML, while the **dry scenario was associated with only 66% reliability**. This could leave irrigators with significantly less water during dry periods. **The reduction of annual on-allocations for the dry scenario when irrigation water demands are high may reduce agricultural production.** Similar patterns were evident for other irrigators both upstream and downstream of this location. The wet and average scenarios were not apparently different to the base scenario.

For the Dumaresq River the annual on-allocation of water to irrigators in QLD for the dry climate change scenario was associated with a **reduction in water allocation reliability – the mean allocation was 12% lower**. Alternatively for irrigators in NSW the dry scenario was associated with more reliable allocations (mean allocation was 8% higher) within the 5000-10000 ML range, and less reliable allocations below 5000 ML, compared to the base scenario. **The wet scenario was not apparently different to the base scenario in either QLD or NSW.**

For the MacIntyre Brook the total area of crops planted did not change under climate change conditions because flows were simulated using full water entitlement modelling.

For QLD irrigators along the Dumaresq River the dry climate change scenario **was associated with a reduction in crop area – the mean was 28% lower.** This was driven by less rainfall (6%) and less water allocation which had a compounding influence on area of crops planted. For irrigators in NSW the dry scenario was associated with a mean reduction in crop area of 13% compared to the base scenario. **The wet scenario was not apparently different to the base scenario in either QLD or NSW.**

For the MacIntyre Brook the environmental flow required was 2 ML/day. Daily flows for Booba Sands showed 94% of the flows for the dry scenario were at least 2 ML/day. The base, wet and average scenarios had 96% to 97% of the flows being at least 2 ML/day. However the occurrence of long periods (5-40 days) of flow below 2 ML/day was higher in the dry scenario compared to base. For example, the chance of exceeding 10 days <2 ML/day was 18%, 11%, 10% and 7% for dry, average, base and wet scenarios respectively. There was a 5% chance that the period of below 2 ML/day flow lasted at least 14, 14, 17 and 22 days for the base, wet, average and dry scenarios respectively. The implications of this for environmental and natural systems need further investigation.

The environmental flow requirement for the Border Rivers was 100 ML/d at Mungundi. Daily flows downstream at the confluence of the MacIntyre Brook and Dumaresq River were below 100 ML/d 18% of the time for the base scenario, 24% of the time for the dry scenario, 20% of the time for the average scenario and 17% of the time for the wet scenario. The likely impacts of changes in flow due to climate change on environmental flows are unclear, as flows appear to be more affected by regulation. If climate change reduces water availability, allocations are likely to be more affected than environmental flows, as environmental flow requirements must be met before water is allocated. The dry scenario may force allocations to irrigators down in order to maintain environmental flows and provide for high security water users (e.g. town water supplies). This may force some irrigators to change their land use (e.g. use more of their land for grazing) which may alter the hydrology of the system.

The reduction of average flows for the dry and average climate change scenarios may lead to a reduction in the sediment load which may result in the decrease of particle deposition downstream. Increases/decreases in sediment load are associated with increases/decreases in the amount of nitrogen and phosphorous in streams. A decrease of nitrogen and phosphorous in streams may result in the decrease of blue-green algal blooms downstream, however the positive effects of this may be outweighed by the negative effects of reduced flows on the environment. These findings are supported by a general understanding of catchment process but more work is required to pinpoint the outcomes particular to this catchment.

The depth and exposed surface area of the water storages (Glenlyon dam - deep with relatively small surface area, and Coolmunda Dam – shallow with relatively high surface area) affects the amount of water lost to evaporation. Under climate change conditions building of deep on-farm storages will help reduce evaporation losses. The effects of wind on evaporation are not included in the models used in this study.

8.2 LIMITATIONS OF THE ASSESSMENT

There are a number of limitations in this assessment that will affect the interpretation and application of its results. These limitations concern:

- uncertainty linked to the greenhouse effect;
- the limitations of climate modelling, which affect how subsequent output can be used,
- the method of scenario construction,
- the application of those scenarios to the impact model,
- the relationship between climate change and ongoing climate variability, and
- hydrological model uncertainties.

8.2.1 Greenhouse-related uncertainties

Climate change uncertainties can be divided into scientific uncertainties and socio-economic uncertainties. Many scientific and some socio-economic uncertainties can be reduced by improved knowledge that can be simulated within models. Some uncertainties are irreducible; for example, the chaotic behaviour of systems or future actions of people affecting rates of greenhouse gas emissions. Some uncertainties will be reduced through human agency; for example adaptation to reduce the impacts of climate change or the mitigation of climate change through greenhouse gas reductions.

In this report, the major greenhouse-related uncertainties we have accounted for are climate sensitivity (model sensitivity to atmospheric radiative forcing), regional climate change (managed by using a suite of climate models providing a range of regional changes, checked for their ability to simulate the current Queensland climate).

8.2.2 Climate model limitations

The main limitations of climate models, apart from incomplete knowledge, which is addressed above, relates to scale. Much of the variability within the real climate is emergent from very fine-scaled processes that may not be well represented in climate models, particularly those models with coarser resolution. The two major limitations relate to changes in the interannual and daily variability of rainfall. A further limitation relates to the coarse resolution of topography, not thought to be a major contributor to regional uncertainty over most of Australia. Incomplete or partially known physical processes also limit climate models – the most significant of those being limited to the behaviour of clouds under climate change, which contributes to climate model sensitivity.

Interannual rainfall variability is subject to large scale teleconnections, and so requires fully coupled climate models of sufficient vertical and horizontal resolution to be adequately simulated. However there is as yet no real agreement between different models as to how important phenomena, such as the El Niño – Southern Oscillation phenomenon may behave under climate change. Each rain event is also limited in scale to the size of the grid spacing in the model. Essentially, each rain event occurs across a whole grid box, which tends to reduce its intensity because fine-scale convection processes cannot easily be produced. Therefore, although climate models indicate increases in daily rainfall intensity, these increases are generally under-estimated under all but the finest resolution regional models. Methods are currently being explored to combine both global and local influences in fine scale model simulations but as yet this data is not available for impact studies. However, a few specialised climate runs would also fail to properly address a range of uncertainties that a larger set of models can provide.

8.2.3 Scenario construction methods

Climate scenario construction needs to strike a balance between representing a realistic set of changes and uncertainty using available resources. Rainfall is the main driver in simulating hydrological change and can potentially change across a range of temporal and spatial scales. Obviously, it is difficult to produce scenarios that represent all changes that a model can realistically simulate or to compensate for those changes where model simulations indicate a change but where the output cannot be used directly (as in downscaling).

In this project, we used the OzClim climate scenario generator which has climate change patterns from a number of different models installed: most importantly for this project, monthly patterns of change per degree of global warming for average rainfall and potential evapotranspiration. These patterns contain normalised representations of local change as a function of global warming that can be re-scaled using a wide range of average global warming to provide changes representing the outcomes for each climate model for any date from 1990 to 2100. This method is valid for the range of global warming provided by IPCC (2001). Therefore, by using a range of climate models we are representing as wide a range of local climate change that can reliably be quantified.

However, changes to climate variability have not been explicitly represented in these scenarios. This would require access to large volumes of high-resolution data and likely involve intensive downscaling methods for data from many models, which we do not have the resources to undertake.

8.2.4 Scenario application

The method of scenario application we have used is to multiply daily changes in rainfall and potential evaporation by a single monthly value of percentage change, the so-called uniform perturbation method. This assumes that all values within that month will change by the same amount e.g. -5%, without any changes in daily variability.

Studies of daily rainfall output from climate models indicate that extreme rainfall is likely to increase, except where decreases in the mean are large. The number of raindays appears likely to decrease, except for larger increases in rainfall. Even for situations where mean rainfall does not change, climate models indicate increases in extreme falls and a decrease in lighter falls and the number of rain days. As detailed in the previous section, we do not have the resources to test the impacts of such changes.

The application of changes in monthly mean to historical daily data means that changes in annual and seasonal mean rainfall are well represented, but not differential changes in daily rainfall or the number of raindays. Where such changes have been simulated from CSIRO Mark2 data, they produce increases of several percent (Chiew *et al.*, 2003) but this rainfall output was not downscaled further, which would increase the simulated intensities of the heaviest falls.

The perturbation of historical data also means that interannual variability is largely preserved (it is altered somewhat by interseasonal changes), so the underlying assumption is that the pattern of dry and wet years will not be greatly altered under climate change. (There is no compelling reason from the investigation of climate model data to either confirm or deny this). This is one reason why long time series of historical data are preferred, so that a reasonable sample of climate variability can be assessed for potential change.

8.2.5 Climate change and variability

The method of scenario application used in this study does not incorporate longer-term changes in climate variability that have been known to occur in the past, beyond those contained in the baseline data. Abrupt changes in rainfall regime affecting both means and variability are known to occur several decades apart but the dynamics of these changes are not well understood and as yet are unpredictable.

8.2.6 Hydrological uncertainties

Impact assessments using different hydrological models indicate that the models themselves may have varying sensitivity to climate change (e.g. Boorman and Sefton, 1987; Chiew *et al.*, 2003). Further work comparing the sensitivity of the Sacramento rainfall-runoff model used in IQQM to other commonly used Australian rainfall-runoff models which have been tested for their sensitivity, would help put the results provided here in a broader context.

8.3 SUMMARY OF RISK ANALYSIS

The methods and results described and presented in this report show that the potential of risk analysis to reduce uncertainty about future streamflow change is considerable. Despite large uncertainties in the spread of possible results, the further one looks into the future the more likely the range of results will be constrained. In terms of planning that takes account of those changes, it is possible to focus on the most likely outcomes, with a watching brief being held to ensure that climate change is not likely to shift outcomes beyond that range.

However, changes affecting water resources due to the greenhouse effect will not occur in isolation. Ongoing changes in climate variability over decadal scales, suggests a whole of climate approach needs to be taken. Non-climatic effects will also affect yield, for example: the development of farm dams, re-forestation and other forms of water harvesting.

Recommendations for further research include:

- Investigate the impact of changes in flow regime on land use change, water balance, sediment and nutrient loading and environmental indicators.
- Discussions with key river users to fully assess the impacts of the current study.
- Investigate modes of decadal rainfall variability for the region.
- Investigate the impacts of climate change that includes changes in rainfall intensity and wind.
- Add the latest 15 years of climate data to the IQQM input and conduct further analysis to bring the model and analysis up to date.
- Conduct further assessment of potential changes in wet-season rainfall, which is the largest driver of changes in water supply, to constrain uncertainties.
- Develop plans to ensure security to dry season water resources, including environmental flows, because of the likelihood of reduced dry season streamflow.
- Assess system vulnerability to water supply and quality to add context to projected changes in catchment water balance.
- Assess current water strategies in light of possible changes.

9 Presentations and publications

An abstract has been submitted for the International Grasslands and Rangeland Congress 2008 titled *Impacts of climate change on regulated and non-regulated water systems in Australia.*

10 Acknowledgements

This work was funded by the Australian Greenhouse Office. Dr Roger Jones provided the scaling factors for the GCM's and emissions scenarios. The Department of Primary Industries supported this project though most of its life before it was transferred to the Department of Natural Resources and Water. The Department of Natural Resources and Water provided the water models.

11 References

Boorman, D.B. and Sefton, C.E.M. (1997). Recognising the uncertainty in the quantification of the effects of climate change on hydrological response. *Climatic Change* 35 (4), 415-434.

Burnash, R.J.C., Ferral, R.L. and Maguire, R.A. (1973) A Generalised Streamflow Simulation System: Conceptual Models for Digital Computers. Joint Fed.-State River Forecast Cent., Sacramento, Calif.

Cai, W., Crimp, S., McInnes, K., Hunt, B., Suppiah, R., Collier, M., Elliott, T., Hennessy, K., Jones, R., Page, C. and Whetton P (2003). Climate change in Queensland under enhanced greenhouse conditions. Final Report 2003 (C/0708). CSIRO Atmospheric Research, Aspendale, VIC.

Chiew FHS, Zhou SL & McMahon TA (2003) Use of seasonal streamflow forecasts in water resources management. Journal of Hydrology, 270: 135-144.

Clifton, C. and Turner, C. (2005). Conceptual mapping workshop for the Queensland Murray-Darling Committee. Summary of workshop held in Toowoomba on 5th September 2005. Australian Greenhouse Office, Queensland Murray-Darling Committee, Sinclair Knight Merz.

Cooke, R. (1999). Border Rivers system: IQQM implementation - Calibration of MacIntyre Brook subsystem, NSW Department of Land and Water Conservation, Sydney.

CSIRO (2001). Climate Change Projections for Australia. Division of Atmospheric Research CSIRO, Aspendale.

Department of Land and Water Conservation (1995) Integrated Quantity-Quality Model (IQQM): User Manual

Durack, P., Jones, R., Page, C. and Ricketts, J. (2005). Climate change impacts on the water resources of the Fitzroy Basin. CSIRO Atmospheric Research and Qld Department of Natural Resources.

IPCC (2001) Technical Summary of the Working Group I Report, In: Houghton, J.T., Ding, Y., Griggs, D.J., Noguer, M., van der Linden, P.J., Dai, X., Maskell, K. and Johnson, C.A. (Eds) Climate Change 2001: The Scientific Basis. Cambridge University Press, UK, 881 pp

Howden, S.M., McKeon, G.M., Meinke, H., Entel, M., and Flood, N. (2001). Impacts of climate change and climate variability on the competitiveness of the wheat and beef cattle production in Emerald, north-east Australia. *Environment International* 27, 155-60.

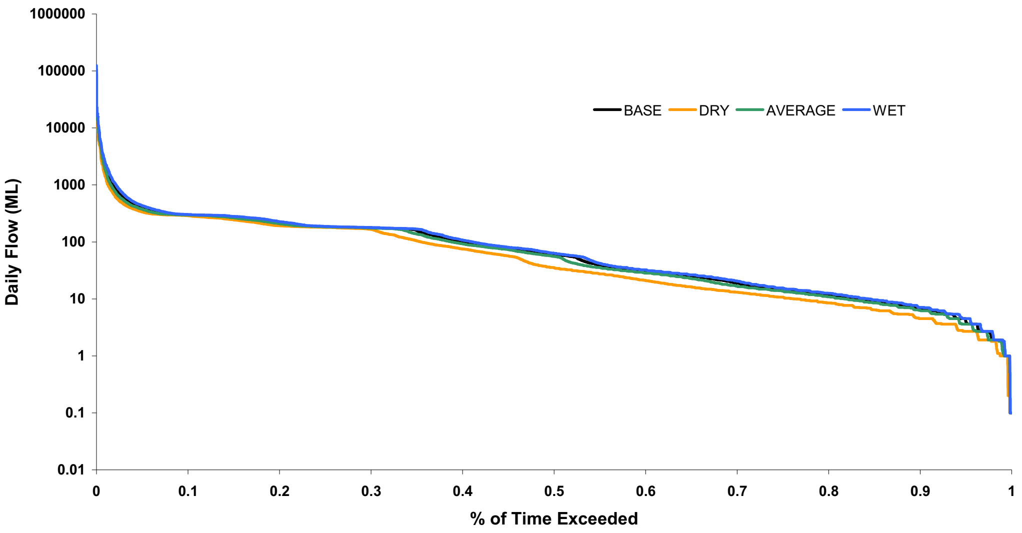
O'Neill, R., Rawson, D., Jones, R. and Page, C. (2003) Possible Impacts of Climate Change in the Namoi/Peel Valley. Published by the Surface and Groundwater Processes Unit, Centre for Natural Resources, New South Wales Department of Infrastructure, Planning and Natural Resources, Paramatta, NSW, 92

Nakicenovic, N., Davidson, O., Davis, G., Grubler, A., Kram, T., LebreLa Rovere, E., Metz, B., Morita, T., Pepper, W., Pitcher, H., Sankovski, A., Shukla, P., Swart, R., Watson, R and Dadi, Z. (2000). IPCC Special Report of Working Group III. Emissions Scenarios. WMO and UNEP.

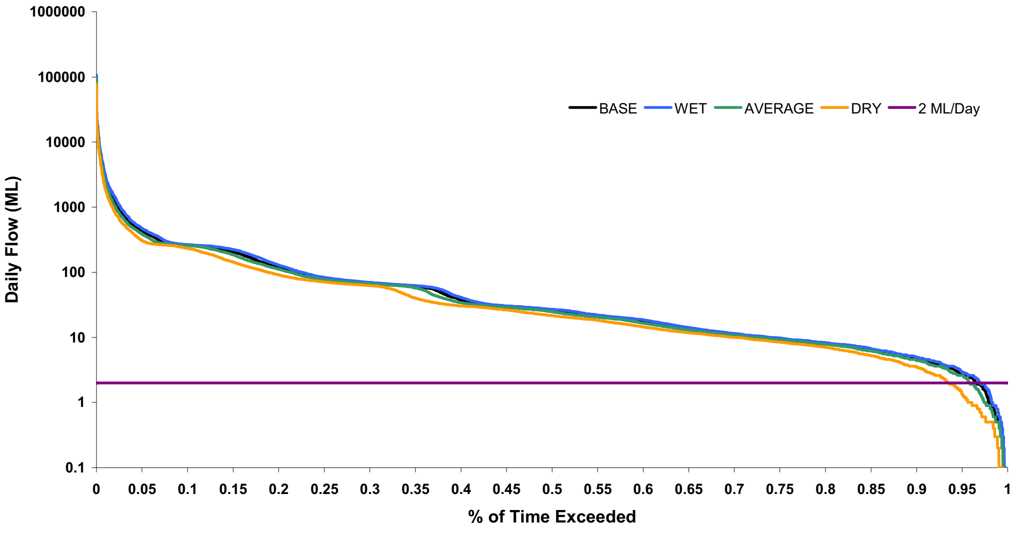
Perkins, I. and Clarkson, N. (2005). Climate change impacts and adaptations: Qld Murray Darling Basin. Report to Australian Greenhouse Office, Canberra.

12 Appendix 1 – Exceedance Curves for Daily Flows at Other Locations – MacIntyre Brook

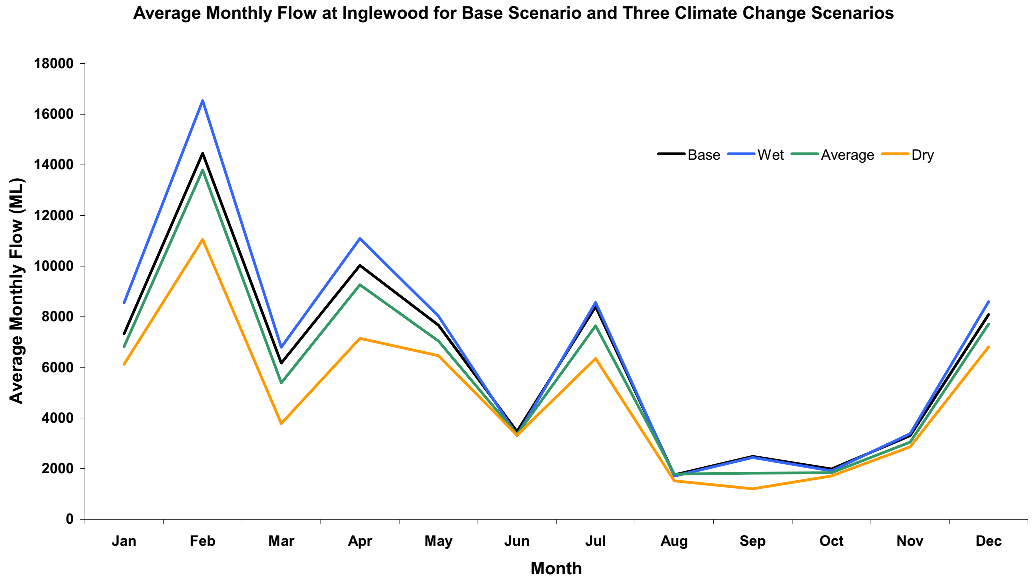
Daily Flow at Inglewood for Base Scenario and Three Climate Change Scenarios

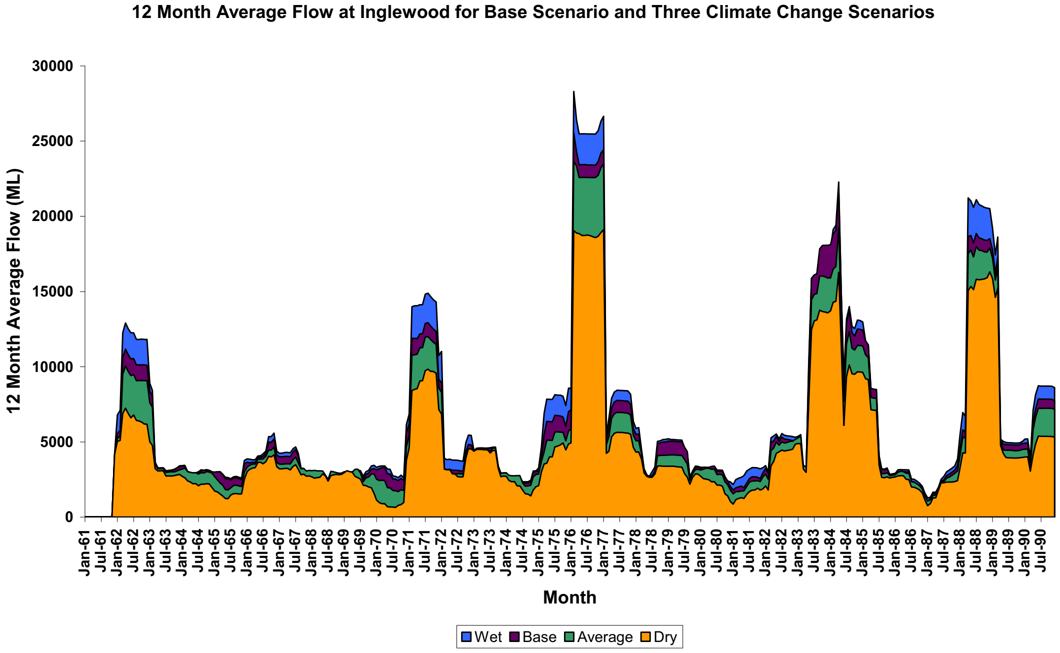


Daily Flow at Booba Sands for Base Scenario and Three Climate Change Scenarios

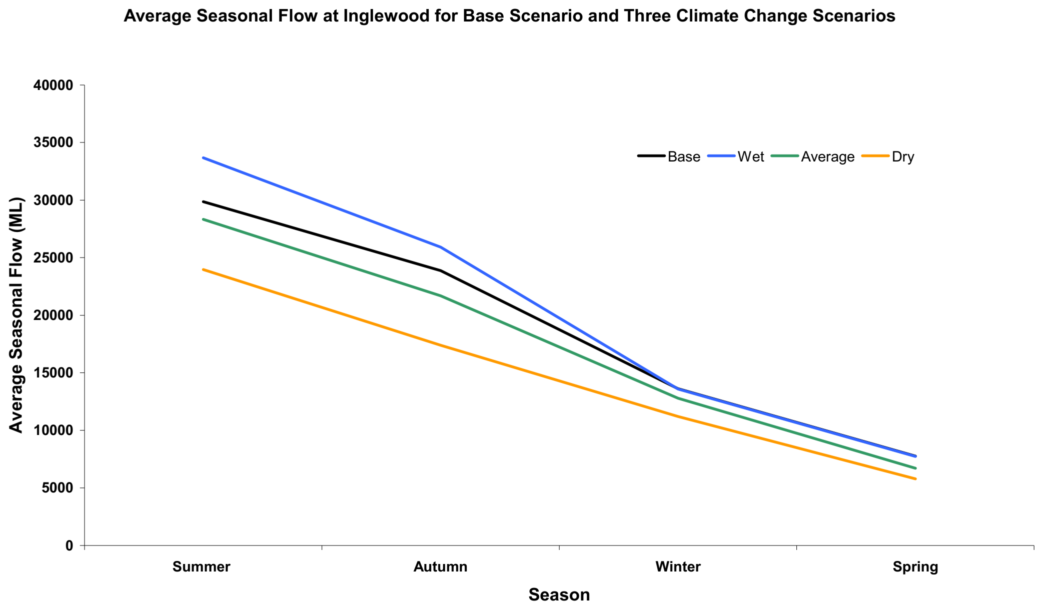


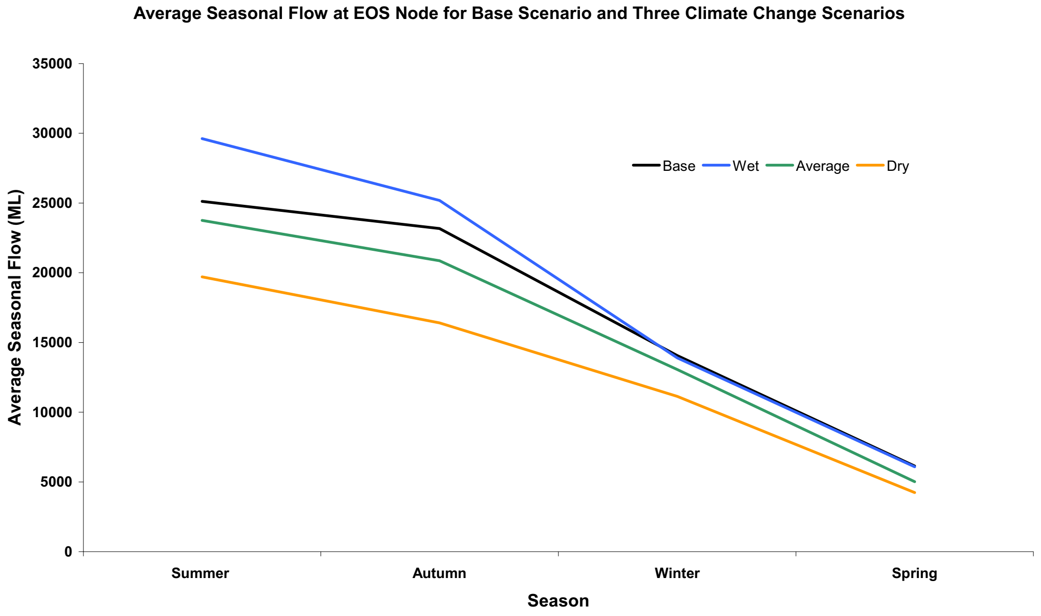
13 Appendix 2 – Average Monthly Flows at Other Locations – MacIntyre Brook



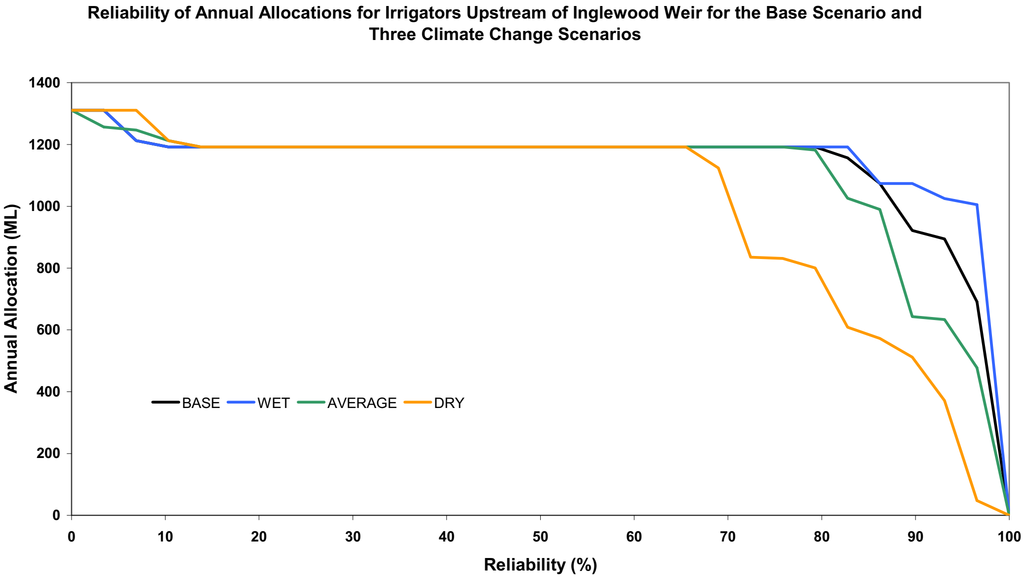


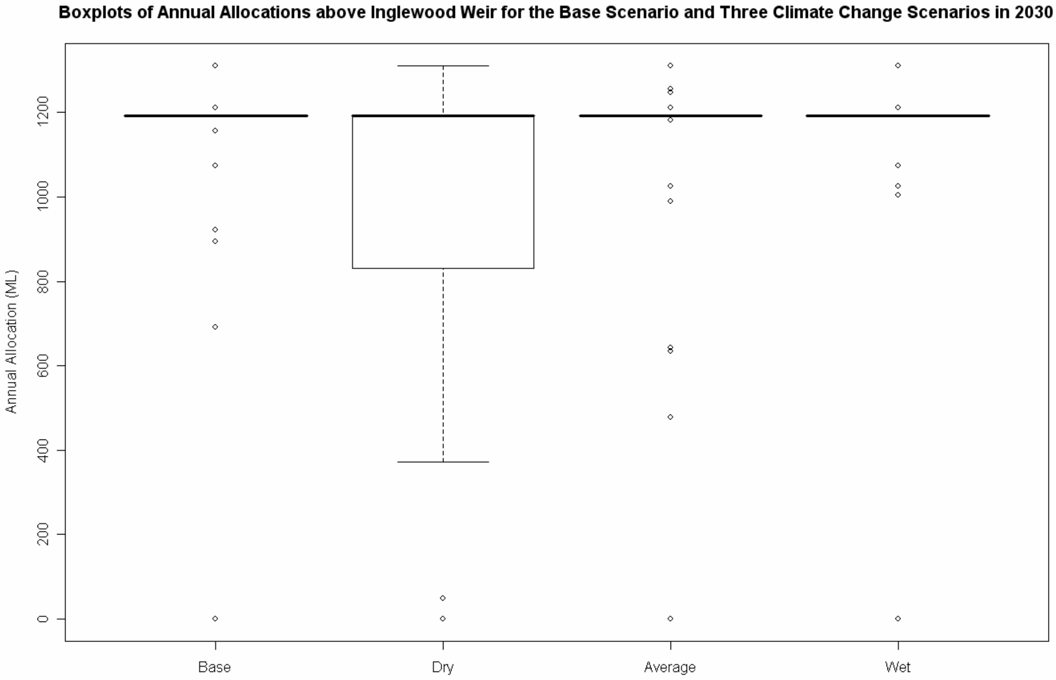
14 Appendix 3 – Average Seasonal Flows – MacIntyre Brook

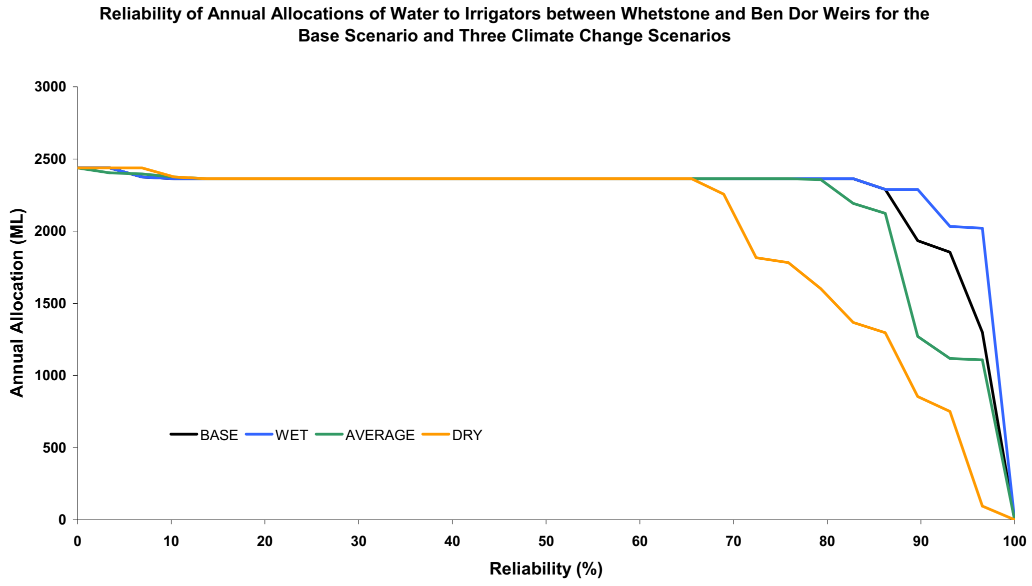


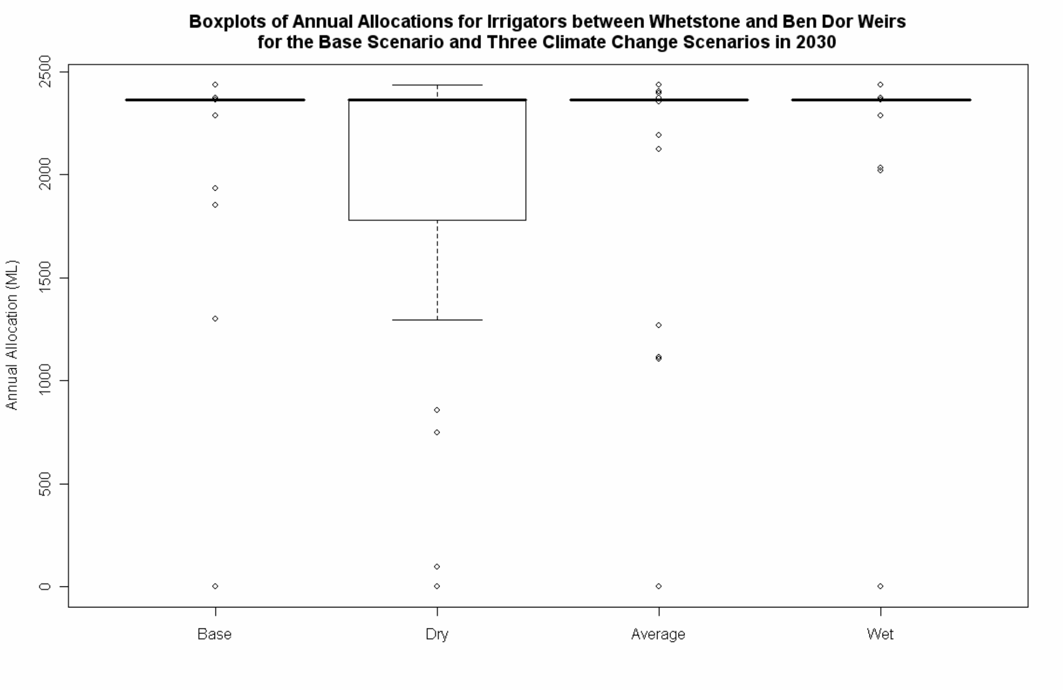


15 Appendix 4A - Annual On-Allocation for Irrigators – MacIntyre Brook

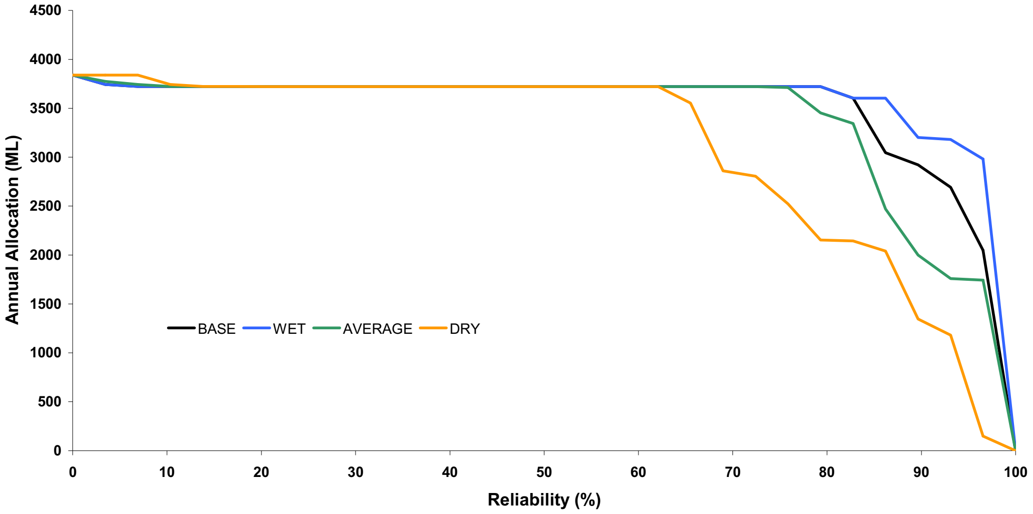




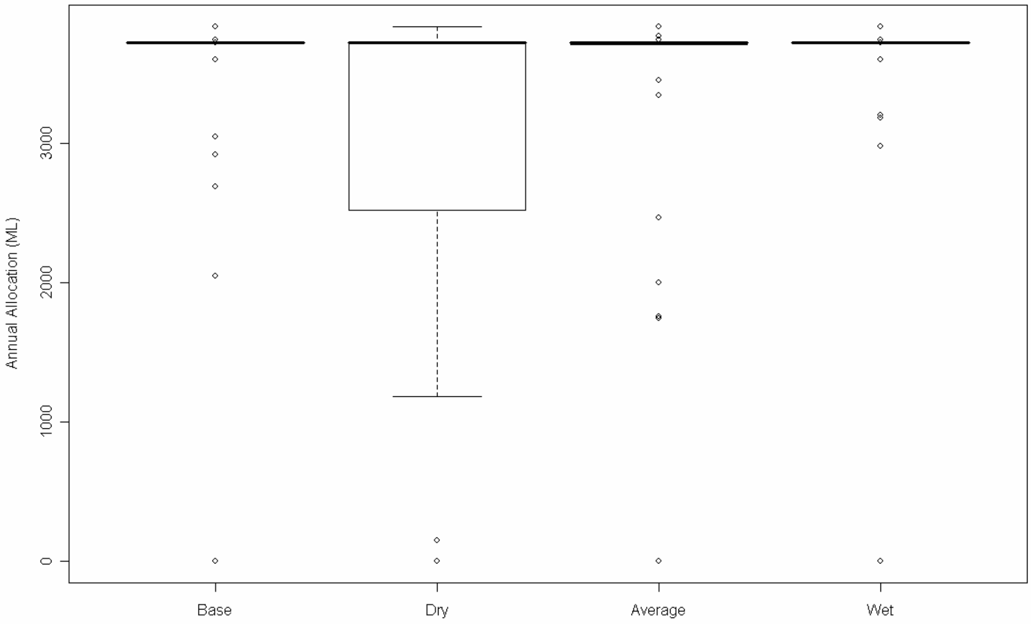

Reliability of Annual Allocations of Water to Irrigators between Whetstone and Ben Dor Weirs for the Base Scenario and Three Climate Change Scenarios
Annual Allocation (ML)
3000
2500
2000
1500
1000
500
0
BASE
WET
AVERAGE
DRY
0
10
20
30
40
50
60
70
80
90
100
Reliability (%)


Boxplots of Annual Allocations for Irrigators between Whetstone and Ben Dor Weirs for the Base Scenario and Three Climate Change Scenarios in 2030
Annual Allocation (ML)
2500
2000
1500
1000
500
0
Base
Dry
Average
Wet

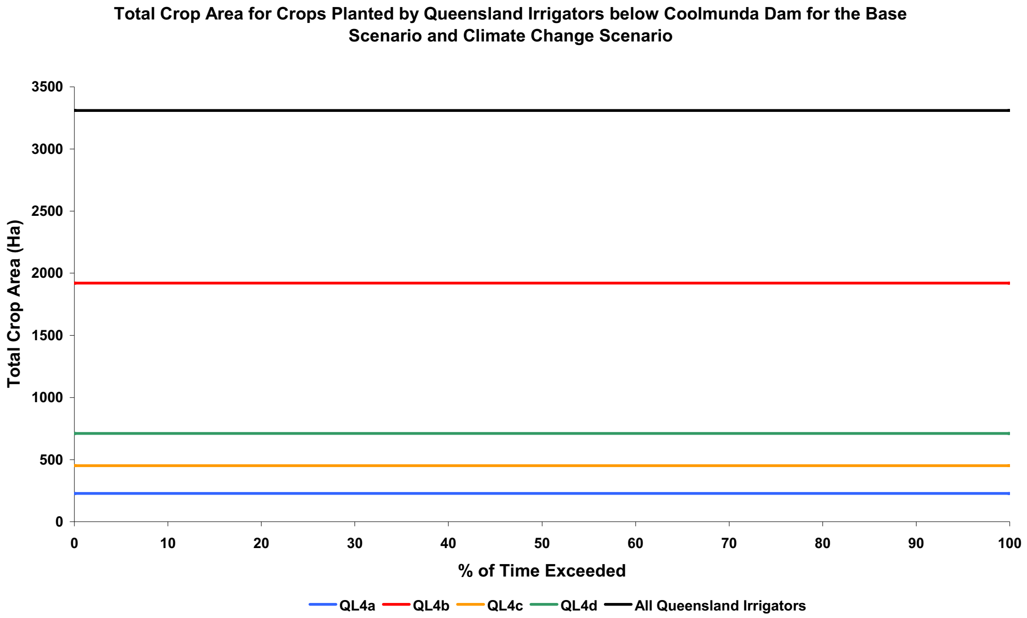
Reliability of Annual Allocations of Water for Irrigators between Ben Dor and Sunnygirl Weirs for the Base Scenario and Three Climate Change Scenarios



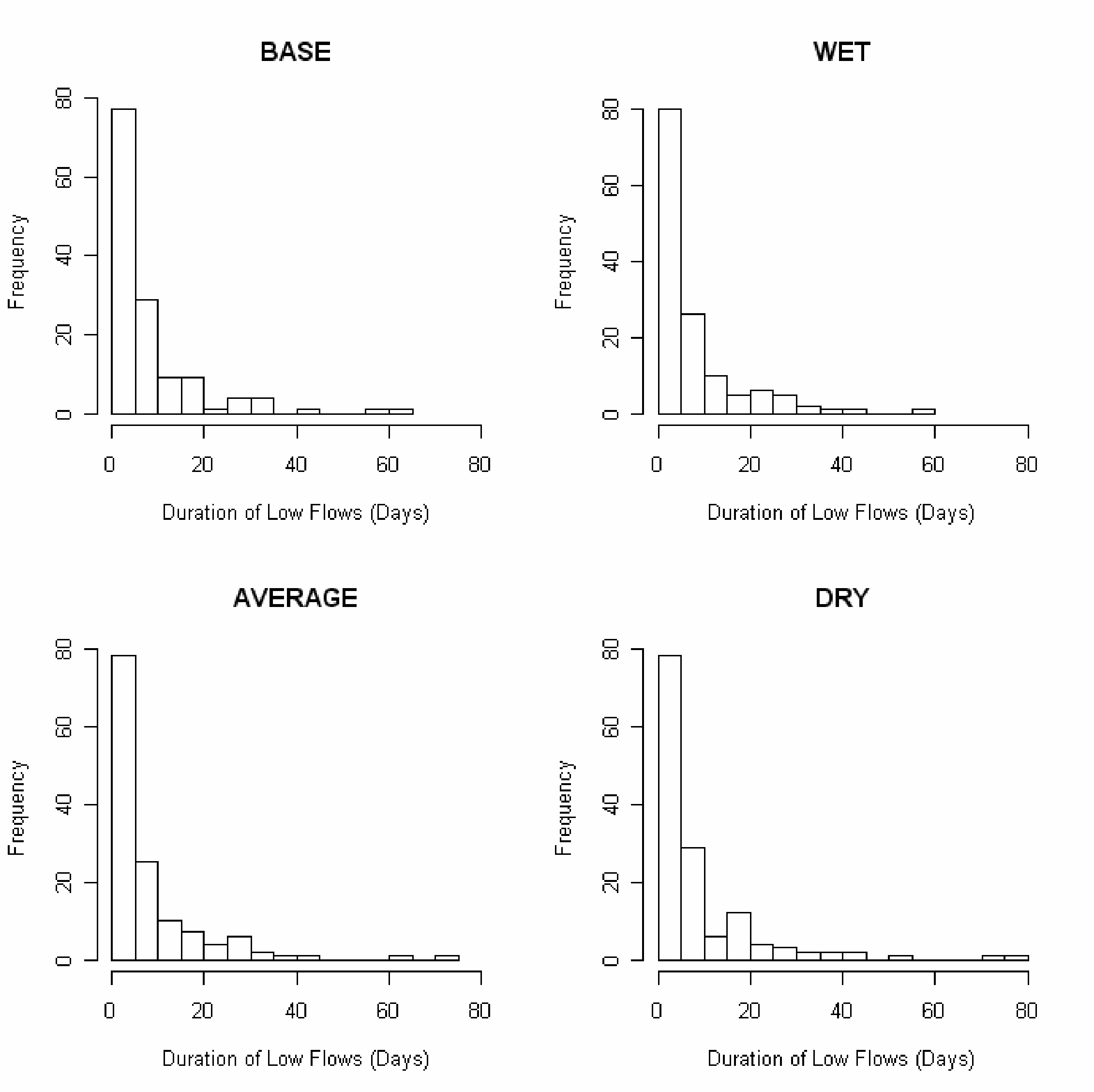
Boxplots of Annual Allocations for Irrigators between Ben Dor and Sunnygirl Weirs for the Base Scenario and Three Climate Change Scenarios in 2030



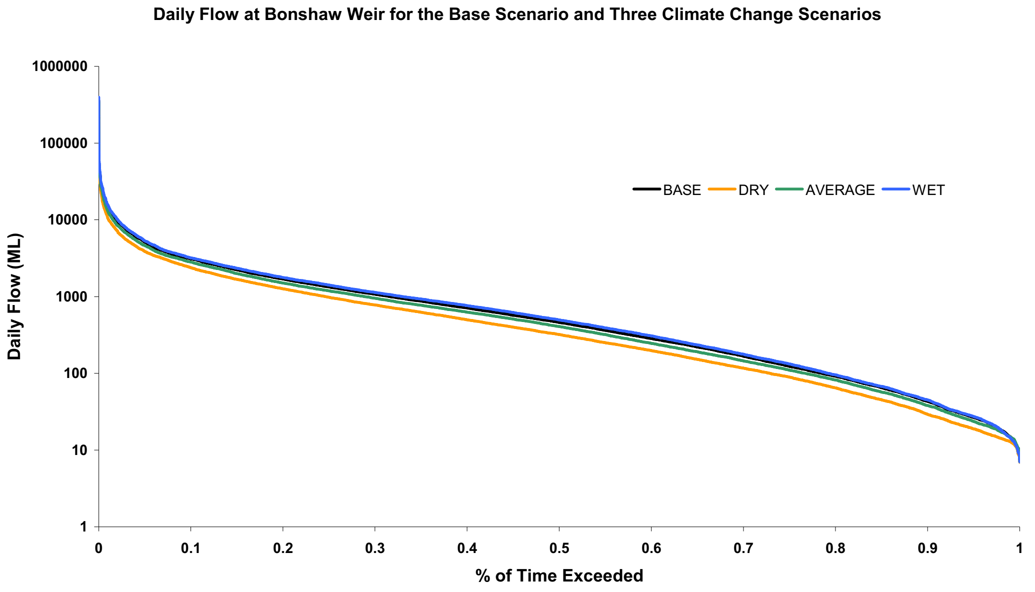
16 Appendix 4B – Total Crop Area for Crops Planted by Irrigators – MacIntyre Brook

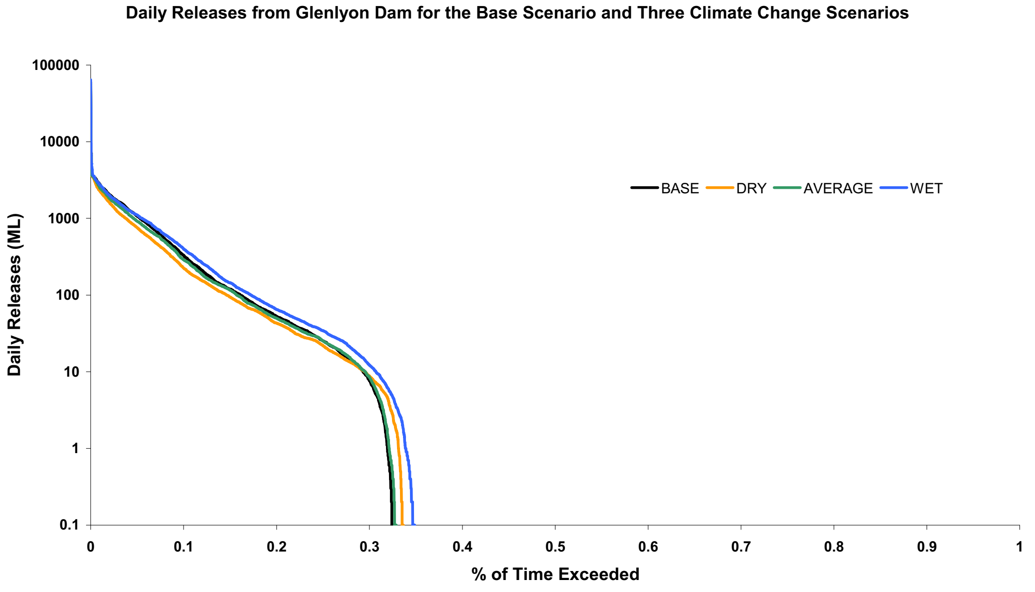


17 Appendix 5 – Frequency Plots of Low Flows – MacIntyre Brook

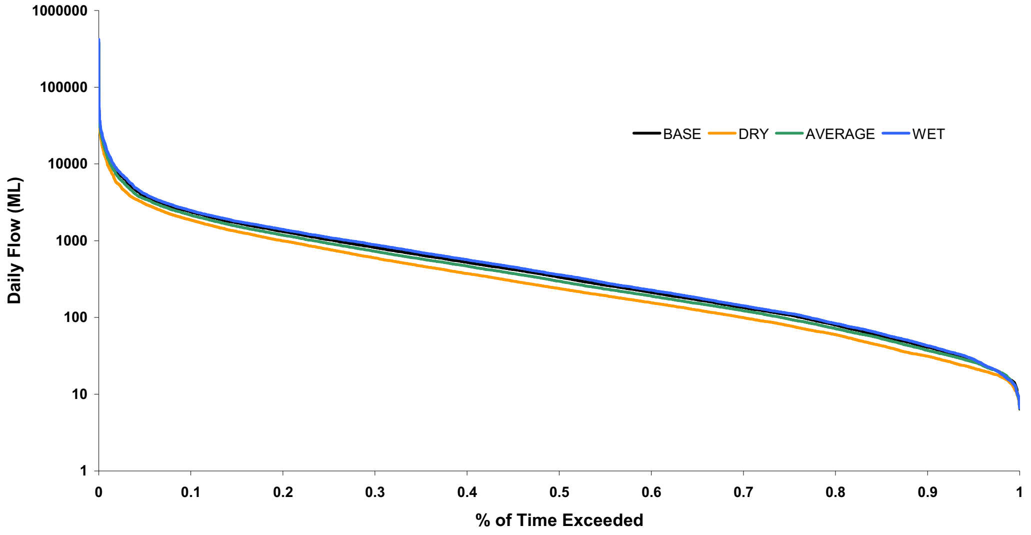


18 Appendix 6 – Exceedance Curves for Daily Flows at Other Locations - Dumaresq

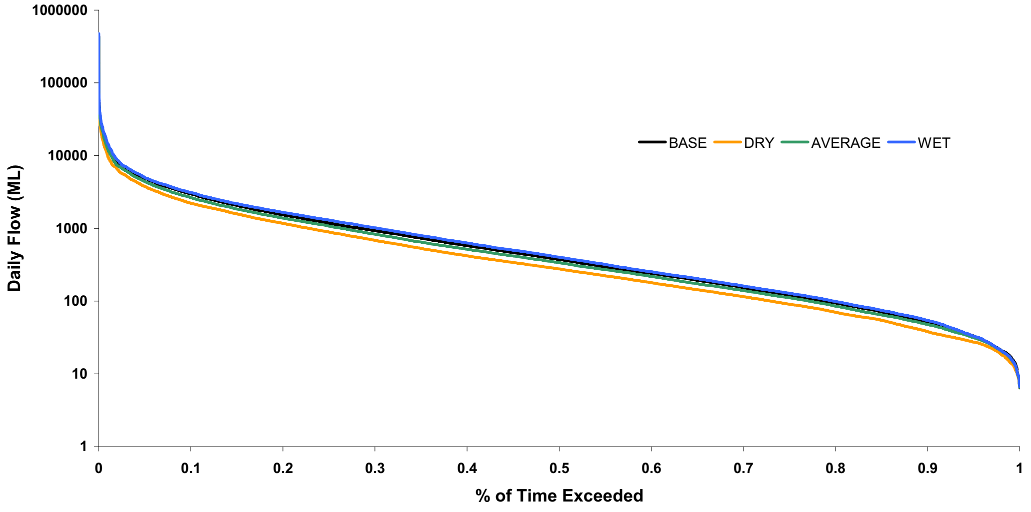




Daily Flow at Mingoola Gauge for the Base Scenario and Three Climate Change Scenarios

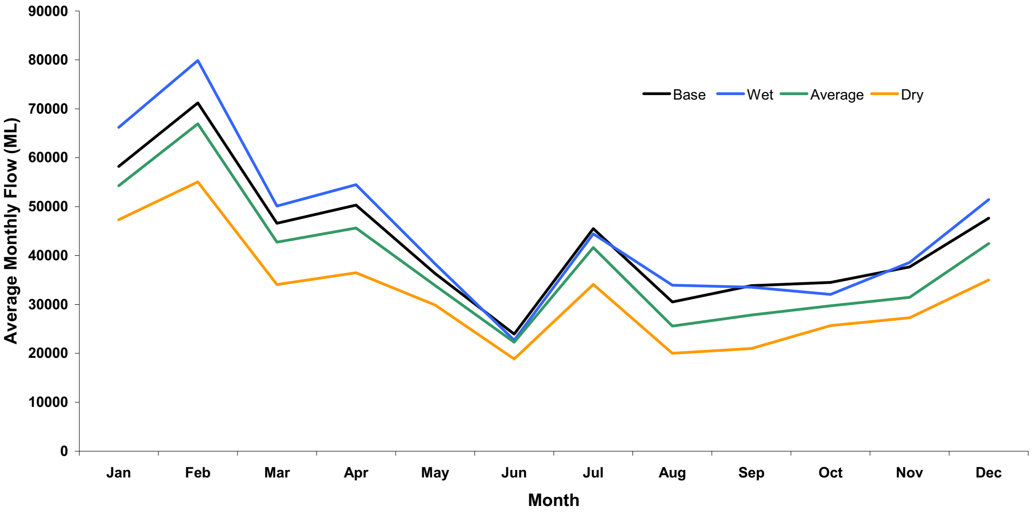


Total Daily Flow for Glenlyon Dam and Mingoola Gauge for the Base Scenario and Three Climate Change Scenarios

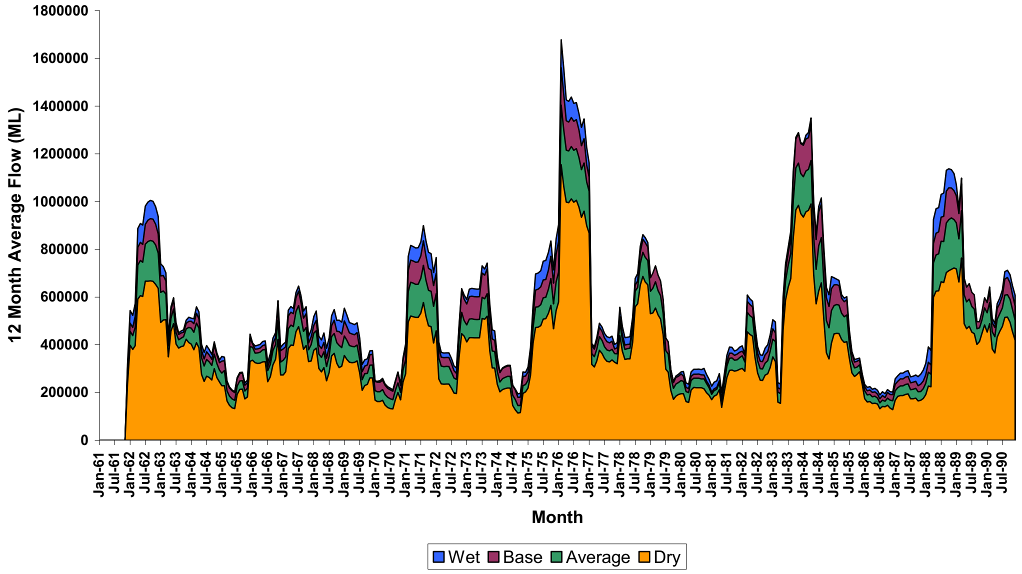


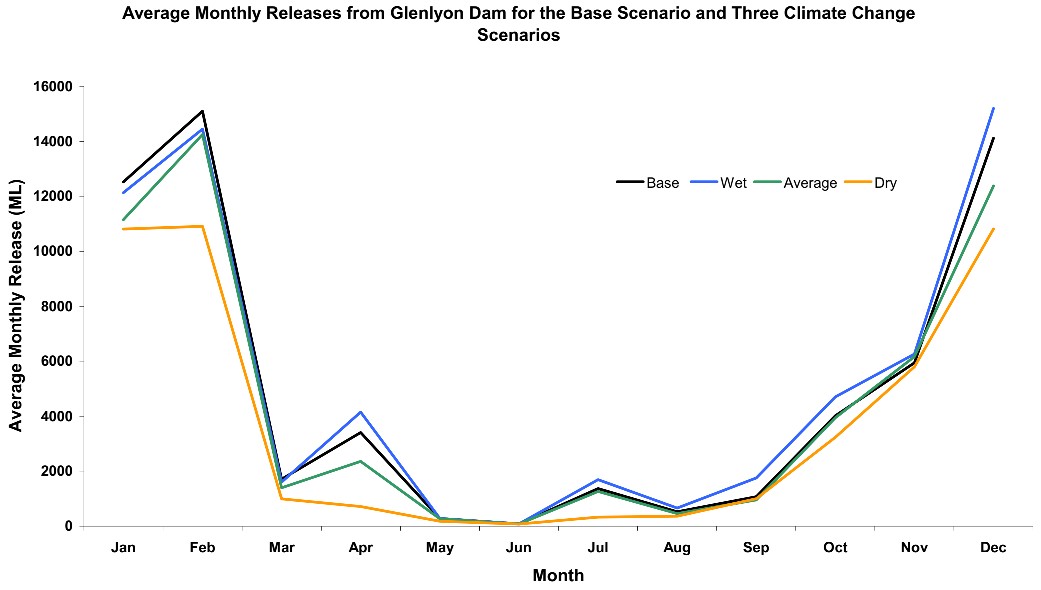
19 Appendix 7 – Average Monthly Flows at Other Locations - Dumaresq

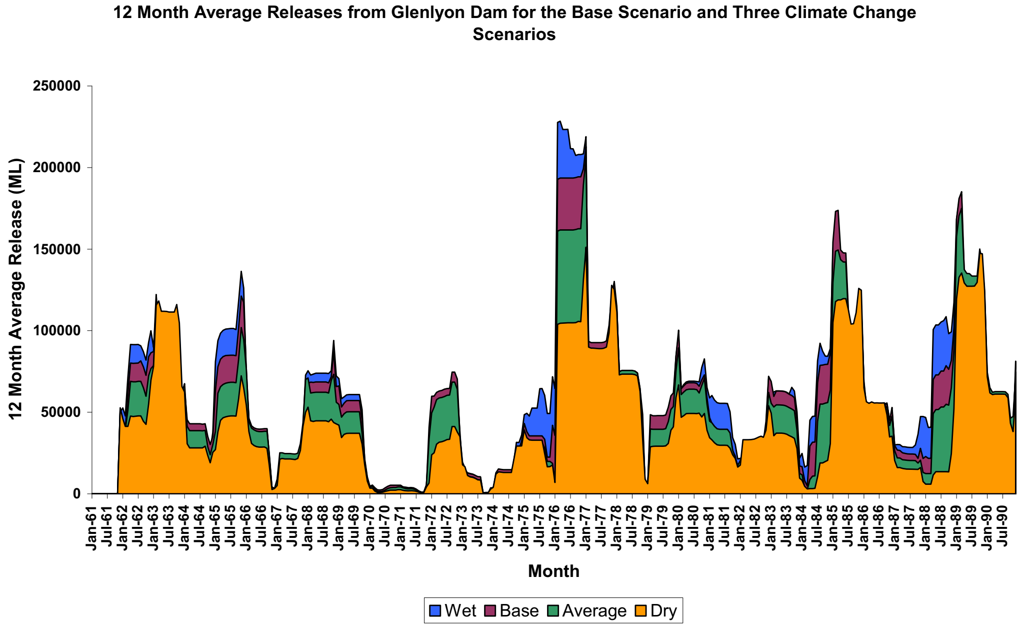
Average Monthly Flows at Bonshaw Weir for the Base Scenario and Three Climate Change Scenarios



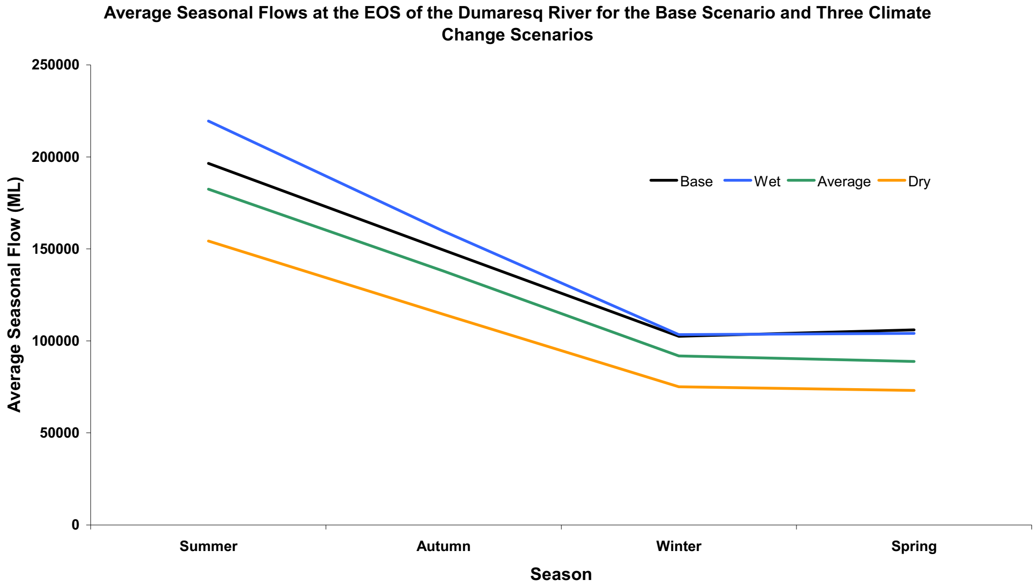
12 Month Average Flow at Bonshaw Weir for Base Scenario and Three Climate Change Scenarios

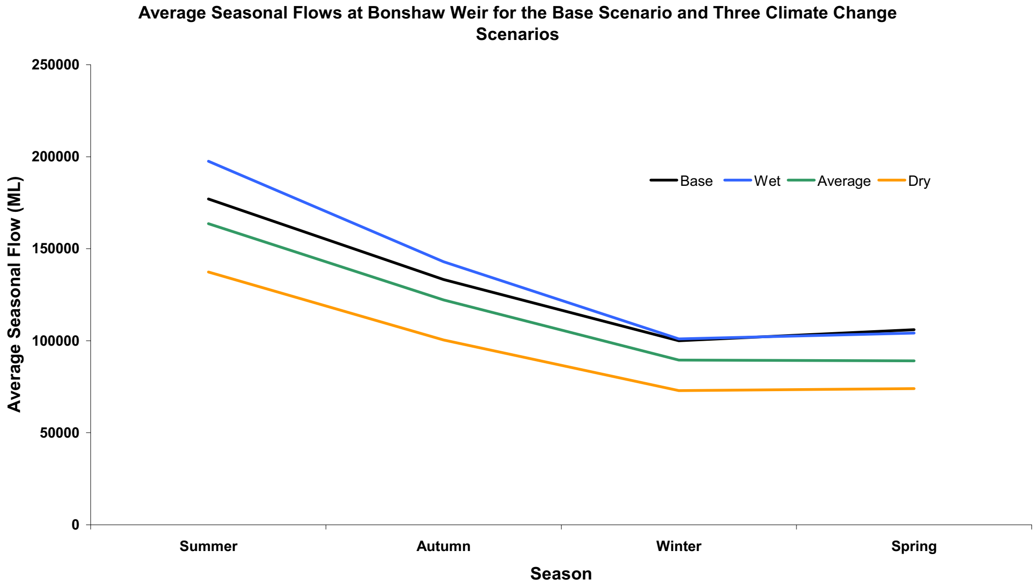


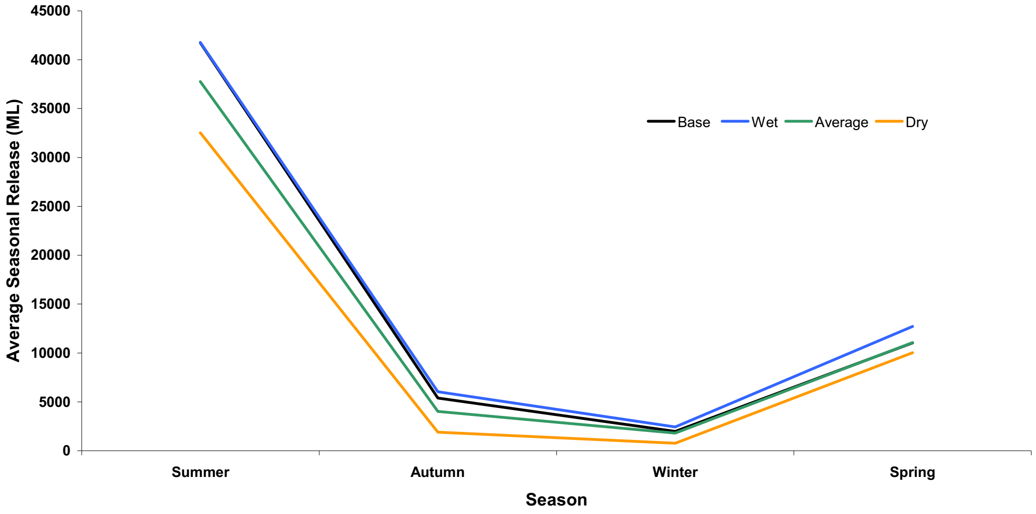

Average Monthly Releases from Glenlyon Dam for the Base Scenario and Three Climate Change Scenarios


12 Month Average Releases from Glenlyon Dam for the Base Scenario and Three Climate Change Scenarios

20 Appendix 8 – Average Seasonal Flows - Dumaresq

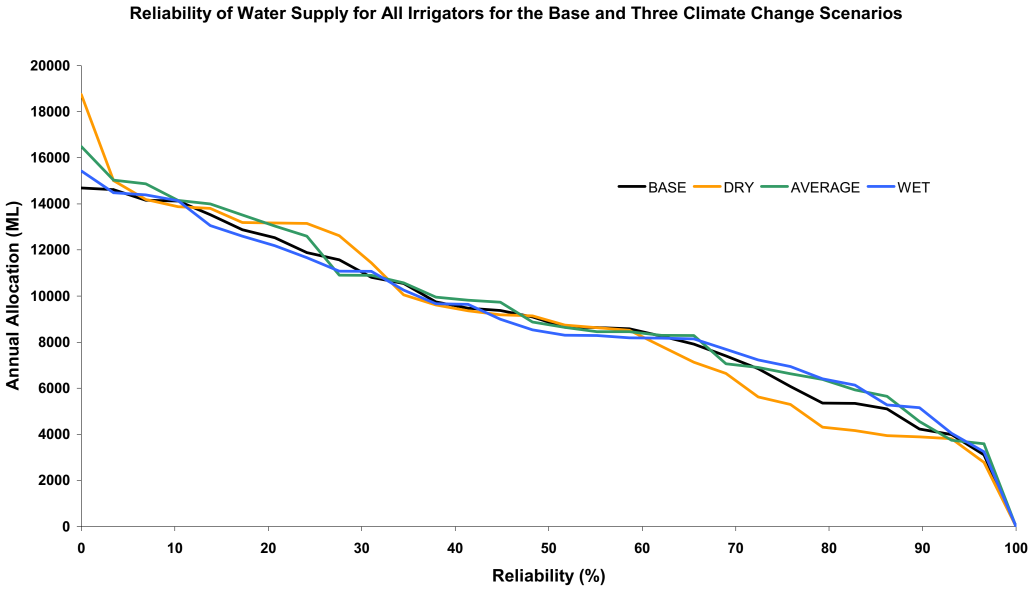


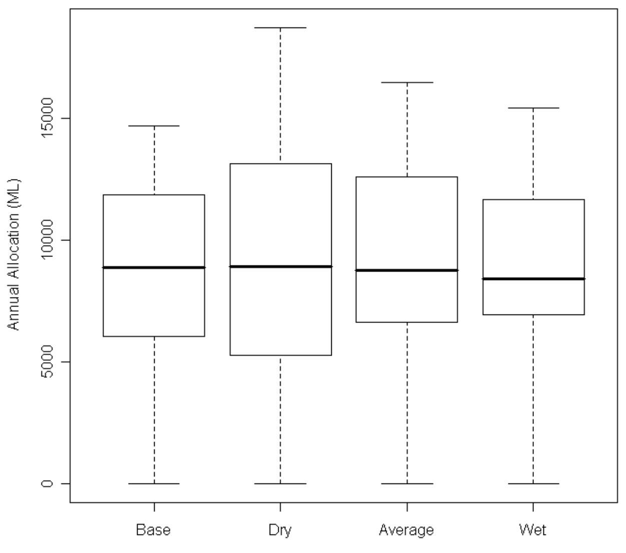




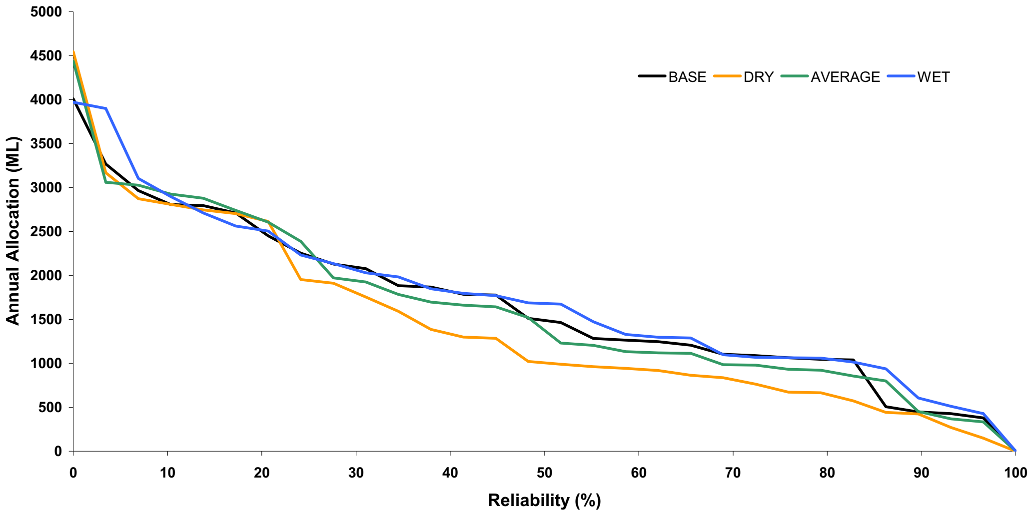
Average Seasonal Releases from Glenlyon Dam for the Base Scenario and Three Climate Change Scenarios

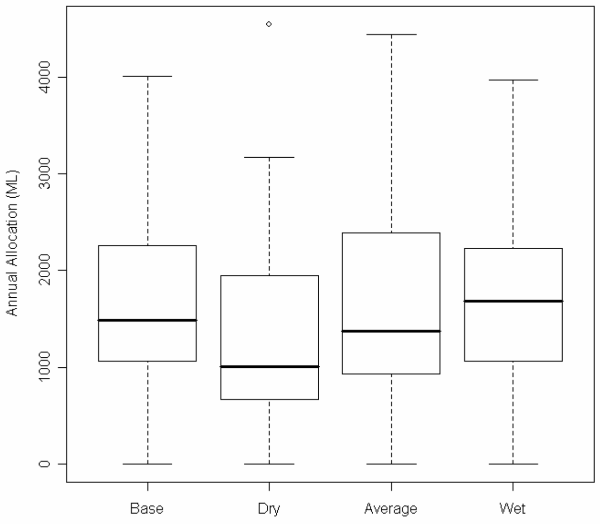
21 Appendix 9 - Annual On-Allocation for Irrigators - Dumaresq



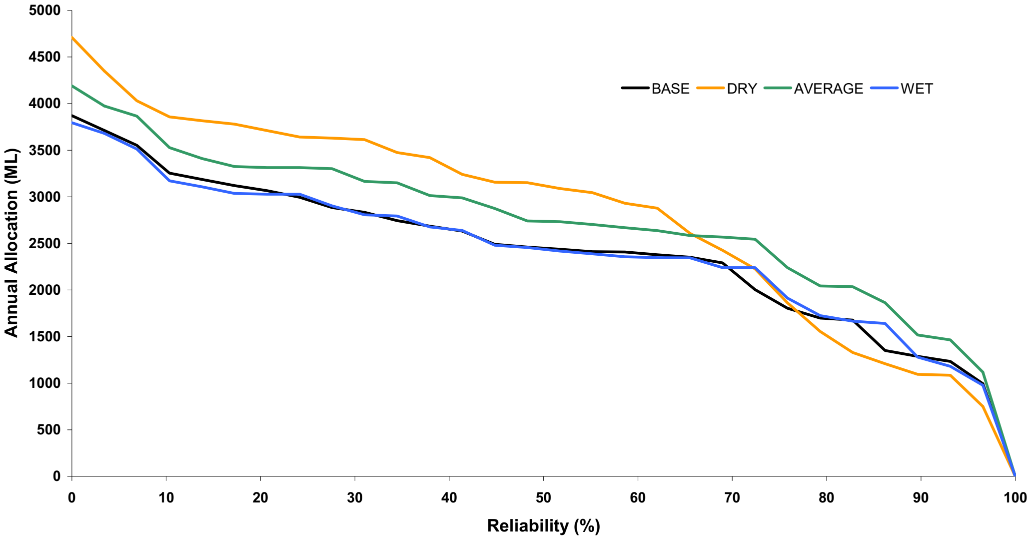


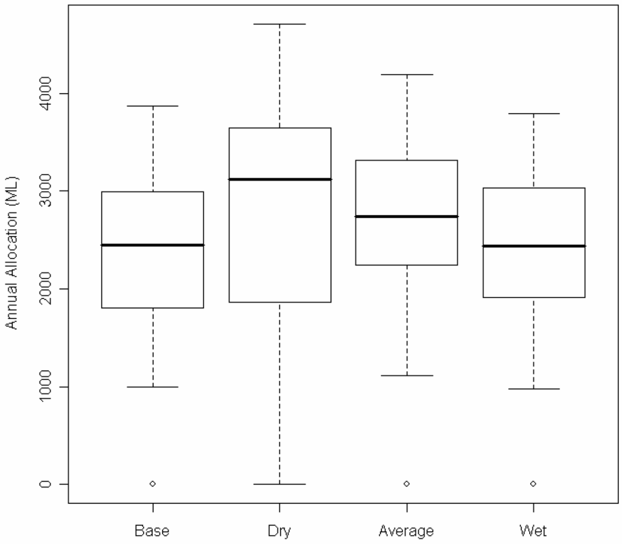
Reliability of Water Supply for Queensland Irrigators between Glenlyon Dam and Bonshaw Weir for the Base Scenario and Three Climate Change Scenarios

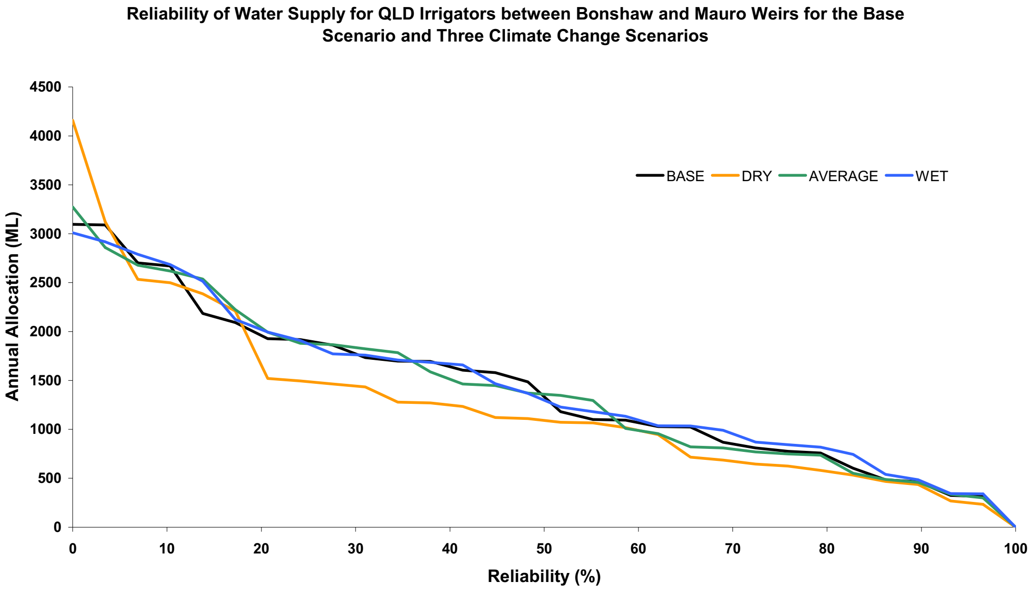




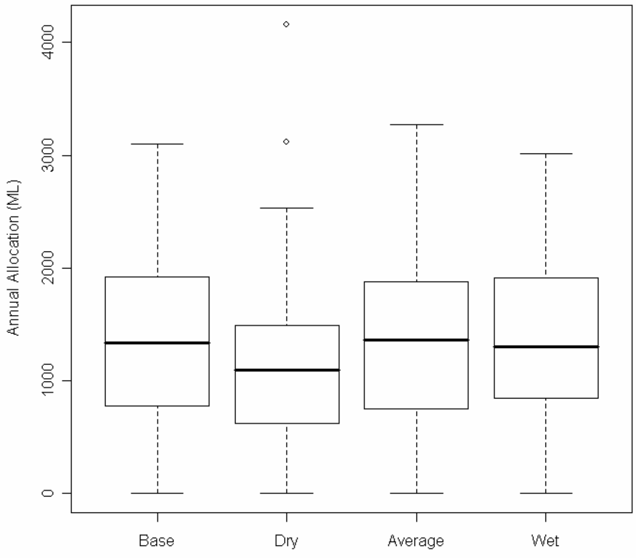
Reliability of Water Supply for NSW Irrigators between Glenlyon Dam and Bonshaw Weir for the Base Scenario and Three Climate Change Scenarios



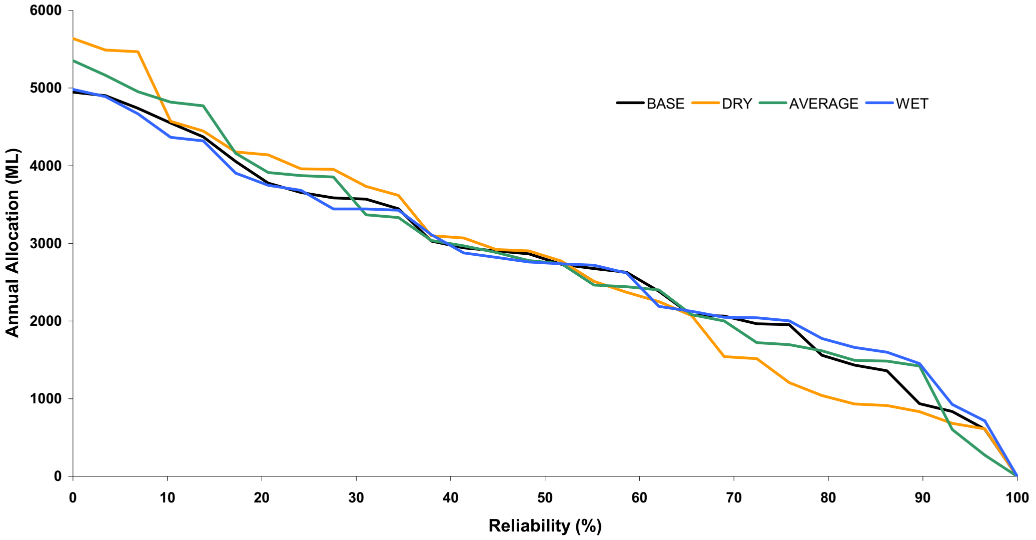


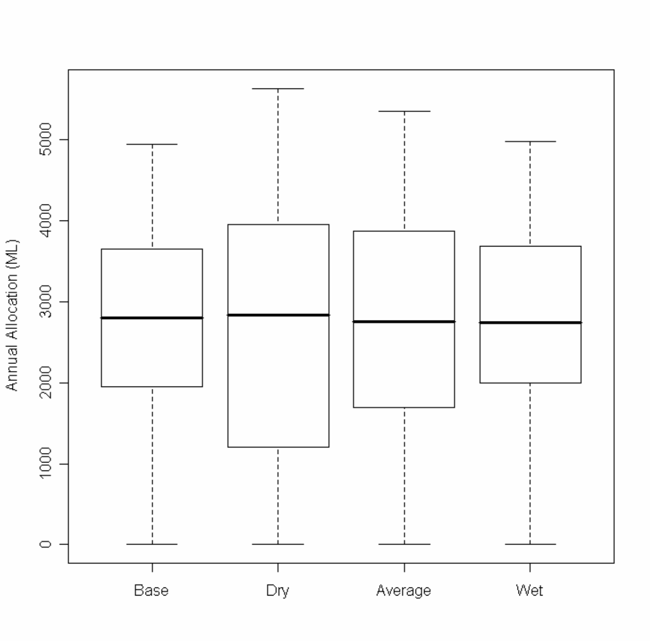


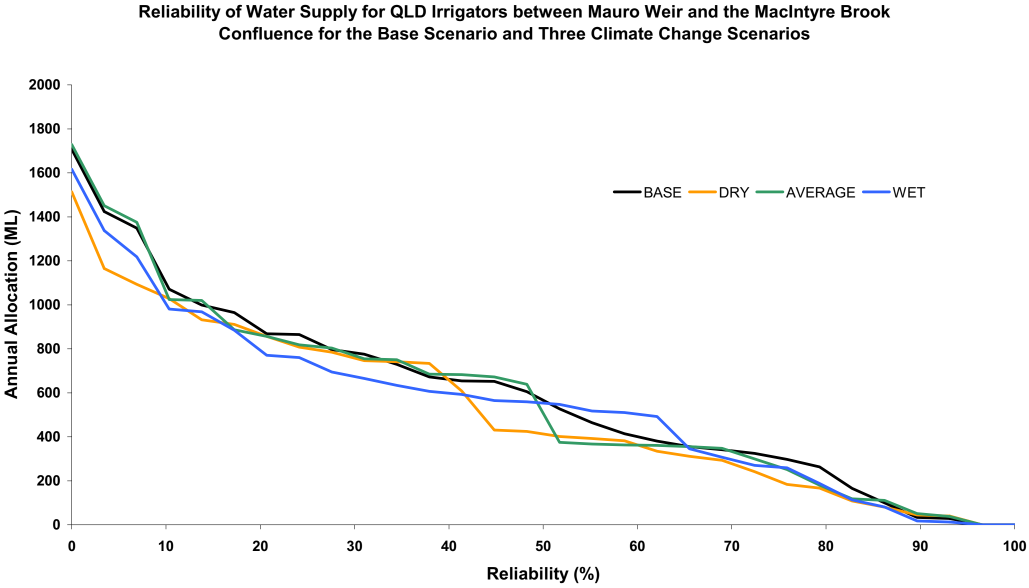
Reliability of Water Supply for QLD Irrigators between Bonshaw and Mauro Weirs for the Base Scenario and Three Climate Change Scenarios

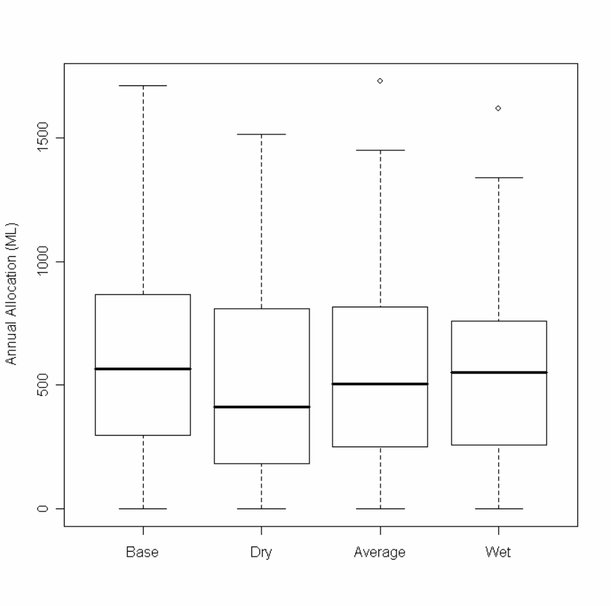


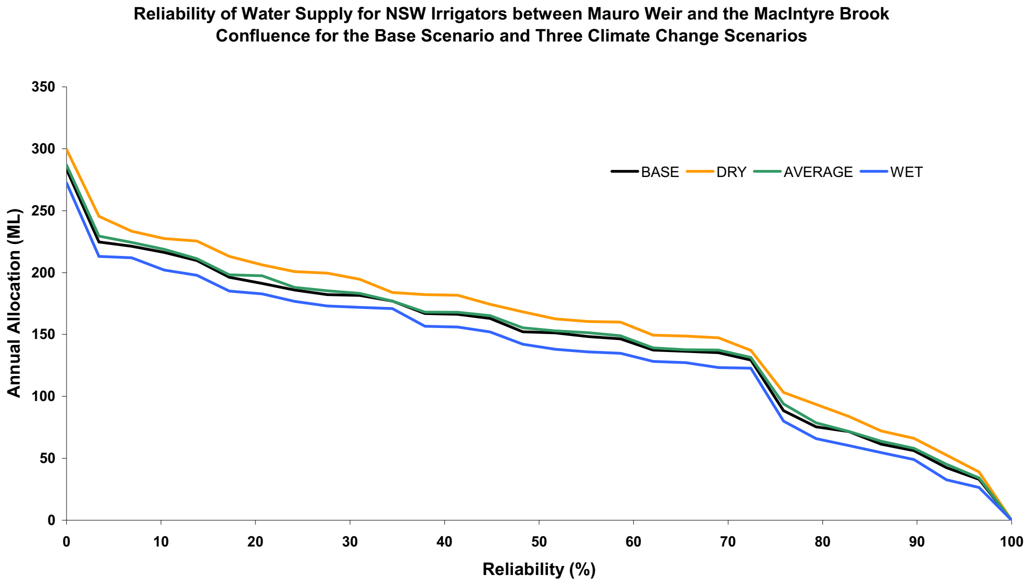
Reliability of Water Supply for NSW Irrigators between Bonshaw and Mauro Weirs for the Base Scenario and Three Climate Change Scenarios



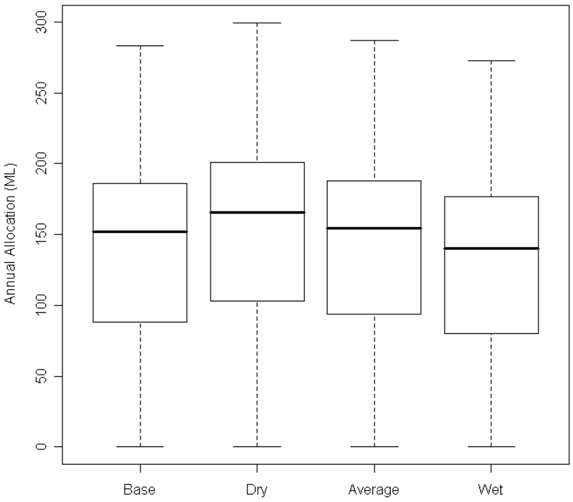



Reliability of Water Supply for QLD Irrigators between Mauro Weir and the MacIntyre Brook Confluence for the Base Scenario and Three Climate Change Scenarios
Annual Allocation (ML)
2000
1800
1600
1400
1200
1000
800
600
400
200
0
BASE
DRY
AVERAGE
WET
0
10
20
30
40
50
60
70
80
90
100
Reliability (%)

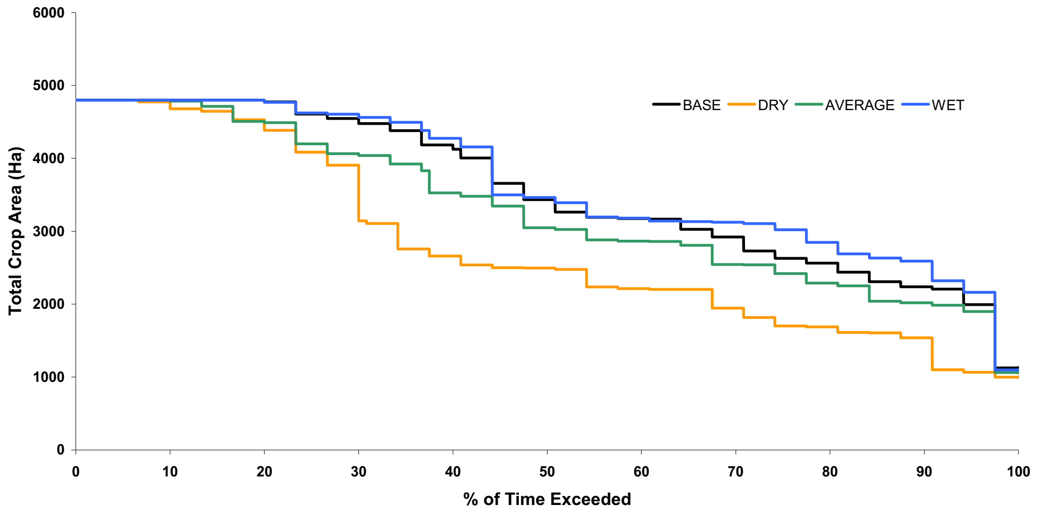

Annual Allocation (ML)
0
500
1000
1500
Base
Dry
Average
Wet



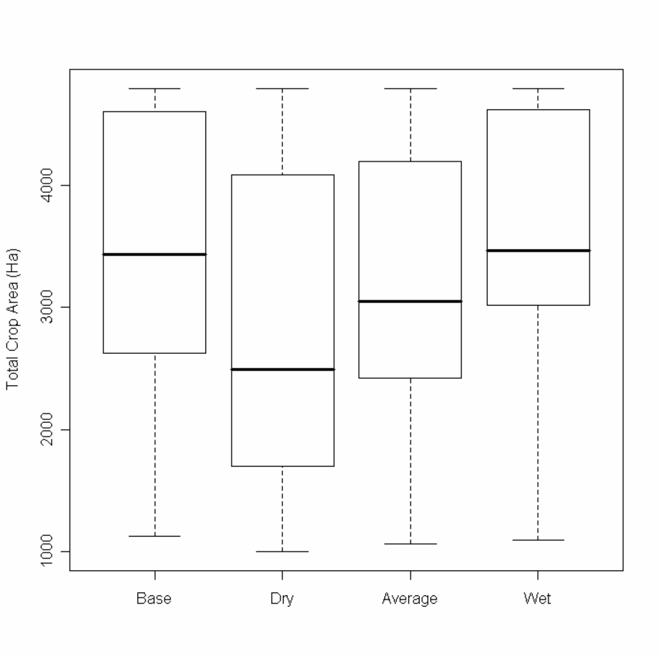
Reliability of Water Supply for NSW Irrigators between Mauro Weir and the MacIntyre Brook Confluence for the Base Scenario and Three Climate Change Scenarios

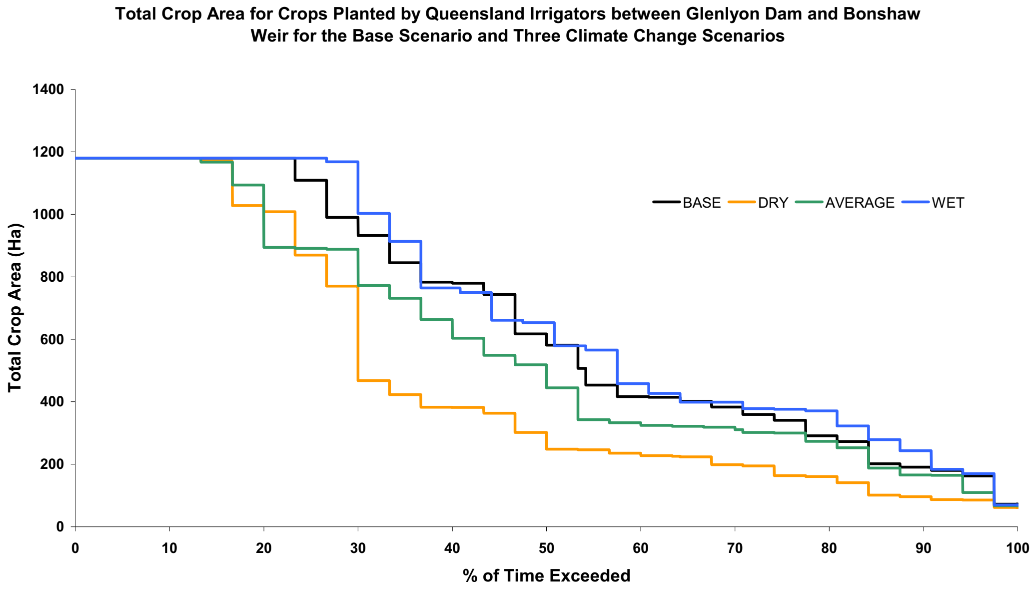


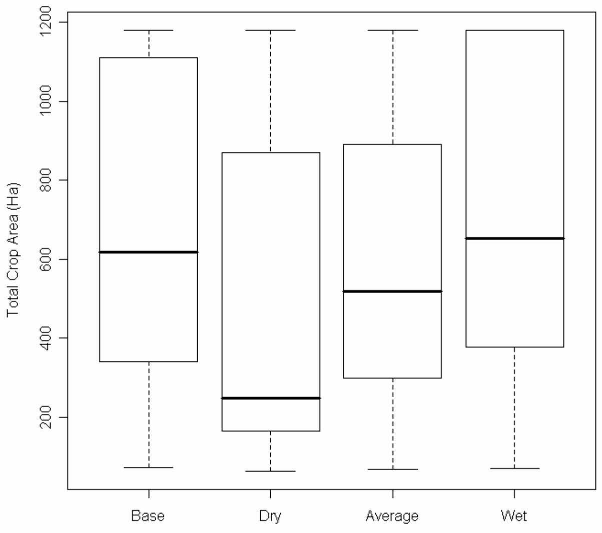
22 Appendix 10 – Total Area of Crops Planted by Irrigators – Dumaresq

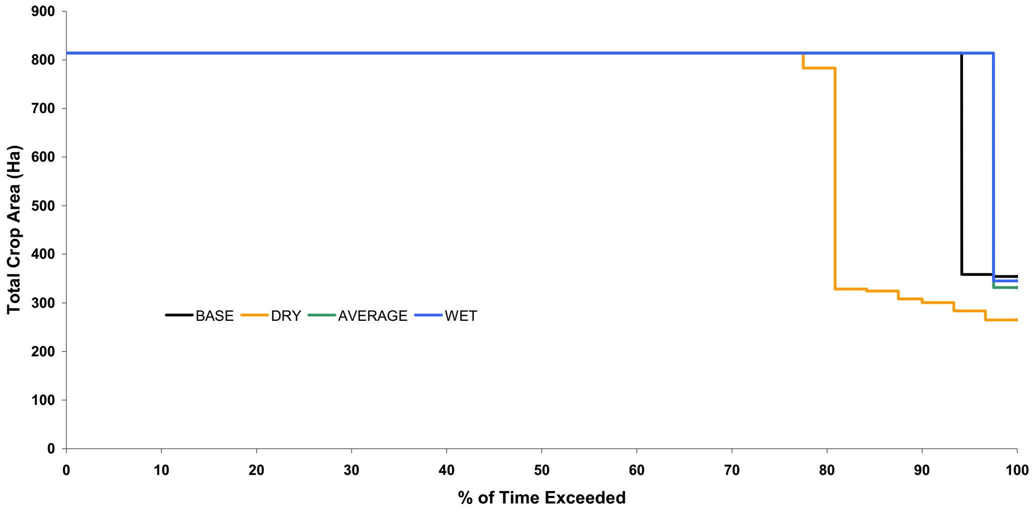


Total Crop Area for Crops Planted by all Irrigators for the Base Scenario and Three Climate Change Scenarios

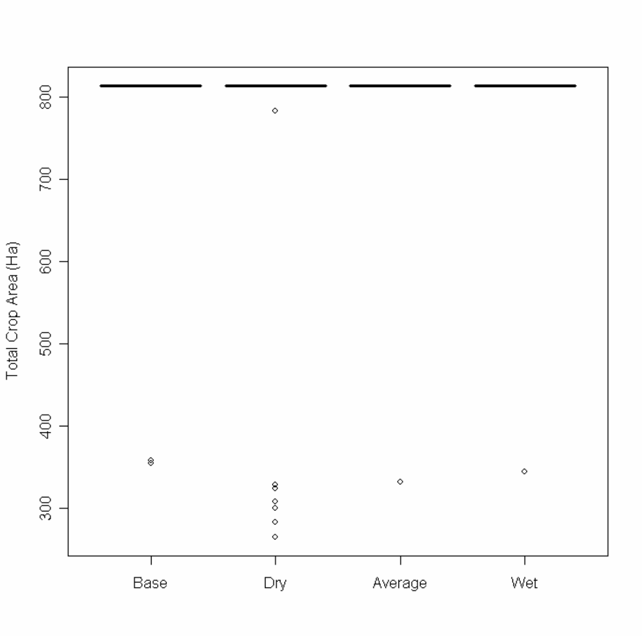



Total Crop Area for Crops Planted by Queensland Irrigators between Glenlyon Dam and Bonshaw Weir for the Base Scenario and Three Climate Change Scenarios

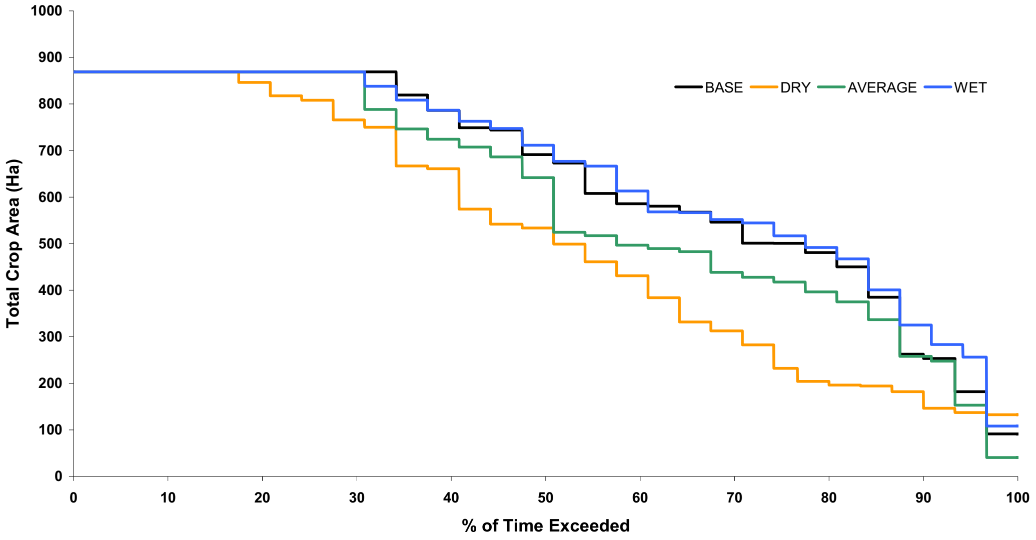


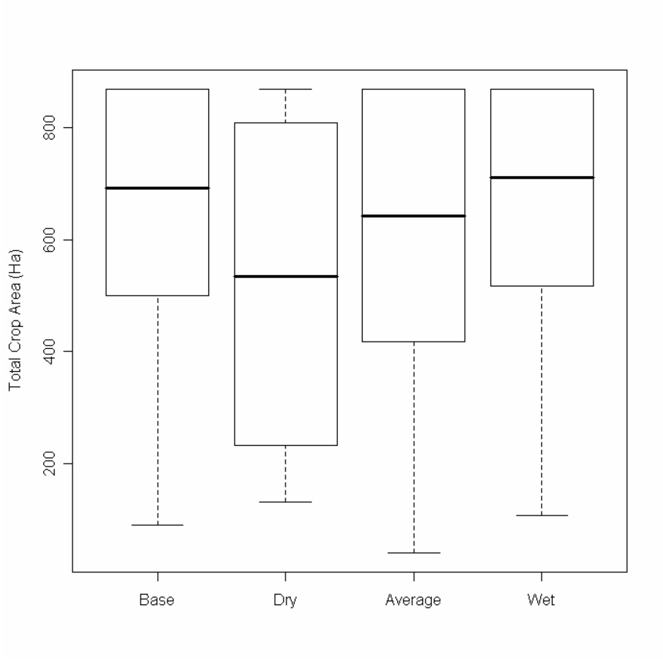


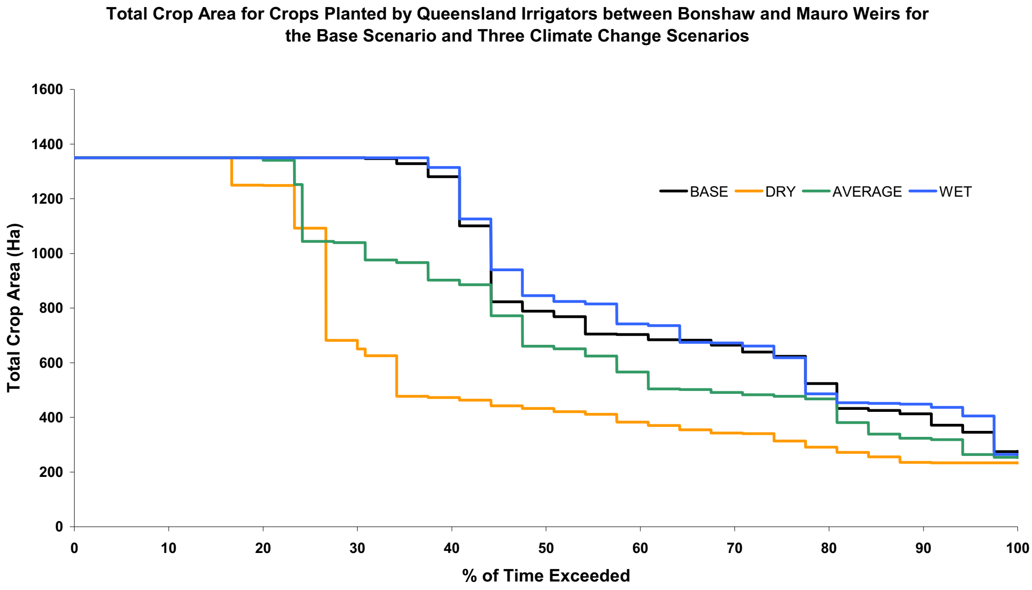
Total Crop Area for Crops Planted by NSW Irrigators between Glenlyon Dam and Bonshaw Weir for the Base Scenario and Three Climate Change Scenarios



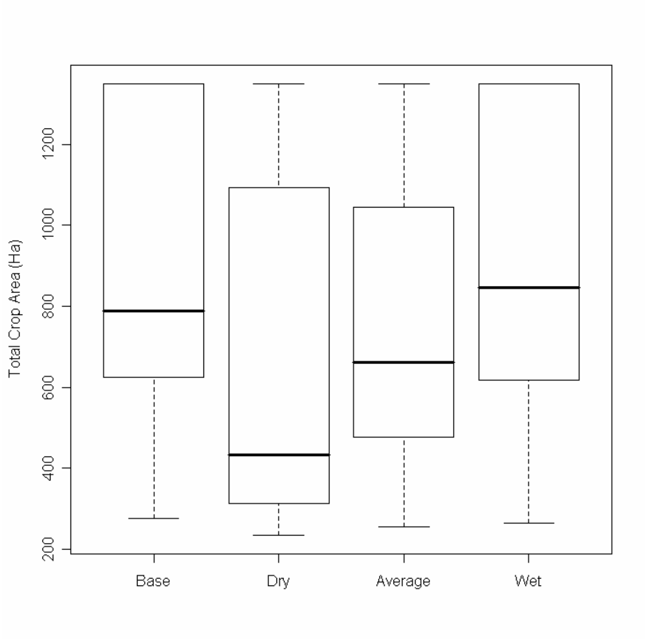
Total Crop Area for Crops Planted by NSW Irrigators between Bonshaw and Mauro Weirs for the Base Scenario and Three Climate Change Scenarios



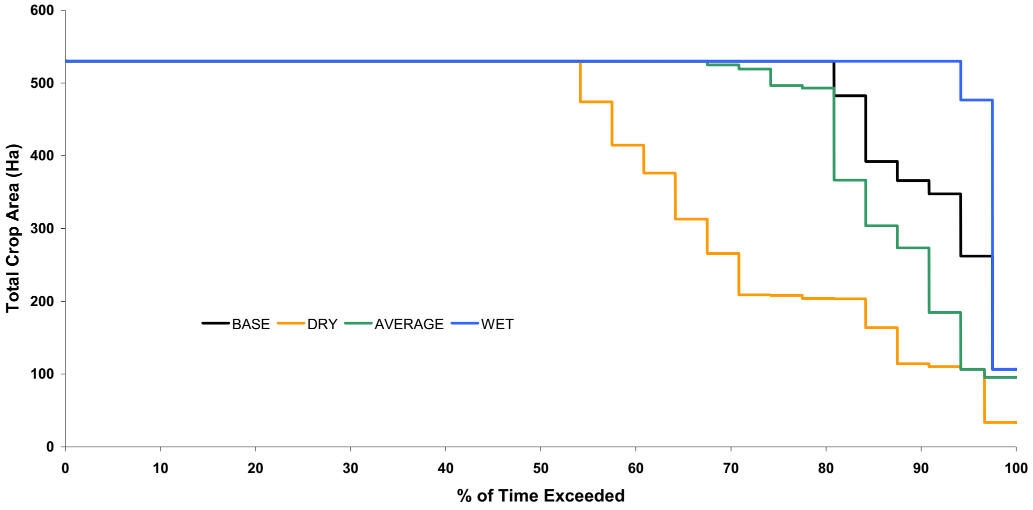


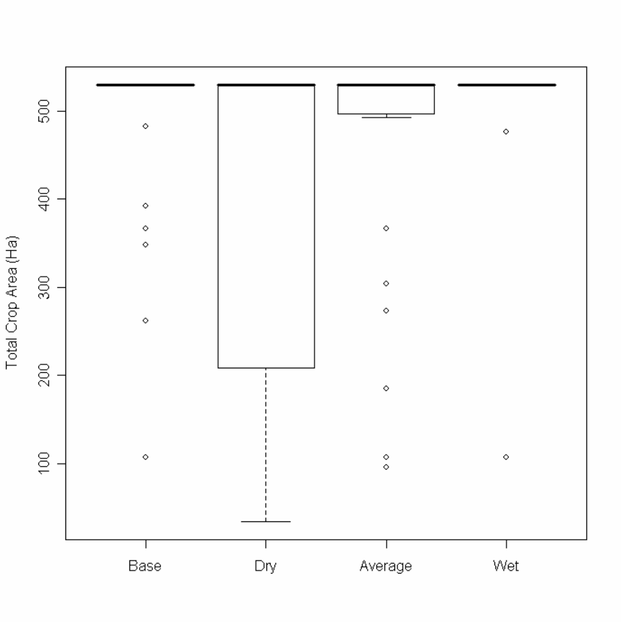


Total Crop Area for Crops Planted by Queensland Irrigators between Bonshaw and Mauro Weirs for the Base Scenario and Three Climate Change Scenarios

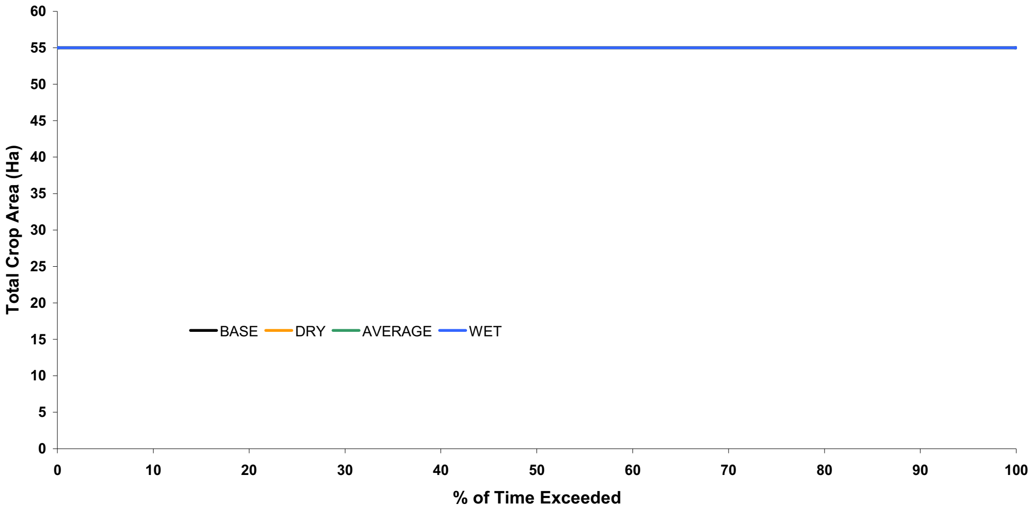


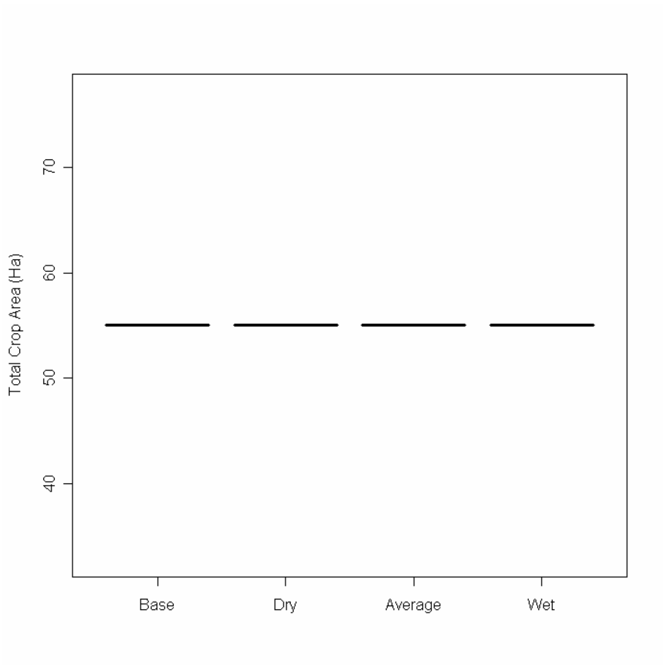
Total Crop Area for Crops Planted by Queensland Irrigators between Mauro Weir and the MacIntyre Brook Confluence for the Base Scenario and Three Climate Change Scenarios



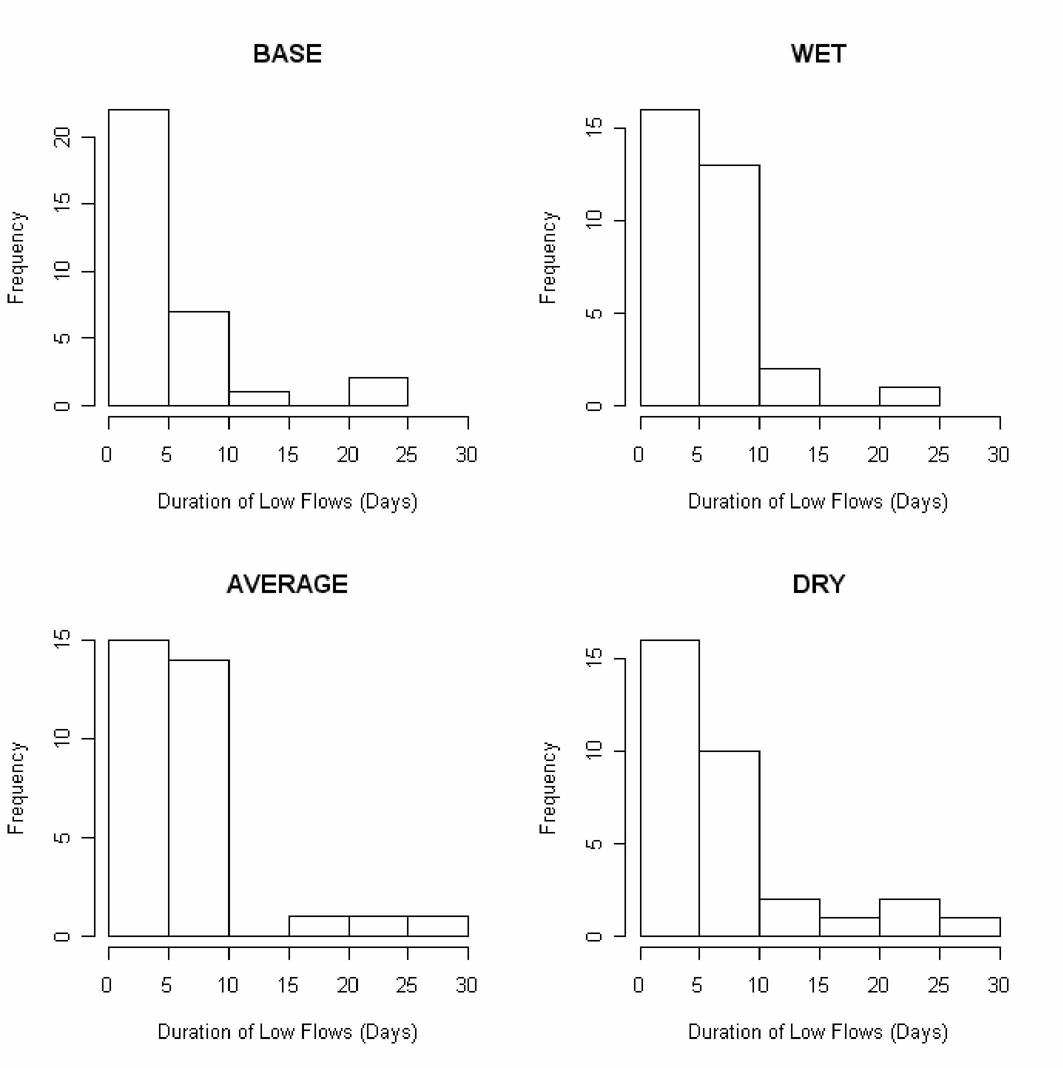


Total Crop Area for Crops Planted by NSW Irrigators between Mauro Weir and the MacIntyre Brook Confluence for the Base Scenario and Three Climate Change Scenarios





23 Appendix 11 – Frequency Plots of Low Flows - Dumaresq



24 Appendix 12 – Simulated flow for the MacIntyre Brook and Dumaresq River

Simulated daily 0 - 100 percentile flows for the base scenario and the dry, average and wet climate change scenarios for the MacIntyre Brook. Percentage change in flow from the base scenario is shown

		Flow (ML/d)			Change in flow (%)		
Percentile	**Base**	**Wet Scenario**	**Average Scenario**	**Dry Scenario**	**Wet Scenario**	**Average Scenario**	**Dry Scenario**
100	103300	114400	100100	80100	11	-3	-22
99	3200	3400	2800	2200	7	-12	-29
95	450	490	400	310	8	-11	-31
92	280	290	270	260	4	-3	-7
90	260	265	260	230	1	-2	-12
88	250	255	235	185	2	-5	-26
85	195	215	170	125	10	-13	-35
80	105	110	95	75	8	-8	-29
75	60	65	60	50	7	-4	-16
70	45	50	45	40	3	-5	-14
65	40	40	40	35	3	-4	-17
60	30	30	25	20	9	-16	-30
55	15	20	15	15	8	-5	-11
50	15	15	15	15	4	-3	-6
45	10	10	10	10	2	-3	-3
40	9	9	9	9	2	-1	-2
35	8	8	8	8	1	-1	-4
30	7	7	6	6	3	-2	-3
25	5	5	5	5	2	-2	-4
20	4	4	4	4	2	-2	-5
15	3	3	3	3	0	-3	-6
10	2	2	2	2	0	-5	-18
5	1	1	1	1	8	-8	-25
0	0	0	0	0	0	0	0

Simulated daily 0 – 100 percentile flows for the base scenario and the dry, average and wet climate change scenarios for the Dumaresq River. Percentage change in flow from the base scenario is shown

		Flow (ML/d)			Change in flow (%)		
Percentile	Base	Wet Scenario	Average Scenario	Dry Scenario	Wet Scenario	Average Scenario	Dry Scenario
100	261100	282000	252600	211100	8	-3	-19
99	18700	20000	17300	14600	7	-7	-22
95	5700	6000	5200	4300	5	-10	-25
92	3900	4100	3500	3000	5	-11	-24
90	3200	3400	2900	2400	5	-10	-24
88	2800	2900	2500	2100	4	-11	-25
85	2300	2400	2100	1700	5	-9	-25
80	1800	1800	1600	1300	5	-11	-27
75	1400	1400	1200	1000	6	-11	-26
70	1100	1200	1000	800	6	-11	-27
65	900	950	800	650	5	-11	-27
60	750	800	655	530	7	-12	-29
55	610	660	540	420	8	-12	-31
50	490	530	440	340	7	-11	-31
45	390	420	350	270	8	-11	-31
40	310	330	270	210	8	-12	-31
35	245	260	210	165	8	-14	-33
30	185	200	160	120	7	-15	-34
25	135	140	115	85	5	-16	-36
20	90	95	75	60	5	-14	-36
15	55	60	50	35	5	-13	-36
10	30	30	25	20	4	-14	-37
5	10	10	10	5	10	-14	-33
0	0	0	0	0	0	0	0