# Cotton Rivers and Climate Change

Prepared for:

## Cotton Research and Development Corporation

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# FINAL REPORT

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# Executive Summary

The *Cotton Rivers and Climate Change* project assesses the impacts of climate change on water resources in the Gwydir, Border and Condamine-Balonne River Systems of north-east NSW and southern Queensland. The project has been undertaken by Hassall & Associates, CSIRO Atmospheric Research, NSW Department of Land and Water Conservation (DLWC) and Queensland Department of Natural Resources and Mines (QNR&M). The project has been funded by the Cotton Research and Development Corporation, with in-kind contributions from DLWC and QNR&M.

Three climate scenarios have been generated for the year 2030: "base", "average" and "dry" scenarios. The scenarios represent plausible outcomes rather than predictions. The scenarios provide changes to rainfall and potential evaporation (predominately through temperature increases), at a regional scale. This modified climatic data is then used to assess the effects of projected climate change scenarios on streamflow and modified crop demand. The process used 1993/94 systems of allocating water between different users, including the allocations to the environment and diversions for irrigation.

The results for each of the three river systems are presented in Tables 1 to 3. Slightly different results are recorded depending on the nature of the system, and these include: inflow, reliability of allocation, irrigation diversions, water harvesting, wetland inflows and/or end of system flows. There are some minor rounding errors in the calculation of percentages.

**Table 1: Results for the Gwydir river system**

| | Base (no climate change) (GL) | Average Scenario (GL and %) | Dry Scenario (GL and %) |
|---|---|---|---|
| Average annual inflow – Copeton | 431 | 377 (87%) | 346 (80%) |
| Allocation reliability | | | |
| 100% | 25% | 20% | 17% |
| 60% | 45% | 37% | 30% |
| Annual average diversions | 339 | 321 (94%) | 304 (89%) |
| Annual average Gwydir Wetlands inflow | 238 | 209 | 187 |

**Table 2: Results for the Condamine-Balonne river system**

| | Base: Draft WAMP Scenario-A (GL) | Average (GL and %) | Dry (GL and %) |
|---|---|---|---|
| Average annual inflow – Leslie | 34 | 32 (94%) | 29 (86%) |
| Average annual inflow – Chinchilla | 387 | 363 (94%) | 327 (85%) |
| Average annual inflow –St George | 1164 | 1113 (96%) | 1028 (88%) |
| Average annual diversions - | | | |
| High Priority | 10.2 | 10.1 (99%) | 10.0 (98%) |
| Medium Priority | 82.8 | 80.9 (98%) | 77.8 (94%) |
| Average annual water harvesting: downstream of Beardmore | 335 | 322 (96%) | 304 (91%) |

## Table 3: Results for the Border river system

| | Base (no climate change) (GL) | Average (GL and %) | Dry (GL and %) |
|---|---|---|---|
| Average annual inflow – Coolmunda, Glenlyon & Pindari | 301 | 282 (94%) | 258 (86%) |
| Average annual diversions | 364 | 366 (101%)* | 360 (99%) |
| Average annual end of system flow at Mungindi | 365 | 331 (91%) | 294 (81%) |

*Note: In the Border river, river flow is reduced but diversions (for irrigation) have increased. This is a function of various factors (such as higher crop use, decreased spills and tributary flows, and increased potential evaporation from on farm dams). On-allocation diversions actually increase but off-allocation diversions decrease. The net effect is that there is less water available downstream.

A time sequence analysis for the Gwydir River indicated that in the "dry" scenario, there are longer sequences of low allocations compared to the base. The number of low flow years, where the flow at Yarraman was less than 236 GL increased by 14%. On the basis that four years duration of low river flow becomes "critical", then the number of times that this happens increases from two in the base case to seven in the dry scenario, which is a dramatic impact.

The economic impacts have been estimated. There are two off-setting forces: reductions in water available (lower area that can be planted) and increases in cotton yield due to higher temperatures and increased carbon dioxide. Other studies indicate that the expected yield increase is over 25%, which is above the forecasted reductions in water available. This confirms that the cotton industry actually gains from the climate change scenarios forecast. In the Gwydir (at a crop area of 70,000 Ha, 7.5 bales/Ha and $400/bale x 18% net increase), this would translate to an overall gross income increase of $37.8 million for the dry scenario in the year 2030.

The study shows that under climate change scenarios:

- River flow for the three river systems experiences annual reductions of 5-20%.
- Diversions vary but generally have been reduced by up to 11%. This translates directly into a decrease in area of production.
- Yield increases for cotton, due to temperature and $CO_2$ fertilisation, more than outweighed the lost production due to less water being available.
- Environment flows have been reduced between 10-20%. This is evident in lower flows for the Gwydir wetlands as well as lower "end-of-system" flows.

On the basis of the study, future R&D and communication efforts might include:

- Refining the models and estimates in the study, e.g. by:
    - Modifying rules and /or modelled irrigation behaviour;
    - Changing the models to take into account changes in vegetation and possible rainfall intensity on run-off;
    - Improving the robustness of climate information factors; and
    - Obtaining different outputs from the existing study (more developed time sequence analyses).
- Increasing awareness in the industry regarding implications of climate change.
- Examining the effects of climate change on river flows for rivers where climate change effects may be more critical for agriculture or the environment.

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# 1. Introduction

CSIRO (2001) outlines projections for climate change in Australia. By 2030, temperatures are predicted to increase by 0.4 to 2°C, relative to 1990, and by 2070 they are predicted to be 1 to 6°C higher. Rainfall impacts are variable. The impacts vary across different regions of Australia. This is likely to present a different set of threats and opportunities to industries within each region.

Although climate change is very uncertain, there are several key projections that have relevance to cotton producing regions and hence the cotton industry:

- Higher temperatures;
- Potentially lower rainfall, although confidence levels are not high;
- A general increase in climate variability;
- Higher atmospheric $CO_2$ levels (a driver of climate change);
- Higher potential evaporation, partly offset by improved plant growth in $CO_2$ rich air;
- Minimum temperatures to rise before maximums, which could be positive for the industry. However, the risk of late frosts will be higher and the consequences more severe in $CO_2$ rich atmosphere; and
- River flows may become more variable with a tendency to decrease (further investigated in this project).

The cotton industry is fortunate in that many of the climate projections and impacts for the next 30-50 years are positive for the industry, particularly the higher growth rates due to higher $CO_2$ concentrations and higher temperatures. However, one key risk factor is to the river flows and water supply.

Two examples of studies where the impacts of climate change on river flows have been quantified include:

- Hassall & Associates (1998) - estimated the impact of climate impacts for the Macquarie River, which showed a decrease of up to 37% inflow into Burrendong Dam by 2030. This translated to lost production of $152 million (a 22% reduction in production). The lost production was predominately from the grazing and wheat enterprises, rather than from cotton. Ecological impacts included a decrease in the area of Macqaurie Marsh wetlands of up to 30% and increased risks to bird breeding events.

- Schreider *et al.* (1997) - estimated a similar reduction in river flows for the Goulburn, Ovens, Kiewa and the Victorian part of the Murray Darling Basin.

The objectives of the project are to assess the impacts of climate change on the water resources in the Gwydir, Border and Condamine-Balonne River Systems[1]. The project considers changes to river flow and irrigation diversions, as well as to sequences of events and economic implications. The project helps answers some of the "so what" questions about the potential impacts of climate change for cotton producers and for the sustainability of natural resources.

The project has been undertaken by Hassall & Associates, CSIRO Atmospheric Research, NSW Department of Land and Water Conservation (DLWC) and Queensland Department of Natural Resources and Mines (QNR&M). The project has been funded by the Cotton Research and Development Corporation, with in-kind contributions from DLWC and QNR&M. The project addresses all three of the Cotton Research and Development Corporation's outputs (sustainability of natural resources, profitability and competitiveness, and people and communities) by considering the impacts of climate change on river flows and water availability.

The report outlines the methods, results, discussion and future R&D and communication needs. Various appendices contain the detailed results of the different components of the study, prepared by the respective team member.

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[1] The project commenced in 1999 and originally set out to include the Namoi and Barwon-Darling Rivers as well. The IQQM models are not sufficiently developed to undertake the modelling for these two river systems. Additional economic and time series analyses have been conducted on the Gwydir River results instead.

# 2. Methods

Three climate scenarios for the year 2030 have been generated by CSIRO Atmospheric Research:

- “base” (no climate change);
- “average” (50th percentile or mid-range); and
- “dry” (95th percentile).

The scenarios represent plausible outcomes rather than predictions. The scenarios provide changes to rainfall and potential evaporation (predominately through temperature increases), at a regional scale. The scenarios are based on probabilities derived from over 10,000 runs, sampling the ranges of regional climate change produced from a suite of six different atmospheric models. More details of the climate change scenarios are provided in Appendix 1.

This modified climatic data is then used to assess the effects of projected climate change scenarios on streamflows and modified crop demands. Firstly, rainfall/run-off models for all sub-catchments are calculated with the modified rainfall and potential evaporation. These then generate modified streamflow inputs to the Integrated Quality and Quantity Model (IQQM) for each river system. Secondly, the IQQM uses the modified rainfall and potential evaporation data to drive its crop demand module. Therefore, the catchment scale IQQM model is modified in two ways, firstly modified streamflows and secondly modified crop demands. The process used 1993/94 systems of allocating water between different users, including the allocations to the environment and diversions for irrigation. DLWC has analysed the Gwydir and Border River systems and QNR&M has analysed the Condamine Balonne river system.

Results have been presented to:

- Cotton industry representatives [at the Greenhouse Workshop for the Cotton Industry, held at Narrabri in August 2001, as part of the Standing Committee of Agriculture Resource Management’s Greenhouse Workshop Series]; and
- DLWC River Managers and modellers [held in Sydney in September 2001].

Comments at these workshops related primarily to the robustness of assumptions, modelling imperfections and the possible mis-use of results should they be taken out of context. These issues have been addressed in the relevant sections of this report.

The economic impact of the climate scenarios for the Gwydir River has been estimated by Hassall & Associates, which takes into account yield increases due to higher $CO_2$ concentrations and decreased areas due to lower water availability. An analysis of the time sequences for the Gwydir River has been prepared under contract to Hassall & Associates.

## 3. Results

Results are presented for:

- Climate change scenarios;
- Gwydir River System;
- Condamine Balonne River System;
- Border River System;
- Time sequence analyses of the Gwydir River results; and
- Economic impact of the Gwydir River results.

### Climate change scenarios

The "base", "average" and "dry" scenarios provide changes to rainfall and potential evaporation (predominately through temperature increases), at a regional scale. The changes, represented as monthly multipliers to the historical records, range from 0.95 to 1.07 and vary according to location.

The actual temperature and $CO_2$ concentrations for the scenarios range from 0.9 to 1.2°C and 430 and 455 parts per million (ppm) for the average and dry scenarios, respectively. The temperature and $CO_2$ concentrations influence plant growth and hence the likely yields expected.

### Gwydir River System

Table 3.1 presents the results for the Gwydir River system. The changes in flow into Copeton Dam are shown in Figure 3.1. More details are provided in Appendix 2.

The main features are that under the climate change scenarios:

- Average annual inflow into Copeton is reduced by between 13-20%, with bigger differences in Spring inflows;
- Allocation reliability (the probability of achieving full allocation) has decreased by 5-8%;
- Average annual total diversions have decreased by 6-11%; and
- Average annual inflow into the Gywdir Wetlands has decreased by 13-22%.

**Table 3.1: Results for the Gwydir river system***

| | Base (no climate change) (GL) | Average Scenario (GL and %) | Dry Scenario (GL and %) |
|---|---|---|---|
| Inflow – Copeton | 431 | 377 (87%) | 346 (80%) |
| Allocation reliability | | | |
| 100% | 25% | 20% | 17% |
| 60% | 45% | 37% | 30% |
| Diversions | 339 | 321 (94%) | 304 (89%) |
| Wetlands inflow | 238 | 209 (87%) | 187 (78%) |

*some rounding errors

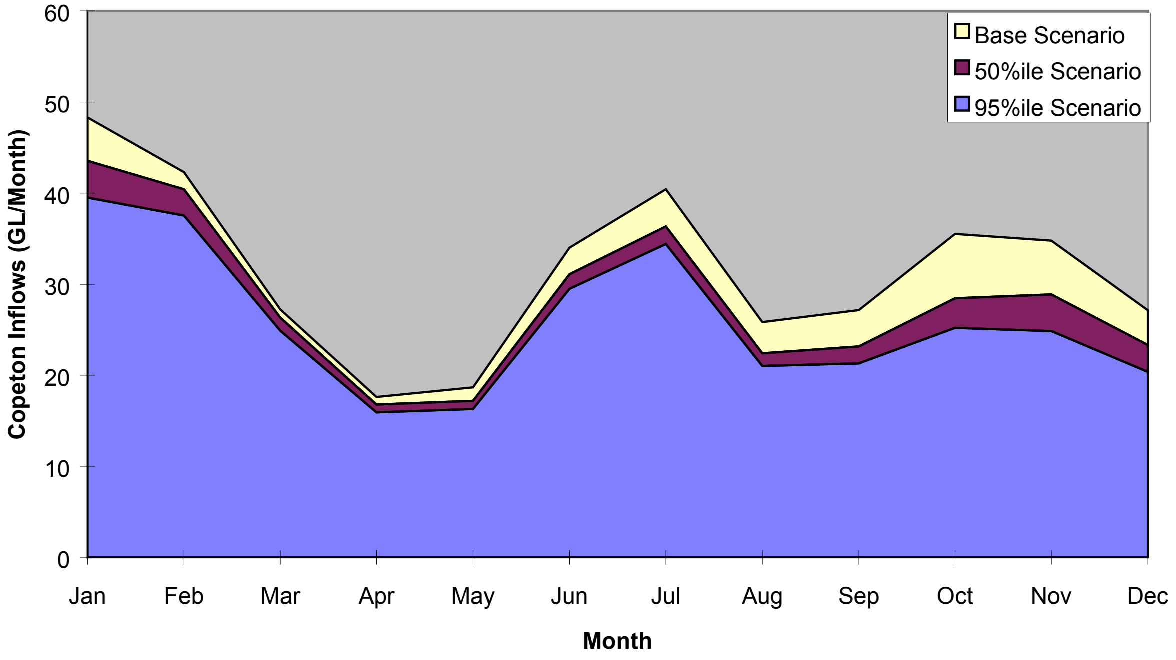

**Figure 3.1: Monthly average Copeton Dam inflows for 1892-1997 period**

## Condamine Balonne River System

Table 3.2 presents the results for the Condamine Balonne River system. More details are provided in Appendix 3.

The main features are that under the climate change scenarios:

- Inflow into the storages is reduced by between 6-14%.
- Medium priority diversions have decreased by 2-6%.
- Water harvesting on the floodplain has decreased by between 4-9%.

**Table 3.2: Results for the Condamine-Balonne river system***

| | Base: Draft WAMP Scenario-A (GL) | Average (GL and %) | Dry (GL and %) |
|---|---|---|---|
| Inflow – Leslie Dam | 34 | 32 (94%) | 29 (86%) |
| Inflow – Chinchilla | 387 | 363 (94%) | 327 (85%) |
| Inflow –St George | 1164 | 1113 (96%) | 1028 (88%) |
| Diversions - | | | |
| High Priority | 10.2 | 10.1 (99%) | 10.0 (98%) |
| Medium Priority | 82.8 | 80.9 (98%) | 77.8 (94%) |
| Water Harvesting: downstream of Beardmore | 335 | 322 (96%) | 304 (91%) |

*some rounding errors

## Border River System

Table 3.3 presents the results for the Border River system. The main features are that under the climate change scenarios:

- Total inflow into the three major storages (Coolmunda, Glenlyon and Pindari) is reduced by between 6-14%.
- Average annual diversions have increased by 1% under the average scenario and decreased by 1% under the dry scenario.
- Average annual end-of-system flows at Mungindi have decreased by between 9-19%.

**Table 3.3: Results for the Border river system***

| | Base (GL) | Average (GL and %) | Dry (GL and %) |
|---|---|---|---|
| Average annual inflow – Coolmunda, Glenlyon & Pindari | 301 | 282 (94%) | 258 (86%) |
| Average annual diversions | 364 | 366 (101%) | 360 (99%) |
| Average annual end of system flow at Mungindi | 365 | 331 (91%) | 294 (81%) |

*some rounding errors

In the Border Rivers, river flow is reduced but diversions (irrigations) have increased. To examine this result more carefully, each factor was analysed to see how it contributed to the results (Appendix 4). The increase in diversions is a function of various factors (such as higher crop use, decreased spills and tributary flows, and increased potential evaporation from on farm dams). On-allocation diversions actually increase but off-allocation diversions decrease. The net effect is that there is less water available downstream for other users (including the environment).

## Time sequence analyses of the Gwydir River results

The results for the Gwydir River System indicate a general reduction in river flows (see Table 3.1). A further issue of concern is whether the number of years of low river flow would increase. There is a high impact from having a number of low flow and low allocation years in succession.

The process to determine the extent of increase of low flow years, based on the previous 109 years of historical data, is:

- Select appropriate thresholds, namely:
    - "low flow" was defined as below the median flow at Yarraman, (236GL); and
    - "low allocation" was defined as occurring approximately one-third of the time – the threshold used was actually 40%, for convenience;
- Determine the number of years below the threshold; and
- Determine the number of years in a row below the threshold.

The time sequence data is presented in Appendix 5.

The results show that:

- The number of low flow years increased by 14%;
- There are longer sequences of low flow periods; and
- There are also more severe sequences in the climate change scenarios.

Discussion with irrigation representatives indicate that receiving low flow for four (or more) years in succession is likely to be critical. In this analysis, the number of times that this happens increases from two in the base case to seven in the “dry” scenario, which is a dramatic impact. Additionally, the length of the low flow sequences increased, with the longest sequence being 7 years in the Base Case and 12 years in the “dry” scenario.

## Economic impacts of climate change scenarios for the Gwydir valley

There are two offsetting factors that drive the economic implications of the climate change scenarios:

- Less water available, which implies less crop can be grown (see Table 3.1); and
- Faster plant growth and increased yield, due to higher temperatures and higher $CO_2$ concentrations (detailed in Appendix 6).

A preliminary analysis indicates that the higher yields are estimated to be between 22 and 29% for the average and dry scenarios (detailed in Appendix 6). This is higher than the forecasted reductions in water available (6 to 11% for the diversions; inflow is reduced up to 20%). This indicates that the cotton industry may in fact gain from the climate change scenarios forecast through the increased production. In the Gwydir (at a crop area of 70,000 Ha, 7.5 bales/Ha and $400/bale x 18% net increase), this would translate to an overall gross income increase of $37.8 million[2] for the dry scenario in the year 2030.

The economic impact is an average impact and does not translate for any one particular year. The area grown will vary according to market predictions, expectations for water availability and other farm management factors. There are expected changes in water supply variability and reliability.

The analysis has not incorporated potential production impacts from potential:

- increases in pest and weed pressures;
- increases in water use efficiency (stomatal conductivity); and
- shorter growing periods.

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[2] This increase in gross income is expected for the Year 2030, which in 2002 dollars (discounted at 7%) is equivalent to $5.3M. A full analysis has not been conducted. It is likely that benefits will be obtained incrementally between 2003 and 2030 (=$158M in 2002 dollars, assuming a constant increase with no lags between diversions and yield increases). It is also likely that the benefits will increase again between 2030 and 2070 to take into account further climate change impacts.

## 4. Discussion and Conclusions

The study shows that under climate change scenarios:

- River flow experiences annual reductions of 5-20%.
- Diversion impacts vary but generally they have been reduced by up to 11%. This translates directly into a decrease in area of production.
- Yield increases for cotton, due to temperature and $CO_2$ fertilisation, are estimated to outweigh the lost production due to less water being available.
- Environmental flows have been reduced between 10-20%. This is evident in lower flows for the Gwydir wetlands as well as lower “end-of-system” flows in other river systems.

The three sets of results allows some generic points to be made about the main physical and catchment drivers for climate change results, including:

- The size of the head-water storage compared to the system inflows [a smaller storage results in more spilling and therefore lower cumulative impacts on diversions];
- Ratio of on and off allocation [off allocation is reduced more, under present allocation rules]; and
- Potential evaporation from storages [is significant only when storages are large, nearly always full and located near the end of system. Otherwise it is insignificant].

The changes to inflow to storages may be useful information for “air space management” (controlling the quantity of water in the storage so that inflows can be managed and reducing flooding impacts).

The changes to river flow and diversions might contribute to the analysis of policy decisions. However, at present, there is little assistance for future management decisions. This is largely because the analysis also does not consider the current pressures on allocations, e.g. to increase environmental flows and to meet the Murray Darling Basin Commission’s cap on water extraction. Changes in operating procedures may have a large impact on the respective allocations. The analysis implies that there is not a direct relationship between inflow, diversion and environmental flow. Reductions in inflow tend to have a larger impact on environmental flows, either to wetlands or end of system, under the current water allocation rules. This is not evidence, however, that the operating rules require changes in order to “protect” the environment.

There is a legitimate question of how the impacts of climate change can be observed, since the climatic variability in the Eastern Australian rivers is so large that it is difficult to detect any underlying trends. An indicator may be if the “drought of record” is surpassed, which is discussed further in Hassall & Associates (1998). Unfortunately, this is only an indicator. The problem is that there is a probability (albeit small) that a year’s flows could be drier than any previously recorded without any underlying climate change. It is likely that climate change data would not influence the actual allocation procedure; rather, it may be possible for the relevant State agencies to change supplementary information when issuing allocations.

It perhaps goes without saying that the impacts are long term. The short term variability of allocations is likely to be more significant for cotton growers. Variability is anticipated to increase under the climate change scenarios.

The study does not consider whether there are water quality issues associated with lower flows, for example sediment, salinity and nutrient loads and water temperature.

Farmer reactions to a presentation included concerns about the accuracy of the modelling (issues with IQQM, inclusion of atypical years, differences between observed and recorded allocation reliability over twenty years). In addition, the modelling does not take into account:

- Vegetation/landuse changes that would affect run-off;
- Increased rainfall intensity may increase run-off;
- Breakeven results for when the climate scenarios can actually become wetter than the base year; and
- Relative impact/importance between rainfall and potential evaporation [although this is detailed in the exercise for the Border Rivers system – see Appendix 4].

Most of all, concern has been expressed that the results could be taken out of context and used to apply further pressure on allocations. The study is exploratory in nature and extreme care should be taken before changes in production, research or water management are considered.

### Future studies

On the basis of the study, future R&D and communication efforts might include:

- Refining the models and estimates in the study, e.g. by:
    - Modifying rules and /or modelled irrigation behaviour (including on and off allocation thresholds; modified resource assessments; Environmental Contingency Allowance triggers and volumes; translucency of dam (the ratio of diversions to inflow), flood mitigation zone evacuation, etc.);
    - Changing the models to take into account changes in vegetation and possible rainfall intensity;
    - Improving climate information inputs (e.g. represent a time series input, including sequences and durations, rather than applying a factor to each month's average rainfall 'factoring' approach where historical records; including frost information); and
    - Obtaining different outputs from the existing study (time sequence analyses considering frequencies of drought, spills and drying cycles).
- Increasing awareness in the industry regarding implications of climate change. This will overlap with strategies to reduce greenhouse gas emissions. Although the benefits for cotton look positive, this does not imply that the issue should be left to popular opinion. There is also a significant issue of whether the area for cotton production will expand or shift (e.g. growing cotton further south), which may require further attention.
- Examining the effects of climate change on river flows for rivers where climate change effects may be more critical for agriculture (e.g. the lower Murray) or the environment (e.g. Lake Eyre or Menindee Lakes).

## 5. References

Hassall & Associates (eds.) (1998) Climate Change Scenarios and Managing the Scarce Water Resources of the Macquarie River, Australian Greenhouse Office.

Hassall & Associates (2001) Greenhouse and Agricultural Workshop Series for the Standing Committee on Agriculture and Resource Management's Phase 1 Work Program, for Agriculture, Fisheries and Forestry Australia

Schreider.S, Jakeman, A, Pittock, A and Whetton, P (1997) Estimation of possible climate change impacts on water availability, extreme flow events and soil moisture in the Goulburn and Ovens basins, Victoria, Centre for Resource and Environmental Studies, Australian National University

Other references relating to climate change, river modelling and plant growth are located in the respective appendices, where they are cited.

# Appendix 1: Climate Change Scenarios

Prepared by Dr. Roger Jones
*CSIRO Atmospheric Research*

## ***Brief***

To supply the 50th and 95th percentile "driest" climate change scenarios of regional precipitation (P) and potential evaporation (Ep) change in 2030 and provide scaling factors that can be used to alter historical P and Ep records. These records will then be used to simulate changes to irrigation supply for the cotton industry in the Gwyder, Border and Condamine-Balonne river catchments of north-east NSW and southern Queensland.

## ***Introduction***

In the project *Climate Change Scenario and Managing the Scarce Water Resources of the Macquarie River* (Hassall and Associates, 1998) two scenarios, describing least change and greatest change based on precipitation and potential evaporation from CSIRO's regional climate model DARLAM, were applied to the IQQM model of NSW DLWC. The ecological and economic impacts summarising changes to dryland agriculture, irrigated agriculture and wetlands were also assessed. The following factors made these outcomes difficult to apply in planning or policy terms:

- The large range of uncertainty encompassed by the results (e.g. the large range of outcomes in dollar terms for each agricultural sector)
- The results were based on only one model that simulated a rainfall decrease, whereas rainfall increases may also be possible
- The version of DARLAM utilised was nested within a "mixed layer" or slab-ocean global climate model (GCM) that has since been superseded by coupled atmosphere-ocean GCMs.

This project aims to manage those limitations by providing scenarios derived from six coupled GCMs. Ranges of uncertainty were calculated from these six models and statistical sampling methods used to construct probability distributions within those ranges. Those probability distributions were tallied on the basis of wettest to driest scenarios using precipitation - potential evaporation (P-Ep) deficit, with the 50th percentile being the mid range estimate and the 95th percentile being at the drier end.

## ***Uncertainty***

A climate scenario is a plausible representation of a future climatic state and is used in preference to predictions because of the large uncertainties associated with climate change (Table 1). Greenhouse gas emissions, aerosol emissions and climate sensitivity all contribute to uncertainties in estimating the degree of global climate change, measured as degrees of global warming. Several other sources of uncertainty, such as greenhouse gas mixing (i.e. how emissions lead to atmospheric concentrations) and radiative forcing (how atmospheric concentrations of greenhouse gases contribute to changes in absorbed radiation) are omitted from the calculations but are limited in effect. The regional climate response, a further source of uncertainty, is accounted for by using the output from several GCMs. These were then converted to ranges of change for P and Ep.

**Table 1. Types and sources of uncertainty associated with projecting average regional climate change**

| Type of uncertainty | Source of uncertainty | Expression | Reference |
|---|---|---|---|
| Greenhouse gas emissions | Social, economic, physical (accounting) | Mass/volume per year | IPCC IS92a–f (Pepper et al., 1992), SRES (Nakicenovic, 2000) |
| Aerosol emissions (including sulphate aerosol) | Scientific, physical (accounting), economic | Mass/volume per year | IPCC (1996) |
| Climate sensitivity | Scientific, emergent chaotic behaviour | Global warming for $2\times CO_2$ atmosphere, or per unit of radiative forcing | IPCC (1996), Hansen et al. (1998) |
| Regional climate response | Scientific, emergent chaotic behaviour | Local change per degree of global warming | CSIRO (1996), This study |

These sources of uncertainty contribute to the large ranges of change for precipitation and potential evaporation. Uncertainty within those ranges has been managed by randomly sampling the ranges of global warming and regional P and Ep changes to create probability distribution functions. Scenarios representing the 50th and 95th percentiles calculated on the basis of P-Ep deficit were then constructed from these distributions.

The distributions represent different possible responses to single-event outcomes and are not the frequency-based outcomes that are more commonly the subject of climate-related impact studies. The major difference is that a single event outcome only occurs once, and has two aspects of likelihood: how likely is the event to occur, and in what form will that event manifest if it does occur? Frequency-based outcomes are events that occur repeatedly but manifest in different forms, e.g. 1 in 50, 1 in 100 and 1 in 500 year flood events. Climate change is a single event that is highly likely to occur, but how it will manifest is associated with uncertainty (e.g. Table 1). The probability of how regional P and Ep may manifest is the subject of these scenarios.

## ***Method***

The steps taken to construct these scenarios include:

1. *Construct range of global warming*
2. *Construct scaled patterns of local rainfall change*
3. *Calculated scaled patterns of point potential evaporation*
4. *Investigate changes to regional rainfall and potential evaporation*
5. *Calculate projected ranges for rainfall and potential evaporation*
6. *Carry out random sampling sequence*
7. *Calculate the 50th and 95th percentiles based on annual changes to P-E deficit*
8. *Extrapolate reference points across the region*
9. *Match climate stations with grid*
10. *Interpolate quarterly changes for 50th P and Ep and 95th P and Ep into monthly values.*

### 1. *Construct range of global warming*

The range of global warming is constructed using the same simple climate model that was used in the construction of the IPCC (1996) projections of global warming. This range differs from the IPCC (1996) results in that the provisional Special Report on Emission Scenarios (SRES; Nakicenovic et al., 2000) marker scenarios were used instead of the IS92a–f scenarios. The SRES scenarios are more realistic than those earlier scenarios, particularly in their representation of sulphate aerosol emissions that cause a relative cooling effect. The simple model accounts for the first three uncertainties in table. A range of 0.44 to 1.09°C was obtained using the SRES marker scenarios as input. This compares with 0.4 to 0.8 (rounded) quoted in CSIRO (1996) and based on the earlier IS92a–f scenarios. This result differs because although greenhouse gas emissions on the whole are lower, sulphate aerosol emissions are projected to undergo even greater reductions, leading to a net warming.

### 2. *Construct scaled patterns of local rainfall change*

Six climate models were used to produce regional changes in climate: Hadley CM3 (UK), DKRZ ECHAM3 (German), CGCM1 (Canadian), CSIRO Mk2 and DARLAM 60 and 125 km (Table 1). Both rainfall and potential evaporation changes were scaled to produce estimates of local change per degree of global warming. This done to remove the individual climate response of each model in order to produce a range of responses based on the entire projected range of global warming (Step 1). The scaling method regresses each climate grid against global average climate to produce a measure of local (gridbox) change per degree of global warming. Rescaling is explained in Step 6. Scaled patterns for rainfall on a monthly basis was calculated over the study region for each model, which was then regridded to a 1/20th of a degree grid and incorporated into OzClim, CSIRO's climate scenario generator.

**Table 1. Model runs used to produce regional scenarios**

| Research Centre | Model | Emission Scenario | Features | Years |
|---|---|---|---|---|
| CSIRO, Australia[1] | Mk2 | IS92a equivalent $CO_2$ | No sulphates, GM ocean* | 1881–2100 |
| CSIRO, Australia[2] | DARLAM 60 km | IS92a equivalent $CO_2$ | Nested in CSIRO Mk2 | 1961–2100 |
| CSIRO, Australia[2] | DARLAM 125 km | IS92a equivalent $CO_2$ | Nested in CSIRO Mk2 | 1961–2100 |
| DKRZ, Germany[3] | ECHAM4/OPYC3 | IS92a | No sulphates | 1860–2099 |
| Hadley Centre, UK[4] | HADCM3 | 1% $CO_2$ pa | No sulphates | 1861–2100 |
| Canadian CCMA[5] | CGCM1 | 1% $CO_2$ pa | No sulphates | 1900–2100 |

Notes:
Historical emissions are used to 1990, after which the listed emission scenarios are applied.
[1]Gordon and O'Farrell (1997)
[2]McGregor and Katzfey (1998)
[3]Roeckner et al. (1999)
[4]Mitchell et al. (1998)
[5]Boer et al. (2000)
*The GM ocean refers to the Gent-McWilliams scheme, which offers a more realistic representation of oceanic processes than earlier schemes (Hirst et al., 1996).

### 3. *Calculate scaled patterns of point potential evaporation*

Point potential evaporation (a model equivalent to Class-A Pan evaporation) was calculated for each model using the inputs of moisture (humidity, dewpoint or vapour pressure), air temperature and downward solar radiation using a technique described in Walsh et al. (2000). Scaled patterns were then calculated, regridded and incorporated onto OzClim as for rainfall.

*4. Investigate changes to regional rainfall and potential evaporation*

The calculation of conditional probabilities for regional climate change was carried out on selected reference points, because to carry it out on a regional basis (i.e. all grids in a spatial array) would be mathematically complex and computer-intensive. The locations of the reference points are listed in Table 2 and shown in Figure 1. Changes per degree of rainfall and potential evaporation from all six models were obtained for each point on a quarterly basis, giving 96 samples in all (Table 3). Table 3 shows that rainfall changes are predominantly decreases in winter and spring (in 60% of cases), with increases in summer and autumn (60% and 75% respectively). Potential evaporation increases in all cases, although these changes are small where projected increases in rainfall are large.

**Table 2. Location of reference points used for random sampling**

| Points | Latitude | Longitude |
|---|---|---|
| NW | 29.00 | 149.00 |
| NE | 29.00 | 152.00 |
| SW | 30.75 | 148.00 |
| SE | 31.25 | 152.00 |

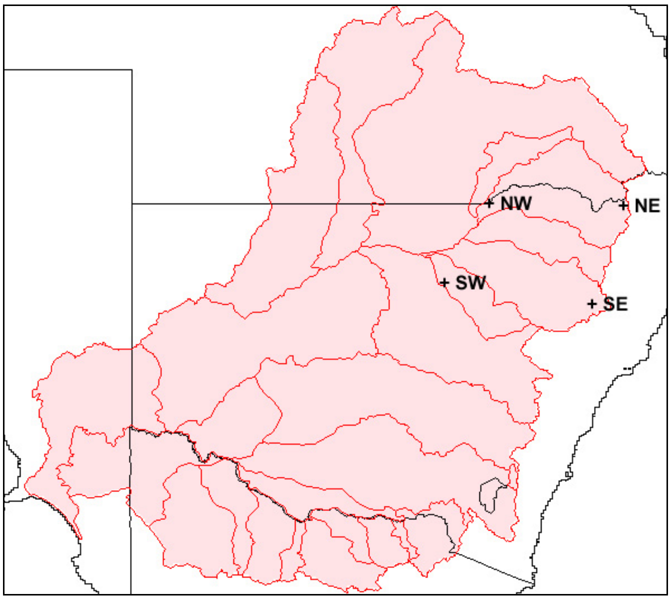

**Figure 1. Map of the major catchments in the Murray-Darling Basin showing the location of the four points used in sampling**

### Table 3. Change per degree of global warming for rainfall and potential evaporation for all six models at the four reference points (in percent)

| | **Rainfall change (%)** | | | | **Potential evaporation change (%)** | | | |
|---|---|---|---|---|---|---|---|---|
| | Summer | Autumn | Winter | Spring | Summer | Autumn | Winter | Spring |
| **North-west** | | | | | | | | |
| Mk2 | -1.1 | 0.1 | -3.1 | -6.9 | 3.4 | 3.7 | 5.0 | 5.7 |
| 125km | 2.1 | 4.6 | -3.1 | 0.8 | 2.7 | 3.6 | 3.1 | 4.1 |
| 60km | 2.5 | 7.0 | 0.8 | 0.5 | 2.2 | 3.2 | 4.6 | 3.8 |
| CCC | -3.4 | 5.6 | -1.7 | -6.9 | 4.3 | 1.8 | 3.1 | 6.3 |
| HCM3 | -0.5 | 1.4 | -5.1 | -12.0 | 5.7 | 7.7 | 9.7 | 10.1 |
| MP3 | 8.4 | 1.3 | 1.9 | 6.0 | 0.7 | 3.9 | 4.5 | 4.3 |
| | | | | | | | | |
| **North-east** | | | | | | | | |
| Mk2 | -1.6 | 0.1 | -1.7 | -6.5 | 3.6 | 4.0 | 4.9 | 5.9 |
| 125km | 0.1 | 3.5 | 2.2 | 0.6 | 3.6 | 2.6 | 6.1 | 5.7 |
| 60km | 0.2 | 2.7 | -0.5 | 0.2 | 3.1 | 2.7 | 5.4 | 4.5 |
| CCC | -1.9 | 4.9 | -1.8 | -7.7 | 2.1 | 0.1 | 1.6 | 3.7 |
| HCM3 | 0.4 | -2.4 | -5.9 | -13.0 | 3.3 | 5.0 | 6.1 | 5.4 |
| MP3 | 8.5 | 0.1 | 1.7 | 5.4 | 0.2 | 3.3 | 3.6 | 3.2 |
| | | | | | | | | |
| **South-west** | | | | | | | | |
| Mk2 | -0.7 | 1.1 | -2.9 | -5.9 | 3.6 | 3.6 | 5.3 | 5.6 |
| 125km | 4.9 | 0.8 | 0.3 | -1.1 | 1.8 | 4.1 | 5.9 | 4.7 |
| 60km | 4.5 | 6.9 | 0.0 | -0.3 | 2.1 | 3.7 | 5.3 | 4.3 |
| CCC | 0.0 | 3.3 | -3.6 | -5.9 | 3.1 | 1.6 | 3.4 | 6.8 |
| HCM3 | 1.6 | 2.6 | -5.3 | -10.2 | 5.7 | 6.9 | 9.6 | 9.7 |
| MP3 | 9.4 | -0.2 | 0.8 | 5.7 | 1.1 | 3.9 | 4.7 | 4.1 |
| | | | | | | | | |
| **South-east** | | | | | | | | |
| Mk2 | -0.9 | 1.6 | -0.9 | -4.8 | 3.0 | 3.2 | 4.4 | 4.8 |
| 125km | -0.7 | 0.7 | 2.9 | -0.1 | 3.2 | 3.6 | 6.7 | 5.1 |
| 60km | 2.0 | -0.1 | -1.0 | 1.2 | 2.7 | 4.4 | 7.5 | 4.6 |
| CCC | -0.9 | 3.5 | -3.9 | -5.1 | 3.0 | 0.5 | 2.5 | 5.0 |
| HCM3 | 0.2 | -1.3 | -6.1 | -9.8 | 4.1 | 6.4 | 8.1 | 7.2 |
| MP3 | 9.1 | -1.5 | 0.1 | 2.9 | 0.2 | 3.7 | 4.2 | 3.4 |

Two tests were run with data to inform the random sampling strategy:

1. Dependency between rainfall and potential evaporation change was explored; and
2. Changes between seasons within models were explored to determine whether they were related.

The first test was investigated as part of a longer-term strategy researching scenario construction that aims to use co-dependency between climate variables to reduce uncertainties. The results showed that dependency between P and Ep can be observed when measured on a seasonal basis. For all 96 samples for changes to both P and Ep, change in Ep is inversely proportional to change in P with about 40% of samples falling within one standard deviation ($r^2$=41%). This relationship occurred within all models and were investigated on a seasonal basis.

The correlations were highest in spring and summer and almost zero in winter (Figure 2). This shows that if P is randomly sampled within a given range, the change in Ep will be partially dependent on that result.

The second test, measuring the direction and degree of change between seasons, was less conclusive. Some models showed large positive swings in rainfall from one season to the next while another showed a large reversal. The question of dependence between seasonal changes is very important for exploring consistencies between models, but the changes investigated here were inconclusive, suggesting that changes between seasons could be regarded as independent. This aspect requires further research.

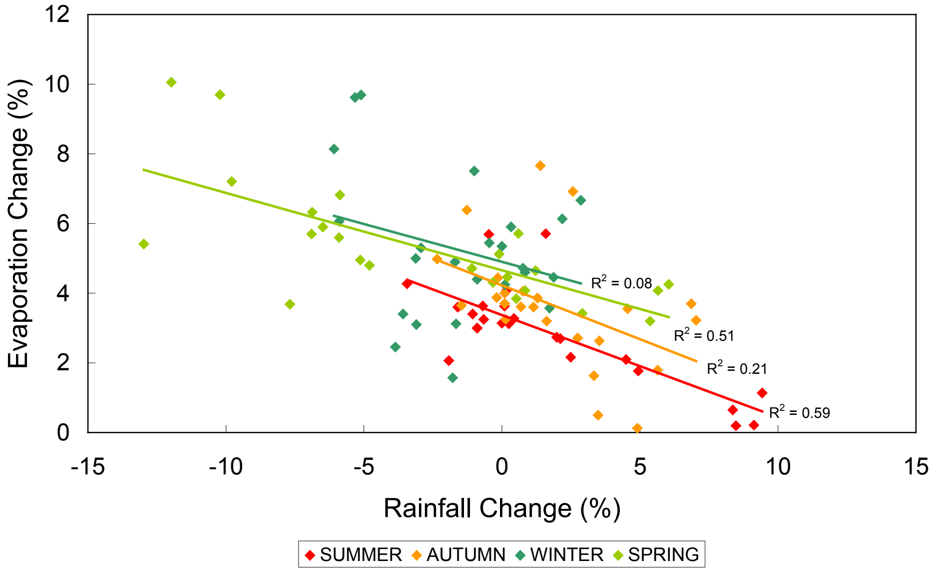

**Figure 2. Relationship between potential evaporation and rainfall change for all six climate models at four locations in the study region, showing regressions on a seasonal basis**

### *5. Calculate projected ranges for rainfall and potential evaporation*

The ranges for P and Ep were constructed from the data shown in Table 3 and are shown in Table 4. They demonstrate that summer and autumn are biased towards rainfall increase whereas winter spring are biased towards decreases. The greatest uncertainties are in spring, exceeding 15%. From the analyses described in the previous step, the sampling strategy for regional climate at each point is as follows:

i. Each season is randomly sampled within the given range of rainfall in Table 5.

ii. The differences between each season are measured. If any difference exceeds the maximum difference between those two seasons displayed by the six models, that sample is rejected.

iii. Potential evaporation is then randomly sampled within a range established by the partial dependency of change in Ep on changes in P.

This method means that the ranges for Ep in Table 5 are not used explicitly, but are calculated on the basis of the relationship between P and Ep change established in the previous step.

**Table 4. Ranges of P and Ep for the four reference points in the study area.**

| **Ranges** | **North-west** | **North-east** | **South-west** | **South-east** |
|---|---|---|---|---|
| **Summer** | | | | |
| Rainfall low | -3.4 | -1.9 | -0.7 | -0.9 |
| Rainfall high | 8.4 | 8.5 | 9.4 | 9.1 |
| Potential evaporation low | 0.7 | 0.2 | 1.1 | 0.2 |
| Potential evaporation high | 5.7 | 3.6 | 5.7 | 4.1 |
| **Autumn** | | | | |
| Rainfall low | 0.1 | -2.4 | -0.2 | -1.5 |
| Rainfall high | 7.0 | 4.9 | 6.9 | 3.5 |
| Potential evaporation low | 1.8 | 0.1 | 1.6 | 0.5 |
| Potential evaporation high | 7.7 | 5.0 | 6.9 | 6.4 |
| **Winter** | | | | |
| | | | | |
| Ranges | North-west | North-east | South-west | South-east |
| | | | | |
| Rainfall low | -5.1 | -5.9 | -5.3 | -6.1 |
| Rainfall high | 3.0 | 2.2 | 0.8 | 2.9 |
| Potential evaporation low | 3.1 | 1.6 | 3.4 | 2.5 |
| Potential evaporation high | 9.7 | 6.1 | 9.6 | 8.1 |
| **Spring** | | | | |
| Rainfall low | -12.0 | -13.0 | -10.2 | -9.8 |
| Rainfall high | 6.0 | 5.4 | 5.7 | 2.9 |
| Potential evaporation low | 3.8 | 3.2 | 4.1 | 3.4 |
| Potential evaporation high | 10.1 | 5.9 | 9.7 | 7.2 |

### 6. *Carry out random sampling sequence*

Random sampling is carried in the following manner: a random sample is taken within a range defined by an upper and lower limit. In all of the examples given here, the range has uniform probability distribution, i.e. the sample could fall anywhere along the range with an equal probability. That sample then becomes a value that is then used to scale or modify another sampled value. Each sampling sequence is assumed to represent a plausible future climate. Probability theory maintains that if sufficient samples are taken, then a pattern of future climate will emerge, allowing probabilities to be attached to specific outcomes. These probabilities are conditional on the assumptions used to construct the sampling strategy and component ranges, in this case, assumptions used to construct projections of global and regional warming. The probabilities are also conditional in the sense that unquantifiable uncertainties are also known to affect the magnitude of global warming. However, these uncertainties are significantly less than the quantifiable uncertainties.

The sampling sequence was carried out for each of the four points as follows:

i. 50,000 independent samples were taken (after filtering, see Step 5.iii), initially sampling within the projected range of global warming (Step 1). The same value of global warming is then used to scale all four seasonal values.
ii. The four seasons were then sampled for P independently (see Step 5.i).
iii. Implausible changes between seasons were filtered out to reflect the changes as represented by the model samples i.e. a change from +5% in summer to –6% in autumn was not observed in the models, so if sampled in a random fashion, was filtered out.
iv. Ep was then randomly sampled within a range constructed using the value for P and the relationship of partial dependence between P and Ep change observed in all models.
v. All 50,000 filtered samples were then used to estimate changes in P-Ep deficit.

This routine produces 50,000 estimates of P and Ep change for each of the four points in the region that were then used to produce a probability distribution of P and Ep for 2030.

### *7. Calculate the 50th and 95th percentiles based on annual changes to P-E deficit*

Changes to P and Ep were converted into mm on a seasonal basis then the following steps undertaken:

i. Changes to P and E for each season were averaged for all climate samples falling within ±0.1 mm P-Ep deficit at the 50th percentile level (>100 samples) at each reference point. This is equivalent to the 50th percentile change on an annual basis.
ii. The 95th percentile was calculated for P-Ep on an annual basis. The change for each season was then selected iteratively on the basis that they contribute an equal probability to the annual outcome. That resulted in seasonal probabilities of 80 to 82% for P-E deficit. All outcomes equivalent to that percentile were averaged as for 7.i. (When each season was sampled at the 95th percentile, then the annual outcome was 99.9%)
iii. The averages for the seasonal 50th and 95th(annual) percentiles then became the 50% and 95% “driest” scenarios for each reference point.

### *8. Extrapolate reference points across the region*

The 50% and 95% “driest” scenarios then were used to create two linear grids across the region at a 0.05-degree resolution. This creates a very “smooth” surface of change, a particular outcome that is unlikely to occur. However, the important outcome in this sense is not the precision of the result, but its representativeness of a particular probability. The 50th percentile result can be treated as an average result while the 95th percentile represents a very dry outcome that is far less likely to occur.

### *9. Match climate stations with grid*

Every climate station within the region was matched to the closest grid point requiring corrections of ±0.02, producing an error less than the final resolution of the monthly scaling factor supplied (at one decimal point).

*10. Interpolate quarterly changes for 50th P and Ep and 95th P and Ep into monthly values.*

This was done through a linear interpolation to obtain monthly values for all twelve months for both variables of the two scenarios.

## ***Overview of results***

Figure 3 shows the results for the NW reference point for the winter season (June, July and August). There are two layers of information in the figure: the lines ranging from 20 to -40 are changes in P-Ep deficit (a positive outcome is a net increase in moisture). The shaded area is sampled climate showing cumulative probabilities sampled from the most frequently occurring future climates to the least frequent. The most frequent 50% of samples occur in the darkest zone in the centre of the sampled area.

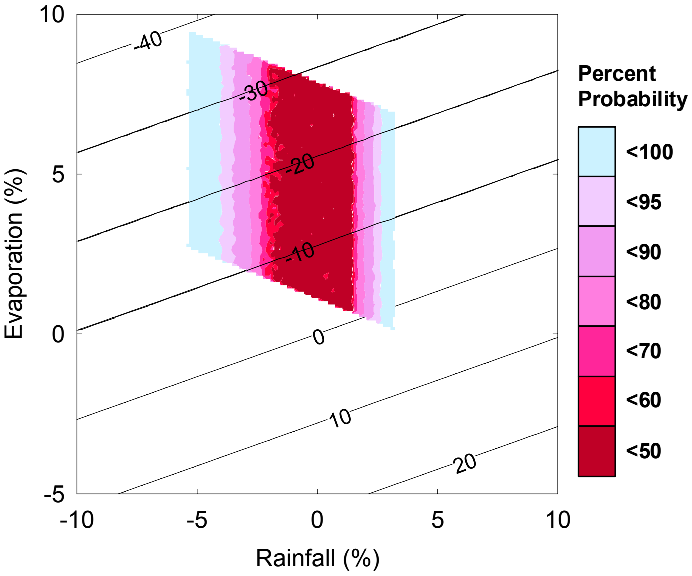

**Figure 3. Response surface showing relationship between change in P, Ep and P-Ep deficit (the black lines) and sampled future climate for the NW reference point in 2030 (shaded area). The probabilities in the shaded area are cumulative and are tallied from the most likely to the leat likely outcomes**

Sampling to measure the 50th and 95th percentile of change in E-Ep deficit proceeds from the lower right corner of the parallelogram in Figure 3, which marks the most positive change in P-Ep deficit, to the upper right corner which marks the most negative deficit. The probability distribution for these data is shown in Figure 4. The 50th percentile is the average outcome of the sample (approximately 18 mm from Figure 3). The 95th percentile was determined on the basis of annual Ep, and was converted into seasonal values using the assumption that each season changes by the same probability (four independent samples of a low probability have an even lower probability of occurring simultaneously), so the contributing probability here is about 81% (approximately 25 mm).

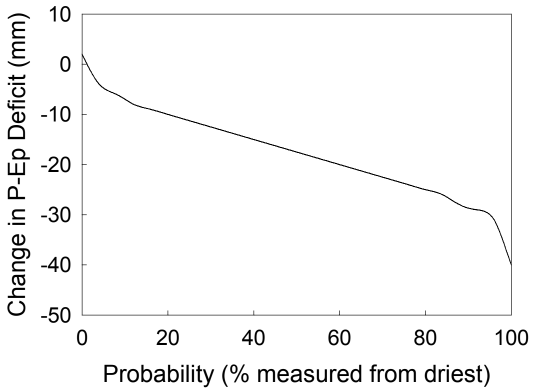

**Figure 4. Probability distribution (tallied from driest to wettest outcome) shown as a function of the change in P-Ep deficit**

The distribution on Figures 3 and 4, while only one of the four reference points and seasons sampled, is typical of the distributions obtained at all four reference points for all four seasons. For instance, for the NW reference point, less than 10% of samples for each of the seasons showed a net increase in moisture tallied in terms of E-Ep. Winter, at the driest end of changes showed <0.5% of samples with increasing P-Ep (Figure 4). These changes help explain why the difference between the 50th and 95th percentile scenarios are not as large as might be assumed for streamflow. As net increases in P-Ep are low probability outcomes on the basis of the analyses shown here, one must assume that the probability of current rates of streamflow being maintained in the Cotton Rivers Region is also low. Just how low this probability is, is a major aim of the RIRDC-funded project currently being conducted by the research team.

## ***Summary***

In this project, sampling strategies have generated 50,000 scenarios for four reference points across four seasons that have been used to produce a probability distribution for changes to the P-Ep deficit in 2030. Based on the 50th and 95th percentile outcomes, measured towards the dry end of possible future climates, a series of reference scenarios for changes to monthly P and Ep in 2030 have been produced. These have been interpolated over the Cotton Rivers Region and matched to specific climate stations so that P and Ep inputs into the IQQM model can be altered to simulate streamflow under climate change.

However, we advise against using the quantified 50th and 95th percentiles too literally. Other sampling strategies, using a wider range of models, a different range of global warming in 2030, and the sampling of Ep as a function of global warming would alter the resultant probability distributions. Despite this caveat, the broad pattern of outcomes is robust with respect to our current knowledge of how climate may change in Australia. In particular, the 50th percentile outcome appears to be a reasonable estimate of a median change in 2030.

With respect to these outcomes:

- Most climate models project rainfall decreases over most of Australia.
- Potential evaporation will increase over almost all areas in response to climate change.
- Due to their inverse relationship, decreases in rainfall are likely to produce relatively larger increases in potential evaporation than would occur if rainfall increased.

The likelihood that these outcomes will reduce streamflow in an environment of increasing demand, and where water quality and environmental river flow regimes need to be improved, requires further investigation, particularly where planning horizons exceed a period of 25 years.

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# Appendix 2: River Flow Modelling – Gwydir River System

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## ***Introduction***

The hydrologic modelling for this investigation involves translating the estimates of rainfall and potential evaporation changes from climate change scenarios into impacts on the surface water regime of the Gwydir River Valley. In addition, assessment is required of the behaviour of flows due to water allocation and operational management of the regulated lower part of this system. For the Gwydir System, water sharing and operating policy includes making provision for the Gwydir Wetlands located downstream of Yarraman.

## ***Methodology for predicting the effect of climate change scenarios***

The analysis used the observed rainfall data for the past 109 years for the Gwydir Valley and synthetically generated potential evaporation data. The modelling hypothesis assumes that the spatial and seasonal rainfall and potential evaporation changes supplied by the CSIRO for each of the specified climate change scenarios are directly applicable to the historic data set. This applies to both the generation of climate change induced streamflow changes and modification of the rainfall and potential evaporation data used to generate crop demands in the planning simulation model of the regulated Gwydir System.

Two models are involved in predicting the effect of the climate change scenarios. Firstly, the modified rainfall and potential evaporation will affect run-off characteristics in the catchment. These changes are modelled using the Sacramento model (Burnash et al. 1984). The modified rainfall and potential evaporation will also affect crop water requirements and therefore irrigation demands. These changes were modelled using a river basin model which contains representations of all the physical details (dams, river reaches, demand centres, etc.) and management/operation rules of the river system. This model is called the 'Integrated Quantity and Quality Model' or IQQM [Department of Land and Water Conservation, 1995a]. Currently, IQQM is set up or being set up in most regulated river systems in New South Wales.

### Sacramento rainfall-runoff model

A process model is required to translate the spatial and temporal rainfall and potential evaporation changes into changes in river flows across the basin. This type of model is commonly referred to as a rainfall-runoff model. The standard model used by DLWC is known as the Sacramento model. It is a physically based lumped parameter rainfall-runoff model that was developed by the National Weather Service, California, USA. 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 the precipitation. Sixteen parameters define these stores and the associated flow characteristics, of which ten have the most significant effect on the calibration.

The values for all sixteen parameters are derived based on calibration with observed streamflows. Burnash et al. (1984) describes storage details, their interactions, and procedures and guidelines for initial parameter estimations.

### Application of Sacramento model to the Gwydir Valley

The Gwydir Valley was divided into twelve sub-catchments, each of which is modelled directly using the Sacramento model. The model was calibrated for each sub-catchment against a long period of historical streamflow, with historical rainfall and mainly generated potential evaporation data as model input. Regression based methods were used to estimate the contributions from residual, or ungauged portions of the catchments [Department of Land and Water Conservation, 1995b]. Six catchments downstream of Copeton Dam were modelled using the Sacramento model, including the Keera, Myall, Warialda, Tycannah and Halls Creeks and Horton River. Six catchments upstream of Copeton Dam were modelled including Georges, Laura, Bakers, Copes, Moredun and Stonybatter Creeks.

The calibrated rainfall runoff model was then used to generate a base case flow regime, using the full 109 year record of observed climatic data. Two streamflow sequences of the same length were also generated for the climate change scenarios, based on changes to the rainfall and potential evaporation records for the above listed catchments.

The simulated 109 year streamflow sequences from the Sacramento model for each of the 12 sub-catchments listed above and contributions from residual or ungauged portions of the catchments were input as point inflows to the Gwydir IQQM at the relevant locations within the system.

### IQQM river basin simulation model

IQQM is being developed as a tool for planning and evaluating water resource management policies at the river basin scale. It is a generic river basin simulation package, which simulates processes in a river system at a time step of one day and has an option to use smaller time steps for carrying out flow routing. This model can be used for application to regulated and unregulated streams, and is being developed to address water quality and environmental issues, as well as water quantity issues. A detailed description of the model is given in the Reference Manual for IQQM [Department of Land and Water Conservation, 1995a].

### Application of IQQM to the Gwydir River Valley

To apply IQQM to a river system, it is necessary to configure the model to represent the physical features and the management/operation of the system. Configuring for the physical features of the system includes defining locations of storages, demand centres, tributary inflows, effluent outflows and returns, characteristics of wetlands and floodplain detention storages and limits of flow routing reaches. Configuring for the management/operation of the system includes defining stretches of river considered for off-allocation assessment, dividing the river system into allocation systems and defining system operating rules and resource assessment procedures.

The IQQM is set up to model the Gwydir River System between Copeton Dam and Collarenebri. The Gwydir IQQM incorporates:

- System inflows from tributaries upstream and downstream of Copeton Dam;
- Operation of Copeton Dam and Tareelaroi Weir;
- Demands from two town water supplies (Bingara and Gravesend);
- Main stream outflows to represent the various effluents/anabranches;
- Irrigation demands;
- Minimum flow requirements;
- Environmental flow requirements (Gwydir Wetlands and replenishments for Gingham Watercourse, Lower Gwydir, Thalaba Creek, Mallowa Creek and Ballin Boora Creek).

It is currently being used to investigate water sharing and management options for the Gwydir Wetlands. For this application, a number of different management scenarios have been investigated with the aim of optimising the flow regime for the Wetlands while minimising impacts on consumptive users. For this study, the management scenario chosen for comparison of the climate change scenarios is defined as follows:

| | |
|---|---|
| Management Rules : | as in place during the 1993/94 water year |
| Development Conditions : | as in place during the 1993/94 water year. |

### ***Climate change scenarios***

The CSIRO provided the DLWC Surface and Groundwater Processes Unit climatic change information in the form of percentage changes in precipitation and potential evaporation for each month of the year for each rainfall and evaporation station in the catchment. The percentage changes for the 95%ile and 50%ile climate change scenarios referred to in Section 2XX of this report were relative to the Base Scenario, which represents historic climatic conditions over the past 109 years. The adopted percentage changes for each rainfall and evaporation station used in the Sacramento model are listed in Tables 1, 2, 5 and 6.

Similarly, the representative rainfall and evaporation stations used for the irrigation demand modelling were adjusted as per the changes provided for each rainfall and evaporation station used in the irrigation demand modelling are listed in Tables 3, 4, 7 and 8.

**Table 1: 50%ile Scenario - Climate change factors (Sacramento rainfall stations)**

| Rainfall Station | Factors Adopted | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
| Stonybatter | | | | | | | | | | | | |
| 056028 | 1.01 | 1.02 | 1.02 | 1.01 | 1.01 | 1.00 | 1.00 | 0.99 | 0.99 | 0.99 | 0.98 | 1.00 |
| 056006 | 1.01 | 1.02 | 1.02 | 1.01 | 1.01 | 1.00 | 1.00 | 0.99 | 0.99 | 0.99 | 0.98 | 1.00 |
| 056016 | 1.01 | 1.02 | 1.02 | 1.01 | 1.01 | 1.00 | 0.99 | 0.99 | 0.99 | 0.99 | 0.98 | 1.00 |
| Laura | | | | | | | | | | | | |
| 056036 | 1.01 | 1.02 | 1.02 | 1.01 | 1.01 | 1.00 | 1.00 | 0.99 | 0.99 | 0.99 | 0.98 | 1.00 |
| 056016 | 1.01 | 1.02 | 1.02 | 1.01 | 1.01 | 1.00 | 0.99 | 0.99 | 0.99 | 0.99 | 0.98 | 1.00 |
| 056006 | 1.01 | 1.02 | 1.02 | 1.01 | 1.01 | 1.00 | 1.00 | 0.99 | 0.99 | 0.99 | 0.98 | 1.00 |
| Georges | | | | | | | | | | | | |
| 056036 | 1.01 | 1.02 | 1.02 | 1.01 | 1.01 | 1.00 | 1.00 | 0.99 | 0.99 | 0.99 | 0.98 | 1.00 |
| 056016 | 1.01 | 1.02 | 1.02 | 1.01 | 1.01 | 1.00 | 0.99 | 0.99 | 0.99 | 0.99 | 0.98 | 1.00 |
| 056006 | 1.01 | 1.02 | 1.02 | 1.01 | 1.01 | 1.00 | 1.00 | 0.99 | 0.99 | 0.99 | 0.98 | 1.00 |
| Moredun | | | | | | | | | | | | |
| 056036 | 1.01 | 1.02 | 1.02 | 1.01 | 1.01 | 1.00 | 1.00 | 0.99 | 0.99 | 0.99 | 0.98 | 1.00 |
| 056006 | 1.01 | 1.02 | 1.02 | 1.01 | 1.01 | 1.00 | 1.00 | 0.99 | 0.99 | 0.99 | 0.98 | 1.00 |
| Bakers | | | | | | | | | | | | |
| 056006 | 1.01 | 1.02 | 1.02 | 1.01 | 1.01 | 1.00 | 1.00 | 0.99 | 0.99 | 0.99 | 0.98 | 1.00 |
| Copes | | | | | | | | | | | | |
| 056036 | 1.01 | 1.02 | 1.02 | 1.01 | 1.01 | 1.00 | 1.00 | 0.99 | 0.99 | 0.99 | 0.98 | 1.00 |
| 056006 | 1.01 | 1.02 | 1.02 | 1.01 | 1.01 | 1.00 | 1.00 | 0.99 | 0.99 | 0.99 | 0.98 | 1.00 |
| Keera | | | | | | | | | | | | |
| 054039 | 1.01 | 1.02 | 1.02 | 1.01 | 1.01 | 1.00 | 1.00 | 0.99 | 0.99 | 0.99 | 0.98 | 1.00 |
| 056006 | 1.01 | 1.02 | 1.02 | 1.01 | 1.01 | 1.00 | 1.00 | 0.99 | 0.99 | 0.99 | 0.98 | 1.00 |
| Myall | | | | | | | | | | | | |
| 054029 | 1.01 | 1.02 | 1.02 | 1.02 | 1.01 | 1.01 | 1.00 | 0.99 | 0.99 | 0.99 | 0.99 | 1.00 |
| 054039 | 1.01 | 1.02 | 1.02 | 1.02 | 1.01 | 1.00 | 1.00 | 0.99 | 0.99 | 0.99 | 0.98 | 1.00 |
| 054004 | 1.01 | 1.02 | 1.02 | 1.01 | 1.01 | 1.00 | 1.00 | 0.99 | 0.99 | 0.99 | 0.99 | 1.00 |
| Horton | | | | | | | | | | | | |
| 054039 | 1.01 | 1.02 | 1.02 | 1.02 | 1.01 | 1.00 | 1.00 | 0.99 | 0.99 | 0.99 | 0.98 | 1.00 |
| 054004 | 1.01 | 1.02 | 1.02 | 1.01 | 1.01 | 1.00 | 1.00 | 0.99 | 0.99 | 0.99 | 0.99 | 1.00 |
| 054021 | 1.01 | 1.02 | 1.02 | 1.02 | 1.01 | 1.01 | 1.00 | 0.99 | 0.99 | 0.99 | 0.99 | 1.00 |
| Halls | | | | | | | | | | | | |
| 054004 | 1.01 | 1.02 | 1.02 | 1.01 | 1.01 | 1.00 | 1.00 | 0.99 | 0.99 | 0.99 | 0.99 | 1.00 |
| 054039 | 1.01 | 1.02 | 1.02 | 1.02 | 1.01 | 1.00 | 1.00 | 0.99 | 0.99 | 0.99 | 0.98 | 1.00 |
| Warialda | | | | | | | | | | | | |
| 054029 | 1.01 | 1.02 | 1.02 | 1.02 | 1.01 | 1.01 | 1.00 | 0.99 | 0.99 | 0.99 | 0.99 | 1.00 |
| 054039 | 1.01 | 1.02 | 1.02 | 1.02 | 1.01 | 1.00 | 1.00 | 0.99 | 0.99 | 0.99 | 0.98 | 1.00 |
| 054004 | 1.01 | 1.02 | 1.02 | 1.01 | 1.01 | 1.00 | 1.00 | 0.99 | 0.99 | 0.99 | 0.99 | 1.00 |
| Tycannah | | | | | | | | | | | | |
| 054017 | 1.01 | 1.02 | 1.02 | 1.02 | 1.02 | 1.01 | 1.00 | 0.99 | 0.99 | 0.99 | 0.98 | 1.00 |
| 054004 | 1.01 | 1.02 | 1.02 | 1.02 | 1.01 | 1.01 | 1.00 | 0.99 | 0.99 | 0.99 | 0.98 | 1.00 |
| 054021 | 1.01 | 1.02 | 1.02 | 1.02 | 1.01 | 1.01 | 1.00 | 0.99 | 0.99 | 0.99 | 0.99 | 1.00 |

### Table 2: 50%ile Scenario - Climate change factors (Sacramento evaporation stations)

| Evaporation Station | Factors Adopted | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
| Stonybatter 095008 | 1.04 | 1.03 | 1.04 | 1.04 | 1.04 | 1.05 | 1.05 | 1.05 | 1.05 | 1.05 | 1.05 | 1.05 |
| Laura 056016 | 1.04 | 1.03 | 1.04 | 1.04 | 1.04 | 1.05 | 1.05 | 1.05 | 1.05 | 1.05 | 1.05 | 1.05 |
| Georges 056016 | 1.04 | 1.03 | 1.04 | 1.04 | 1.04 | 1.05 | 1.05 | 1.05 | 1.05 | 1.05 | 1.05 | 1.05 |
| Moredun 056016 | 1.04 | 1.03 | 1.04 | 1.04 | 1.04 | 1.05 | 1.05 | 1.05 | 1.05 | 1.05 | 1.05 | 1.05 |
| Bakers 056016 | 1.04 | 1.03 | 1.04 | 1.04 | 1.04 | 1.05 | 1.05 | 1.05 | 1.05 | 1.05 | 1.05 | 1.05 |
| Copes 056016 | 1.04 | 1.03 | 1.04 | 1.04 | 1.04 | 1.05 | 1.05 | 1.05 | 1.05 | 1.05 | 1.05 | 1.05 |
| Keera 054039 | 1.04 | 1.04 | 1.04 | 1.04 | 1.04 | 1.04 | 1.05 | 1.05 | 1.05 | 1.05 | 1.05 | 1.05 |
| Myall 054029 | 1.04 | 1.04 | 1.04 | 1.04 | 1.04 | 1.04 | 1.05 | 1.05 | 1.05 | 1.05 | 1.05 | 1.05 |
| Horton 054021 | 1.04 | 1.04 | 1.04 | 1.04 | 1.04 | 1.04 | 1.05 | 1.05 | 1.05 | 1.05 | 1.05 | 1.05 |
| Halls 054004 | 1.04 | 1.04 | 1.04 | 1.04 | 1.04 | 1.04 | 1.05 | 1.05 | 1.05 | 1.05 | 1.05 | 1.05 |
| Warialda 054029 | 1.04 | 1.04 | 1.04 | 1.04 | 1.04 | 1.04 | 1.05 | 1.05 | 1.05 | 1.05 | 1.05 | 1.05 |
| Tycannah 054017 | 1.04 | 1.04 | 1.04 | 1.04 | 1.04 | 1.04 | 1.05 | 1.05 | 1.05 | 1.05 | 1.05 | 1.05 |

### Table 3: 50%ile Scenario - Climate change factors (irrigation demand rainfall stations)

| Rainfall Station | Factors Adopted | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
| Copeton | 1.01 | 1.02 | 1.02 | 1.01 | 1.01 | 1.00 | 1.00 | 0.99 | 0.99 | 0.99 | 0.98 | 1.00 |
| 054039 | 1.01 | 1.02 | 1.02 | 1.01 | 1.01 | 1.00 | 1.00 | 0.99 | 0.99 | 0.99 | 0.98 | 1.00 |
| 054004 | 1.01 | 1.02 | 1.02 | 1.02 | 1.01 | 1.01 | 1.00 | 0.99 | 0.99 | 0.99 | 0.98 | 1.00 |
| 054029 | 1.01 | 1.02 | 1.02 | 1.02 | 1.01 | 1.01 | 1.00 | 0.99 | 0.99 | 0.99 | 0.98 | 1.00 |
| 054021 | 1.01 | 1.02 | 1.02 | 1.02 | 1.01 | 1.01 | 1.00 | 0.99 | 0.99 | 0.99 | 0.99 | 1.00 |
| 054017 | 1.01 | 1.02 | 1.02 | 1.02 | 1.02 | 1.01 | 1.00 | 0.99 | 0.99 | 0.99 | 0.98 | 1.00 |
| 052008 | 1.01 | 1.02 | 1.02 | 1.02 | 1.02 | 1.01 | 1.00 | 0.99 | 0.99 | 0.99 | 0.99 | 1.00 |
| 052019 | 1.01 | 1.02 | 1.02 | 1.02 | 1.03 | 1.01 | 1.00 | 0.99 | 0.99 | 0.99 | 0.99 | 1.00 |
| 048031 | 1.01 | 1.02 | 1.02 | 1.02 | 1.02 | 1.01 | 1.00 | 0.99 | 0.99 | 0.99 | 0.99 | 1.00 |
| 053034 | 1.01 | 1.02 | 1.02 | 1.02 | 1.02 | 1.01 | 1.00 | 0.99 | 0.99 | 0.99 | 0.99 | 1.00 |
| 052020 | 1.01 | 1.02 | 1.02 | 1.02 | 1.02 | 1.01 | 1.00 | 0.99 | 0.99 | 0.99 | 0.99 | 1.00 |
| 052019a | 1.01 | 1.02 | 1.02 | 1.02 | 1.03 | 1.01 | 1.00 | 0.99 | 0.99 | 0.99 | 0.99 | 1.00 |

**Table 4: 50%ile Scenario - Climate change factors (irrigation demand evap. stations)**

| Evaporation Station | Factors Adopted | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
| 048031 | 1.04 | 1.04 | 1.04 | 1.04 | 1.04 | 1.04 | 1.05 | 1.05 | 1.05 | 1.05 | 1.05 | 1.05 |
| 054039 | 1.04 | 1.04 | 1.04 | 1.04 | 1.04 | 1.04 | 1.05 | 1.05 | 1.05 | 1.05 | 1.05 | 1.05 |
| 054029 | 1.04 | 1.04 | 1.04 | 1.04 | 1.04 | 1.04 | 1.05 | 1.05 | 1.05 | 1.05 | 1.05 | 1.05 |
| 054021 | 1.04 | 1.04 | 1.04 | 1.04 | 1.04 | 1.04 | 1.05 | 1.05 | 1.05 | 1.05 | 1.05 | 1.05 |
| Copeton | 1.04 | 1.04 | 1.04 | 1.04 | 1.04 | 1.04 | 1.05 | 1.05 | 1.05 | 1.05 | 1.05 | 1.05 |
| Moree | 1.04 | 1.04 | 1.04 | 1.04 | 1.04 | 1.04 | 1.05 | 1.05 | 1.05 | 1.05 | 1.05 | 1.05 |

**Table 5: 95%ile Scenario - Climate change factors (Sacramento rainfall stations)**

| Rainfall Station | Factors Adopted | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
| Stonybatter | | | | | | | | | | | | |
| 056028 | 1.00 | 1.02 | 1.01 | 1.01 | 1.00 | 0.99 | 0.99 | 0.98 | 0.97 | 0.96 | 0.95 | 0.97 |
| 056006 | 0.99 | 1.01 | 1.01 | 1.01 | 1.00 | 1.00 | 0.99 | 0.98 | 0.97 | 0.96 | 0.95 | 0.97 |
| 056016 | 0.99 | 1.01 | 1.01 | 1.01 | 1.00 | 0.99 | 0.99 | 0.98 | 0.97 | 0.96 | 0.95 | 0.97 |
| Laura | | | | | | | | | | | | |
| 056036 | 0.99 | 1.01 | 1.01 | 1.01 | 1.00 | 0.99 | 0.99 | 0.98 | 0.97 | 0.96 | 0.95 | 0.97 |
| 056016 | 0.99 | 1.01 | 1.01 | 1.01 | 1.00 | 0.99 | 0.99 | 0.98 | 0.97 | 0.96 | 0.95 | 0.97 |
| 056006 | 0.99 | 1.01 | 1.01 | 1.01 | 1.00 | 1.00 | 0.99 | 0.98 | 0.97 | 0.96 | 0.95 | 0.97 |
| Georges | | | | | | | | | | | | |
| 056036 | 0.99 | 1.01 | 1.01 | 1.01 | 1.00 | 0.99 | 0.99 | 0.98 | 0.97 | 0.96 | 0.95 | 0.97 |
| 056016 | 0.99 | 1.01 | 1.01 | 1.01 | 1.00 | 0.99 | 0.99 | 0.98 | 0.97 | 0.96 | 0.95 | 0.97 |
| 056006 | 0.99 | 1.01 | 1.01 | 1.01 | 1.00 | 1.00 | 0.99 | 0.98 | 0.97 | 0.96 | 0.95 | 0.97 |
| Moredun | | | | | | | | | | | | |
| 056036 | 0.99 | 1.01 | 1.01 | 1.01 | 1.00 | 0.99 | 0.99 | 0.98 | 0.97 | 0.96 | 0.95 | 0.97 |
| 056006 | 0.99 | 1.01 | 1.01 | 1.01 | 1.00 | 1.00 | 0.99 | 0.98 | 0.97 | 0.96 | 0.95 | 0.97 |
| Bakers | | | | | | | | | | | | |
| 056006 | 0.99 | 1.01 | 1.01 | 1.01 | 1.00 | 1.00 | 0.99 | 0.98 | 0.97 | 0.96 | 0.95 | 0.97 |
| Copes | | | | | | | | | | | | |
| 056036 | 0.99 | 1.01 | 1.01 | 1.01 | 1.00 | 0.99 | 0.99 | 0.98 | 0.97 | 0.96 | 0.95 | 0.97 |
| 056006 | 0.99 | 1.01 | 1.01 | 1.01 | 1.00 | 1.00 | 0.99 | 0.98 | 0.97 | 0.96 | 0.95 | 0.97 |
| Keera | | | | | | | | | | | | |
| 054039 | 0.99 | 1.01 | 1.01 | 1.01 | 1.01 | 1.00 | 0.99 | 0.98 | 0.97 | 0.96 | 0.95 | 0.97 |
| 056006 | 0.99 | 1.01 | 1.01 | 1.01 | 1.00 | 1.00 | 0.99 | 0.98 | 0.97 | 0.96 | 0.95 | 0.97 |
| Myall | | | | | | | | | | | | |
| 054029 | 0.99 | 1.01 | 1.01 | 1.01 | 1.01 | 1.00 | 0.99 | 0.98 | 0.97 | 0.96 | 0.95 | 0.97 |
| 054039 | 0.99 | 1.01 | 1.01 | 1.01 | 1.01 | 1.00 | 0.99 | 0.98 | 0.97 | 0.96 | 0.95 | 0.97 |
| 054004 | 0.99 | 1.01 | 1.01 | 1.01 | 1.01 | 1.00 | 0.99 | 0.98 | 0.97 | 0.96 | 0.96 | 0.97 |
| Horton | | | | | | | | | | | | |
| 054039 | 0.99 | 1.01 | 1.01 | 1.01 | 1.01 | 1.00 | 0.99 | 0.98 | 0.97 | 0.96 | 0.95 | 0.97 |
| 054004 | 0.99 | 1.01 | 1.01 | 1.01 | 1.01 | 1.00 | 0.99 | 0.98 | 0.97 | 0.96 | 0.96 | 0.97 |
| 054021 | 1.00 | 1.01 | 1.01 | 1.01 | 1.01 | 1.00 | 0.99 | 0.98 | 0.97 | 0.97 | 0.96 | 0.98 |
| Halls | | | | | | | | | | | | |
| 054004 | 0.99 | 1.01 | 1.01 | 1.01 | 1.01 | 1.00 | 0.99 | 0.98 | 0.97 | 0.96 | 0.96 | 0.97 |
| 054039 | 0.99 | 1.01 | 1.01 | 1.01 | 1.01 | 1.00 | 0.99 | 0.98 | 0.97 | 0.96 | 0.95 | 0.97 |
| Warialda | | | | | | | | | | | | |
| 054029 | 0.99 | 1.01 | 1.01 | 1.01 | 1.01 | 1.00 | 0.99 | 0.98 | 0.97 | 0.96 | 0.95 | 0.97 |
| 054039 | 0.99 | 1.01 | 1.01 | 1.01 | 1.01 | 1.00 | 0.99 | 0.98 | 0.97 | 0.96 | 0.95 | 0.97 |
| 054004 | 0.99 | 1.01 | 1.01 | 1.01 | 1.01 | 1.00 | 0.99 | 0.98 | 0.97 | 0.96 | 0.96 | 0.97 |
| Tycannah | | | | | | | | | | | | |
| 054017 | 0.99 | 1.01 | 1.01 | 1.01 | 1.01 | 1.00 | 0.99 | 0.98 | 0.97 | 0.96 | 0.96 | 0.97 |
| 054004 | 0.99 | 1.01 | 1.01 | 1.01 | 1.01 | 1.00 | 0.99 | 0.98 | 0.97 | 0.96 | 0.96 | 0.97 |
| 054021 | 1.00 | 1.01 | 1.01 | 1.01 | 1.01 | 1.00 | 0.99 | 0.98 | 0.97 | 0.97 | 0.96 | 0.98 |

**Table 6: 95%ile Scenario - Climate change factors (Sacramento evaporation stations)**

| Evaporation Station | Factors Adopted | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
| Stonybatter<br>095008 | 1.06 | 1.06 | 1.06 | 1.06 | 1.06 | 1.06 | 1.07 | 1.07 | 1.07 | 1.07 | 1.07 | 1.06 |
| Laura<br>056016 | 1.06 | 1.06 | 1.06 | 1.06 | 1.06 | 1.06 | 1.07 | 1.07 | 1.07 | 1.07 | 1.07 | 1.06 |
| Georges<br>056016 | 1.06 | 1.06 | 1.06 | 1.06 | 1.06 | 1.06 | 1.07 | 1.07 | 1.07 | 1.07 | 1.07 | 1.06 |
| Moredun<br>056016 | 1.06 | 1.06 | 1.06 | 1.06 | 1.06 | 1.06 | 1.07 | 1.07 | 1.07 | 1.07 | 1.07 | 1.06 |
| Bakers<br>056016 | 1.06 | 1.06 | 1.06 | 1.06 | 1.06 | 1.06 | 1.07 | 1.07 | 1.07 | 1.07 | 1.07 | 1.06 |
| Copes<br>056016 | 1.06 | 1.06 | 1.06 | 1.06 | 1.06 | 1.06 | 1.07 | 1.07 | 1.07 | 1.07 | 1.07 | 1.06 |
| Keera<br>054039 | 1.06 | 1.06 | 1.06 | 1.06 | 1.06 | 1.06 | 1.07 | 1.07 | 1.07 | 1.07 | 1.07 | 1.07 |
| Myall<br>054029 | 1.06 | 1.06 | 1.06 | 1.06 | 1.06 | 1.06 | 1.07 | 1.07 | 1.07 | 1.07 | 1.07 | 1.07 |
| Horton<br>054021 | 1.06 | 1.06 | 1.06 | 1.06 | 1.06 | 1.06 | 1.07 | 1.07 | 1.07 | 1.07 | 1.07 | 1.07 |
| Halls<br>054004 | 1.06 | 1.06 | 1.06 | 1.06 | 1.06 | 1.06 | 1.07 | 1.07 | 1.07 | 1.07 | 1.07 | 1.07 |
| Warialda<br>054029 | 1.06 | 1.06 | 1.06 | 1.06 | 1.06 | 1.06 | 1.07 | 1.07 | 1.07 | 1.07 | 1.07 | 1.07 |
| Tycannah<br>054017 | 1.06 | 1.06 | 1.06 | 1.06 | 1.06 | 1.06 | 1.07 | 1.07 | 1.07 | 1.07 | 1.07 | 1.07 |

**Table 7: 95%ile Scenario - Climate change factors (irrigation demand rainfall stations)**

| Rainfall Station | Factors Adopted | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
| Copeton | 0.99 | 1.01 | 1.01 | 1.01 | 1.01 | 1.00 | 0.99 | 0.98 | 0.97 | 0.96 | 0.95 | 0.97 |
| 054039 | 0.99 | 1.01 | 1.01 | 1.01 | 1.01 | 1.00 | 0.99 | 0.98 | 0.97 | 0.96 | 0.95 | 0.97 |
| 054004 | 0.99 | 1.01 | 1.01 | 1.01 | 1.01 | 1.00 | 0.99 | 0.98 | 0.97 | 0.96 | 0.96 | 0.97 |
| 054029 | 0.99 | 1.01 | 1.01 | 1.01 | 1.01 | 1.00 | 0.99 | 0.98 | 0.97 | 0.96 | 0.95 | 0.97 |
| 054021 | 1.00 | 1.01 | 1.01 | 1.01 | 1.01 | 1.00 | 0.99 | 0.98 | 0.97 | 0.97 | 0.96 | 0.98 |
| 054017 | 0.99 | 1.01 | 1.01 | 1.01 | 1.01 | 1.00 | 0.99 | 0.98 | 0.97 | 0.96 | 0.96 | 0.97 |
| 052008 | 1.00 | 1.01 | 1.01 | 1.02 | 1.02 | 1.01 | 1.00 | 0.99 | 0.98 | 0.97 | 0.96 | 0.98 |
| 052019 | 0.99 | 1.01 | 1.01 | 1.02 | 1.02 | 1.01 | 1.00 | 0.99 | 0.98 | 0.97 | 0.96 | 0.98 |
| 048031 | 1.00 | 1.01 | 1.01 | 1.02 | 1.02 | 1.01 | 1.00 | 0.99 | 0.98 | 0.97 | 0.96 | 0.98 |
| 053034 | 1.00 | 1.02 | 1.02 | 1.02 | 1.02 | 1.01 | 1.00 | 0.99 | 0.98 | 0.97 | 0.96 | 0.98 |
| 052020 | 0.99 | 1.01 | 1.01 | 1.02 | 1.02 | 1.01 | 1.00 | 0.99 | 0.98 | 0.97 | 0.96 | 0.98 |
| 052019a | 0.99 | 1.01 | 1.01 | 1.02 | 1.02 | 1.01 | 1.00 | 0.99 | 0.98 | 0.97 | 0.96 | 0.98 |

**Table 8: 95%ile Scenario - Climate change factors (irrigation demand evap. stations)**

| Evap. Station | Factors Adopted | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
| 048031 | 1.06 | 1.06 | 1.06 | 1.06 | 1.06 | 1.06 | 1.07 | 1.07 | 1.07 | 1.07 | 1.07 | 1.07 |
| 054039 | 1.06 | 1.06 | 1.06 | 1.06 | 1.06 | 1.06 | 1.07 | 1.07 | 1.07 | 1.07 | 1.07 | 1.07 |
| 054029 | 1.06 | 1.06 | 1.06 | 1.06 | 1.06 | 1.06 | 1.07 | 1.07 | 1.07 | 1.07 | 1.07 | 1.07 |
| 054021 | 1.06 | 1.06 | 1.06 | 1.06 | 1.06 | 1.06 | 1.07 | 1.07 | 1.07 | 1.07 | 1.07 | 1.07 |
| Copeton | 1.06 | 1.06 | 1.06 | 1.06 | 1.06 | 1.06 | 1.07 | 1.07 | 1.07 | 1.07 | 1.07 | 1.07 |
| Moree | 1.06 | 1.06 | 1.06 | 1.06 | 1.06 | 1.06 | 1.07 | 1.07 | 1.07 | 1.07 | 1.07 | 1.07 |

***Results for changes in runoff (from Sacramento model).***

This section is based on the streamflows generated by the Sacramento model for the period 1892 to 1997. The general increases in potential evaporation and decreases in rainfall provided by CSIRO, when input into the Sacramento Model reduced the total streamflow for all sub-catchments of the Gwydir Valley, for both the 50%ile and 95%ile scenarios.

The average sub-catchment streamflow decrease for the 50%ile and 95%ile scenarios was 11% and 18% respectively. Table 9 lists the total estimated flows both upstream and downstream of Copeton Dam for the period 1890 to 1997 for the base case and the two climate change scenarios.

**Table 9 Average annual system inflows (GL) for 1890-1999**

| Catchment | Base Case | 50%ile Case | | 95%ile Case | |
|---|---|---|---|---|---|
| | Total Vol. (GL) | Total Vol. (GL) | Change (%) | Total Vol. (GL) | Change (%) |
| Upstream Copeton Dam | 41540 | 37058 | -11 | 34083 | -18 |
| Downstream Copeton Dam | 159600 | 141800 | -11 | 130600 | -18 |
| Overall | 201140 | 178858 | -11 | 164683 | -18 |

**Copeton Dam inflows**

Copeton Dam is the major reservoir in the Gwydir River System and changes to reservoir inflows have a significant impact on regulated water supply. The plot of daily inflow duration curves for the 50%ile scenario (Figure 1) shows that the Sacramento model produced consistently lower flows in all ranges compared to the base case. A similar pattern is visible for the 95%ile scenario (Figure 2). The annual flow duration curves for the base case and the two climate change scenarios are shown in Figure 3.

The monthly average Base, 50%ile and 95%ile scenario inflows to Copeton Dam for the 1892-1997 period are listed in Table 10 and plotted in Figure 4.

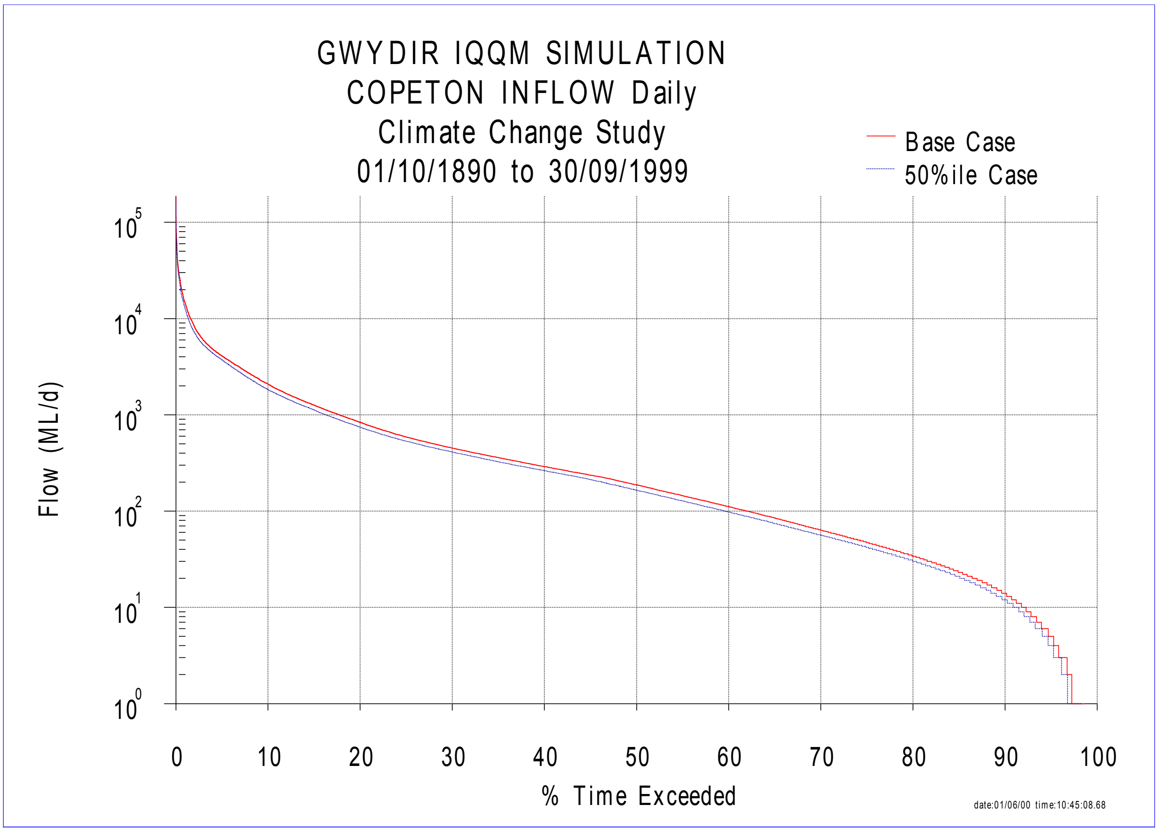

**Figure 1: Daily Inflows into Copeton Dam (Base vs 50%ile Case)**

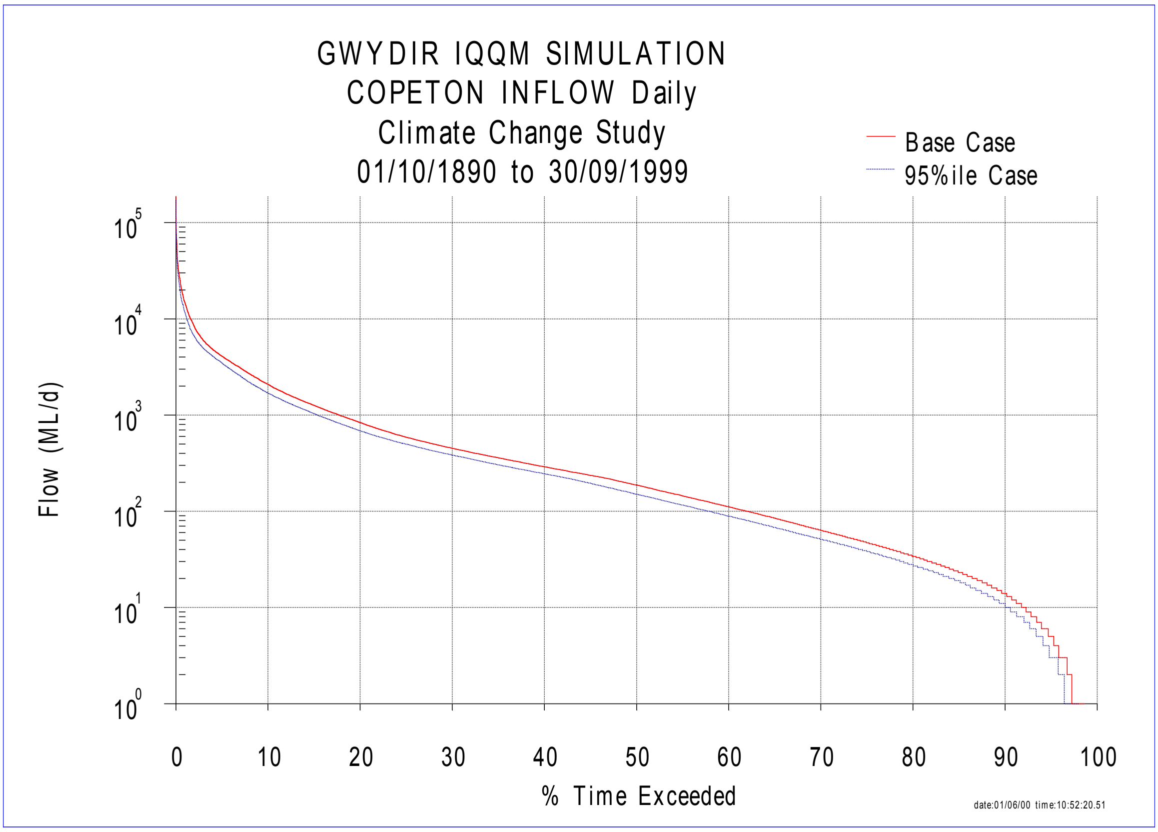

**Figure 2: Daily Inflows into Copeton Dam (Base vs 95%ile Case)**

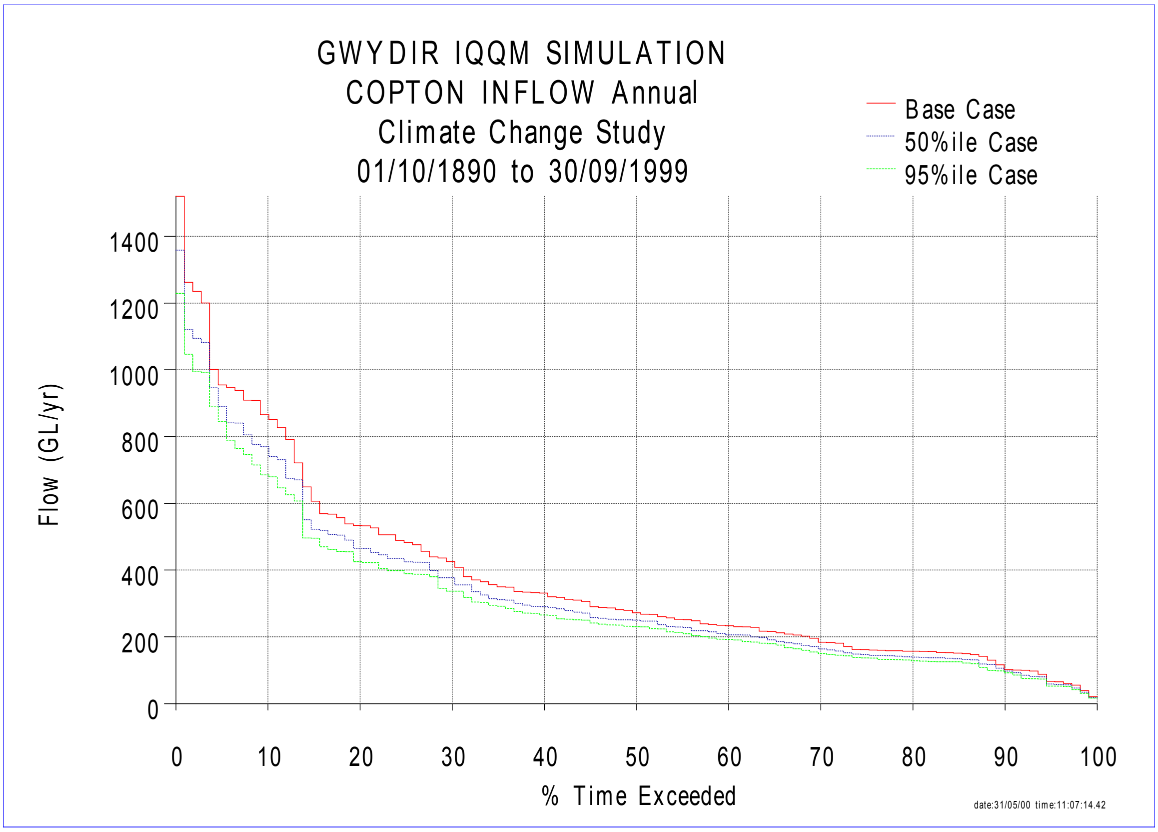

Figure 3: Annual Inflows into Copeton Dam

## Table 10: Monthly Average Copeton Inflows

| **Month** | **Base Case** | **50%ile Case** | | **95%ile Case** | |
|---|---|---|---|---|---|
| | Vol. (GL) | Vol. (GL) | Change (%) | Vol. (GL) | Change (%) |
| January | 48 | 44 | -10 | 40 | -18 |
| February | 42 | 40 | -4 | 38 | -11 |
| March | 27 | 26 | -3 | 25 | -9 |
| April | 18 | 17 | -5 | 16 | -10 |
| May | 19 | 17 | -8 | 16 | -13 |
| June | 34 | 31 | -9 | 29 | -13 |
| July | 40 | 36 | -10 | 34 | -15 |
| August | 26 | 22 | -13 | 21 | -19 |
| September | 27 | 23 | -15 | 21 | -22 |
| October | 35 | 28 | -20 | 25 | -29 |
| November | 35 | 29 | -17 | 25 | -28 |
| December | 27 | 23 | -14 | 20 | -25 |
| Annual | 379 | 338 | -11 | 311 | -18 |

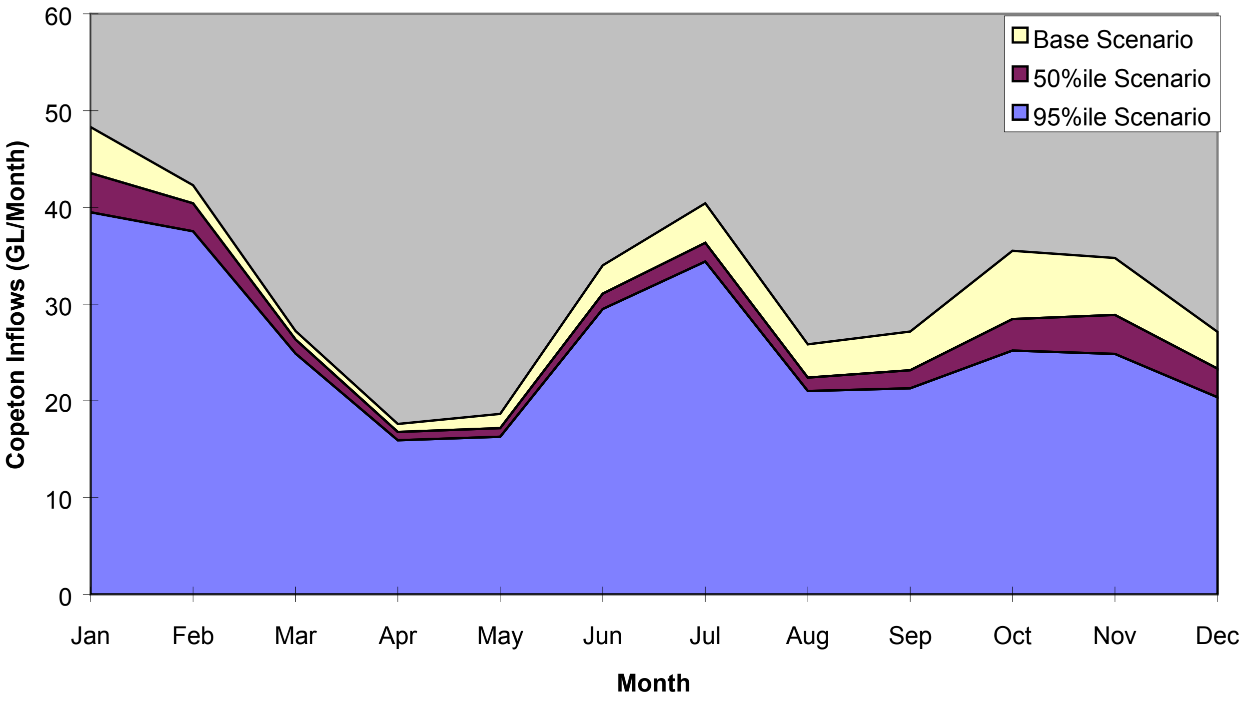

**Figure 4: Monthly average Copeton Dam inflows for 1892-1997 period**

***Results for changes in crop demands (from Gwydir IQQM)***

As described previously, Gwydir IQQM is a planning model that simulates the behaviour of the Gwydir River system over a long period of records. The modelling assumes that infrastructure (storages, irrigation development, towns) and operating rules (water allocation and river operation, environmental replenishments, etc) are stationary during this time frame. Thus the model indicates how the system (infrastructure and rules) would behave over a long climatic sequence. This applies equally for the Base Scenario climatic record, as well as for the modified flows and climate for each of the climate change scenarios. Models such as IQQM enable testing of a large range of policies or operating rules, to see how the system would respond over a long sequence of years. This case is different in that the operating rules and infrastructure have not been altered, but the climate has been changed.

***Regulated Gwydir system allocation reliability***

IQQM models water availability for normal security irrigators in terms of announced allocations. An allocation announcement at the start of any water year represents the proportion of an irrigator's entitlement that will be available for that season. The allocation is progressively reviewed if resources improve, up to a maximum announcement of 100% of entitlement for the water year. Given that the calculations made to determine this allocation are very conservative (it assumes future inflows to the system will be equivalent to the minimum observed during the 109 year climatic record), the allocation has minimal risk of reducing over the year. This conservative approach also means that even if initial allocations are low, the likelihood of an improvement is very high.

The security of water supply for irrigation in the Gwydir system is described in terms of system reliability. This is indicated by the allocation announcement on the 1st of January in any water year added to the amount of carry over at the start of that water year. Taking the January announcement gives a balanced picture of the probability of water availability, given that the conservative allocation process will usually under-allocate early in the year and that improvement in allocation after January may not be particularly useful to many irrigators. The carry over at the start of the water year must be included because it contributes to the total amount of water available in that year.

The reduced inflow to Copeton Dam has the effect of a corresponding reduction in the allocation reliability for general security irrigators. Figure 5 and Table 11 show the relative effects of each of the scenarios on allocation reliability.

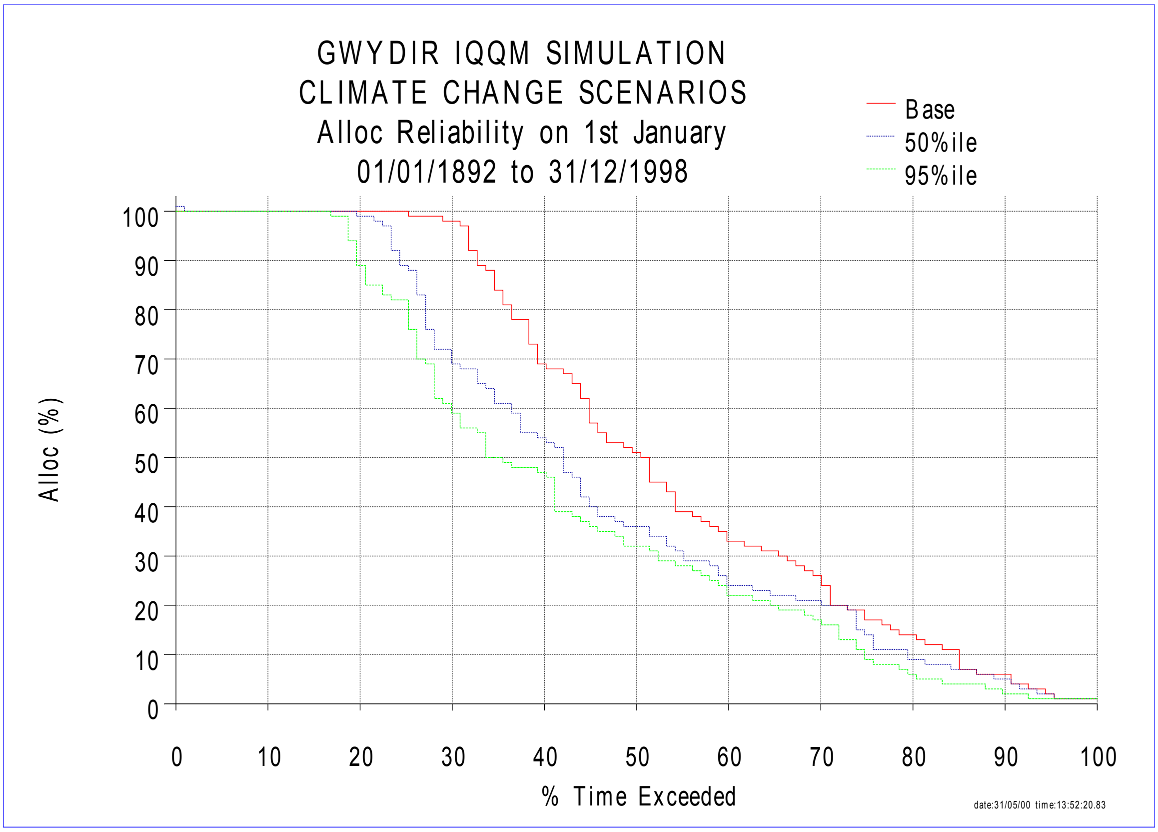

**Figure 5 Allocation Reliability on 1st January**

### Table 11: Reliability of allocation + carry over being equalled or exceeded on 1st January

| Allocation Level (%) | System Reliability (%) | | |
|---|---|---|---|
| | Base Scenario | 50%ile Scenario | 95%ile Scenario |
| 100 | 25 | 20 | 17 |
| 80 | 36 | 27 | 25 |
| 60 | 45 | 37 | 30 |
| 40 | 54 | 45 | 41 |
| 20 | 73 | 70 | 65 |
| 1 | 95 | 95 | 92 |

## ***Irrigation diversions***

The model computes the required river diversions to satisfy crop demands, either from off-allocation sources or water ordered from headwater storages. Off-allocation water can be used directly to water crops or be stored in on-farm storages for use at a later time. Table 12 shows a comparison between the on-allocation, off-allocation and total diversions for each of the scenarios.

### Table 12 Comparison of Average Annual Diversions (GL/Year)

| | Average Annual Diversions (GL) | | |
|---|---|---|---|
| | Base Scenario | 50%ile Scenario | 95%ile Scenario |
| On-Allocation | 141 | 134 | 126 |
| Off-Allocation | 209 | 192 | 183 |
| Total | 350 | 326 | 309 |

## ***Results for changes in Gwydir Wetlands Inflows***

Table 13 lists the mean and median annual inflows to the marshes (measured as surplus flow at Gwydir River at Yarraman) for the period 1890 to 1999 for all scenarios.

### Table 13: Average Annual Inflows to Gwydir Wetlands (GL) for 1890-1999

| | Average Annual Gwydir Wetlands Inflows (GL) | | |
|---|---|---|---|
| | Base Scenario | 50%ile Scenario | 95%ile Scenario |
| Mean | 238 | 209 | 187 |
| Median | 151 | 134 | 123 |

The annual flow duration curves for the three scenarios are shown in Figure 6.

The monthly average Base, 50%ile and 95%ile Scenario inflows to the Gwydir Wetlands for the 1890-1999 period are listed in Table 14 and plotted in Figure 7. The monthly average flows generally decrease for both climate change cases. The reduction in flows appears to be most significant in the months outside the major period of irrigation demands.

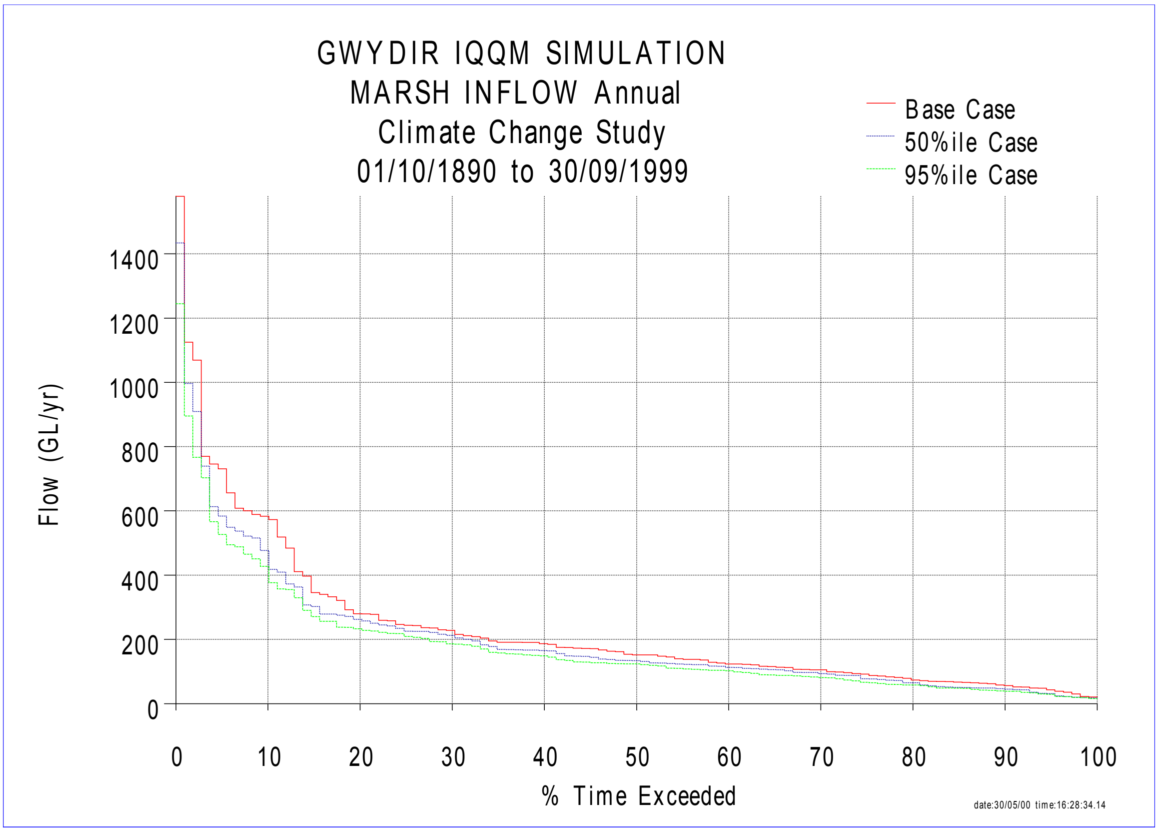

Figure 6: Annual Inflows into Gwydir Wetlands

**Table 14: Monthly Average Gwydir Wetlands Inflows**

| **Month** | **Base Case** | **Low Case** | | **High Case** | |
|---|---|---|---|---|---|
| | Vol. (GL) | Vol. (GL) | Change (%) | Vol. (GL) | Change (%) |
| January | 41 | 38 | -6 | 35 | -15 |
| February | 37 | 35 | -7 | 32 | -14 |
| March | 18 | 18 | -2 | 17 | -10 |
| April | 09 | 09 | -5 | 08 | -12 |
| May | 11 | 10 | -12 | 09 | -19 |
| June | 17 | 14 | -15 | 13 | -25 |
| July | 24 | 20 | -14 | 18 | -22 |
| August | 13 | 11 | -16 | 10 | -22 |
| September | 11 | 09 | -17 | 09 | -26 |
| October | 18 | 13 | -26 | 11 | -41 |
| November | 20 | 15 | -18 | 12 | -39 |
| December | 18 | 16 | -13 | 14 | -24 |
| Year | 238 | 209 | -12 | 187 | -21 |

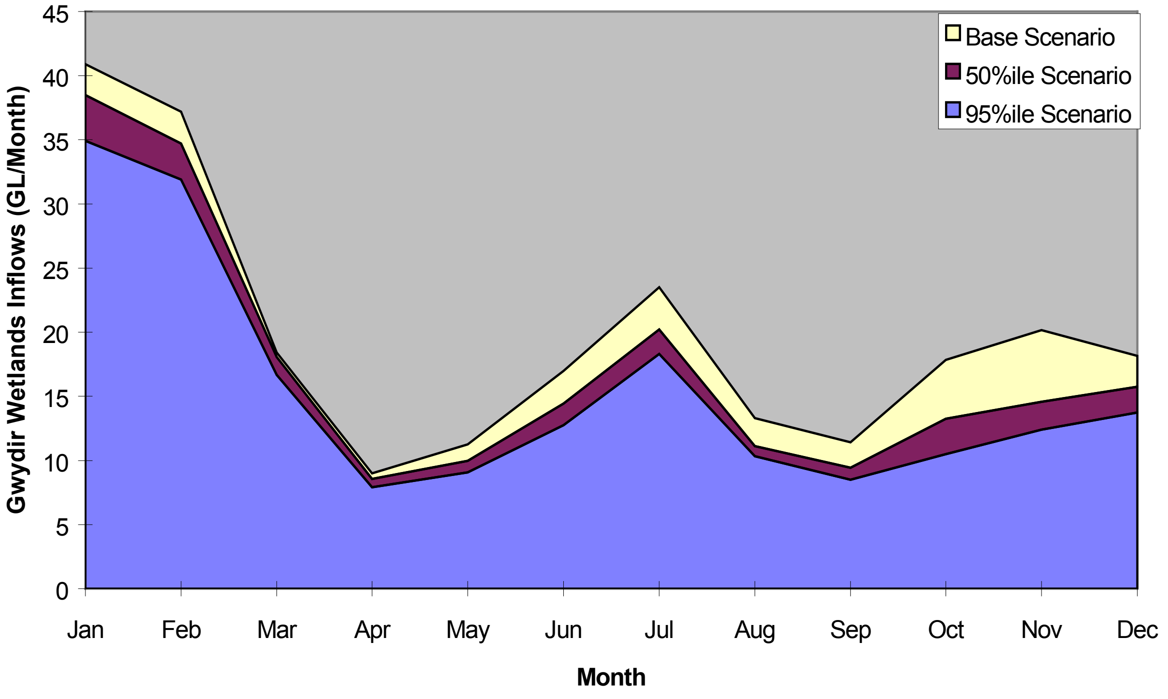

**Figure 7: Monthly Average Gwydir Wetlands Inflows for 1890-1999 Period**

## ***References***

Burnash, R.J.E., R.L. Ferral and R.A. McGuire (1984) *A Generalised Streamflow Simulation System*, Joint Federal-State River Forecast Centre, Sacramento, California.

Department of Land & Water Conservation (1995a) *Integrated Quantity-Quality Model (IQQM) Reference Manual*, NSW.

Department of Land & Water Conservation (1995b) *IQQM - Macquarie River System Calibration Report*, TS94.041, NSW.

# Appendix 3: Condamine Balonne River System

Prepared by the Surface Water Assessment Group [Clayton Vale]
*Queensland Department of Natural Resources and Mines*

## *1 INTRODUCTION*

The purpose of this study is to determine the impact climate change on estimated water usage and flows in the Condamine-Balonne Basin. Two levels of climate change scenarios were investigated. The scenarios were derived by changing the rainfall and potential evaporation in the hydrological models representing the Condamine-Balonne catchment.

## *2 CATCHMENT DESCRIPTION*

The Condamine River begins on the western side of the Great Dividing Range in southern Queensland. The river flows northwest towards Chinchilla where it tends to a more westerly direction and becomes the Balonne River near Surat. From Surat the Balonne River flows in a southerly direction towards St George. The Maranoa River flows into the Balonne River above St George. Below St George the Balonne divides into a distributary river consisting of the Culgoa, Ballandool, Bokhara, Birrie and Narran Rivers and Briarie Creek. The Narran River flows into Narran Lake while the other rivers interjoin and eventually flow into the Barwon River in New South Wales. Due to the catchment size, four distinct hydrological models represent the catchment. Catchment characteristics for each model area are listed below.

### 2.1 Upper Condamine

The Upper Condamine extends from the headwaters of the Condamine-Balonne Catchment (AMTD 1200.0km) to the confluence of the Condamine North Branch (AMTD 880.0km). This covers an area of approximately 8500km$^2$. The Great Dividing Range forms the eastern boundary of the catchment. Numerous tributaries drain from the range into the Condamine River. The headwaters of the Condamine River and these tributaries are predominately steep and hilly country. The vegetation in these areas varies from open to closed forest with areas of grassy open woodland. The lower plains are of alluvial nature with very deep dark cracking clays.

The mean annual rainfall for most of the Upper Condamine catchment section varies from 600 – 700mm. The headwaters of the Condamine River and tributaries rising from the western side of the Great Dividing Range have mean annual rainfall in excess of 1000mm.

Irrigated agriculture is common within the area. Irrigation water sources include extractions from the river and tributaries, overland flow and groundwater. Water is also extracted for town water supply to local community centers including Kilarney, Warwick, Clifton, Millmerran and Cecil Plains. Several dams and weirs have been constructed to improve the supply and distribution of water to the catchments user groups. Leslie Dam on Sandy Creek is the major storage in the catchment and supplies water for the regulated section down to Cecil Plains. Water is manually diverted to users on the Condamine North Branch via a pump station located at Yarramalong Weir (AMTD 966.3km).

## 2.2 Lower Condamine and Balonne Rivers

The Lower Condamine and Balonne area continues from the Upper Condamine starting at the confluence of the Condamine North Branch (AMTD 880.0km) and continuing to the headwaters of Beardmore Dam on the Balonne River (AMTD 260km). The catchment area for this section is approximately 66,700km2. This includes the Maranoa River catchment with an area of 19,500km2. The Great Dividing Range forms the eastern and northern boundaries of the catchment section. Numerous tributaries drain from the range into the Condamine River. The headwaters of these tributaries are predominately steep and hilly country. The vegetation in these areas is native forest and open woodland. The lower plains are of alluvial nature with very deep dark cracking clays.

The mean annual rainfall for most of the Lower Condamine catchment section varies from 600 – 700mm. A very small percentage of the headwater section of the section experiences mean annual rainfall as high as 1000mm.

Major water storages in the area include Cooby Creek Reservoir, Chinchilla Weir and Neil Turner Weir. Beardmore Dam is not modelled as a storage in this section, only the headwater inflows for the dam are derived. The Lower Condamine and Balonne Rivers model includes the Chinchilla Weir Water Supply Scheme base on Chinchilla Weir. Town water supply is provided for many community centers, the major of these include Toowoomba, Dalby, Chinchilla, Condamine and Surat. All of the alluvial soils in the area have been developed for agricultural production. The Area from Cecil Plains to Chinchilla is estimated to be about 30% light forested to native pasture and 70% cultivated land. The area from Chinchilla to Beardmore is less developed with an estimated 70% area light forest or native pasture and 30% area cultivated land.

## 2.3 St George

The St George Regulated System extends from Beardmore Dam at the junction of the Maranoa and Balonne Rivers to the first bifurcation where the Balonne River divides into the Culgoa and Balonne Minor Rivers. The area is approximately 4170km 2 . The mean annual rainfall at St George is 500mm, while the mean annual pan potential evaporation is 1,850mm. There are no significant tributary inflows at St George, all inflows enter the system from upstream (The Lower Condamine and Balonne Rivers section).

The St George Water Supply Scheme is the main focus of the St George section. The system regulates water to allocation holders along the Balonne River downstream of St George and the Irrigation Area to the east of St George. A number of storages are part of the scheme. The most significant storage is Beardmore Dam. Jack Taylor Weir is immediately downstream of Beardmore Dam on the Balonne River. Moolabah and Buckinbah Weirs are on the Thuraggi Watercourse. The scheme supplies town water supply for St George, approximately 55,000 megalitres of nominal allocation through a channel system and another 20,000 megalitres to private diversions from the Balonne River.

### 2.4 Distributary System

The Culgoa/Balonne Distributary System is a distinct system downstream of St George Regulated Area. Approximately 60 km downstream of St. George, the Balonne River begins splitting into a number of distributaries, the principal of which are the Culgoa, Birrie, Bokhara, Ballandool, Narran, Balonne Minor and Briarie Ck. The total length of distributaries is about 1700km. The catchment area to the Queensland – New South Wales border covers and area of approximately 3,200km2. The topography away from the channel banks is such that the catchment boundaries are difficult to define. Local catchment inflow is insignificant compared with the volume of water coming from upstream. Inflows from the Neebine, Mungallala, Wallam, Widgeagora and Bow Creeks occur below the Brenda gauging stations in New South Wales. The Distributary System ultimately flows into the Barwon River. However the Narran River terminates at Narran Lake, an important bird breeding and wetland habitat. A number of other lakes are scattered in the Distributary System area. Lake Bokhara and Lake Angledool fill during periods of flooding.

Bifurcation weirs in the system were constructed at four of the natural stream bifurcations in early 1970's. They were built to control the low flow distribution at the bifurcation points of:

- Culgoa/Balonne Minor Rivers
- Balonne Minor/ Narran Rivers
- Bokhara/Ballandool Rivers
- Bokhara/Birrie Rivers

The vegetation is the area is scrubby open woodland dominated by acacias and gums. There are patches of lignum bush where the land becomes inundated during floods. North of the border in the vicinity of the local community centre Dirranbandi there are extensive areas of agricultural development. Irrigation water is obtained mainly from unregulated water harvesting from all major streams. Townships of Dirranbandi and Hebel have small town water supply demands.

## *3 METHODOLOGY*

The assessment of impact for two climatic change scenarios was based on changes made to observed rainfall data and potential evaporation data integrated within hydrological models representing the Condamine-Balonne Catchment. The high scenarios represent the higher end of the range of estimated impact of climate change on potential evaporation and rainfall for 2030. The low case represents the lower end of the range of estimates produced by Global Climate Models (GCM). These changes were calculated as a percent change for each month of the annual cycle. They were applied to the rainfall data and potential evaporation data inputs of hydrological models representing the Condamine-Balonne catchment for the period 1898 to 1995.

Firstly, high and low case runoff sequences were generated for the various sub-catchments using the Sacramento Model (Burnash et al. 1984). The runoff sequences were then applied as inflows to hydrologic models representing the operation and development within the catchment. Currently the 'Integrated Quantity Quality Model' or IQQM (DLWC, 1995) is used to model the Condamine-Balonne System.

Within the IQQM model evapotranspiration and precipitation directly affect crop demand. It was therefore necessary to apply the climate change modified rainfall and potential evaporation inputs to the IQQM models.

For the impacts of the climate change scenarios to be effectively assessed, the streamflow inputs for the IQQM model required to be completely derived by the Sacramento Model. This is done to isolate the impact of climate change from the differences created using recorded streamflow data.

### 3.1 Sacramento Model

The Sacramento rainfall-runoff model was developed by Burnash, Ferral and McGuire (1973) and is implemented as a component within the IQQM interface. The Sacramento Model is an explicit soil moisture accounting type model, which was developed by the United States National Weather Service and the California Department of Water Resources originally for flood forecasting applications.
The Sacramento Model consists of a number of storages connected by catchment processes.

To implement the model in a given catchment, a set of 18 parameters must be defined. These parameters define the generalised model form for a particular catchment. The parameters are usually derived from a gauged catchment by a process of calibration, which is the process of comparing recorded streamflows with calculated streamflows and adjusting the parameters to produce the best possible reproduction of recorded streamflows.

Model calibration depends on the quality of the rainfall, streamflow and potential evaporation data that is available. The accuracy of data used in model calibration needs to be considered in assessing the quality of model calibration. In ungauged catchments, parameter sets from adjacent or nearby gauged catchments are used.

## ***4 CLIMATE CHANGE SCENARIOS***

The output from the CSIRO model DARLAM was provided to NR&M Surface Water Assessment Group in the form of monthly percentage changes in precipitation and potential evaporation for both the high and low scenarios. This was done for all rainfall and potential evaporation recording locations used as data inputs for the Condamine-Balonne hydrological. These are presented in Appendix A. The percentage changes for the high and low cases were relative to the base scenario that represents the historic climatic conditions for the period 1898 to 1995.

Due to rounding errors associated with the IQQM data file format, the high and low case monthly totals did not correspond to the required monthly percent change. This error was noted to be very significant with some data files. To apply the correct monthly percent change from the base case, the first non-zero daily value of the each month was adjusted to give the required monthly total.

## *5 RESULTS FOR CHANGES IN RUNOFF (FROM SACRAMENTO MODEL)*

The Sacramento Model shows that sub-catchment runoff is reduced in all areas of the Condamine-Balonne catchment for Low and High Scenarios[3]. The average sub-catchment runoff decrease for the low and high case scenarios were 5.0% and 11.9% respectively. Table 5.1 lists the estimated mean and median annual flows for the base case and the percentage change for the low and high case scenarios.

### 5.1 Results for Changes to System Streamflow (from Condamine-Balonne IQQM)

The Sacramento Model runoff sequences for each climate change scenario were used as inflow sequences for the IQQM models. The IQQM models used for the investigation were those used for the Scenario A (mid 1999 development) models of the "Draft Condamine Water Allocation and Management Plan (WAMP)". It should be noted that the flows in the Base Case were different from those in the Draft WAMP, because in this study the flows were completely derived by the Sacramento Model. In the Draft WAMP, large sections of streamflow data were based on recorded measurements. Streamflow statistics for various locations were analysed for the low and high climate change scenarios. A summary of changes for each location caused by climate change are presented in Tables 5.2 to 5.6 and Figures 5.1 to 5.20 addressing:

- Inflow to Leslie Dam
- Inflow to Chinchilla Weir
- Inflow to Beardmore Dam
- Streamflow at GS 422205A Hastings
- Streamflow at GS 422204A Whyenbah

The results of the Draft WAMP Scenario-A case have been presented for comparison.

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[3] In this appendix, the terminology is recorded differently. "Low" scenario translates to "Average" or "50th percentile" scenario and "High" translates to "Dry" or "95th percentile" scenario.

## Table 5.1: Sub-Catchment Runoff Volumes

| | Draft WAMP Scenario-A (ML/Annum) | Low Case* | High Case* |
|---|---|---|---|
| **Elbow Valley** | | | |
| *Mean* | 39155 | -4.9% | -11.4% |
| *Median* | 27232 | -5.4% | -10.8% |
| **Elbow Valley to Warwick** | | | |
| *Mean* | 62793 | -8.7% | -18.3% |
| *Median* | 46885 | -7.8% | -17.9% |
| **Leslie Dam/Sandy Creek** | | | |
| *Mean* | 33711 | -6.2% | -14.1% |
| *Median* | 24021 | -7.7% | -16.1% |
| **Warwick to Pratten** | | | |
| *Mean* | 23350 | -6.7% | -14.7% |
| *Median* | 17804 | -7.8% | -13.4% |
| **Kings Creek (inc. Darymple and Hodgson Creeks)** | | | |
| *Mean* | 53167 | -6.3% | -13.8% |
| *Median* | 28020 | -5.9% | -12.0% |
| **Canal and Thanes Creek** | | | |
| *Mean* | 27542 | -3.5% | -10.5% |
| *Median* | 20459 | -4.5% | -12.9% |
| **Yarramalong to Cecil** | | | |
| *Mean* | 109851 | -2.8% | -9.4% |
| *Median* | 59256 | -1.8% | -6.9% |
| **North Branch** | | | |
| *Mean* | 9922 | -4.7% | -12.1% |
| *Median* | 8699 | -6.1% | -14.3% |
| **Oakey/Cooby Creek (inc. Ashall Creek)** | | | |
| *Mean* | 69247 | -4.0% | -11.0% |
| *Median* | 48781 | -4.4% | -14.3% |
| **Dalby to Chinchilla** | | | |
| *Mean* | 243644 | -4.8% | -12.1% |
| *Median* | 142370 | -9.3% | -18.0% |
| **Chinchilla to Cotswold** | | | |
| *Mean* | 307793 | -3.7% | -9.9% |
| *Median* | 218951 | -0.4% | -3.9% |
| **Cotswold to Weribone (inc. Weribone to Beardmore Dam)** | | | |
| *Mean* | 532703 | -3.2% | -8.3% |
| *Median* | 354748 | -5.5% | -14.2% |
| **Forest Vale (Maranoa)** | | | |
| *Mean* | 66307 | -7.8% | -15.0% |
| *Median* | 20296 | -3.1% | -6.9% |
| **Forest Vale to Neil Turner Weir (Maranoa)** | | | |
| *Mean* | 70665 | -4.5% | -10.5% |
| *Median* | 27362 | -6.2% | -13.0% |
| **Neil Turner Weir to Old Cashmere (Maranoa)** | | | |
| *Mean* | 35996 | -2.6% | -7.5% |
| *Median* | 18594 | -6.8% | -12.4% |

*The runoff volumes are shown as a percentage change from the Base Case

**Table 5.2: Monthly Statistics for Leslie Dam Inflows**

| Month | Draft WAMP Scenario-A (ML/Month) | Low Case* | High Case* |
|---|---|---|---|
| January | 4155 | -6.1% | -15.7% |
| February | 5565 | -2.1% | -9.5% |
| March | 2209 | -3.0% | -9.7% |
| April | 2532 | -2.5% | -9.5% |
| May | 2664 | -2.2% | -7.0% |
| June | 2447 | -4.8% | -9.1% |
| July | 2786 | -6.0% | -11.1% |
| August | 1227 | -9.0% | -14.2% |
| September | 1652 | -10.2% | -18.0% |
| October | 2973 | -10.7% | -21.1% |
| November | 2389 | -13.6% | -27.2% |
| December | 2570 | -9.6% | -22.5% |
| **Annual Total** | **33169** | **-6.1%** | **-14.1%** |

*The inflows are shown as a percentage change from the Base Case

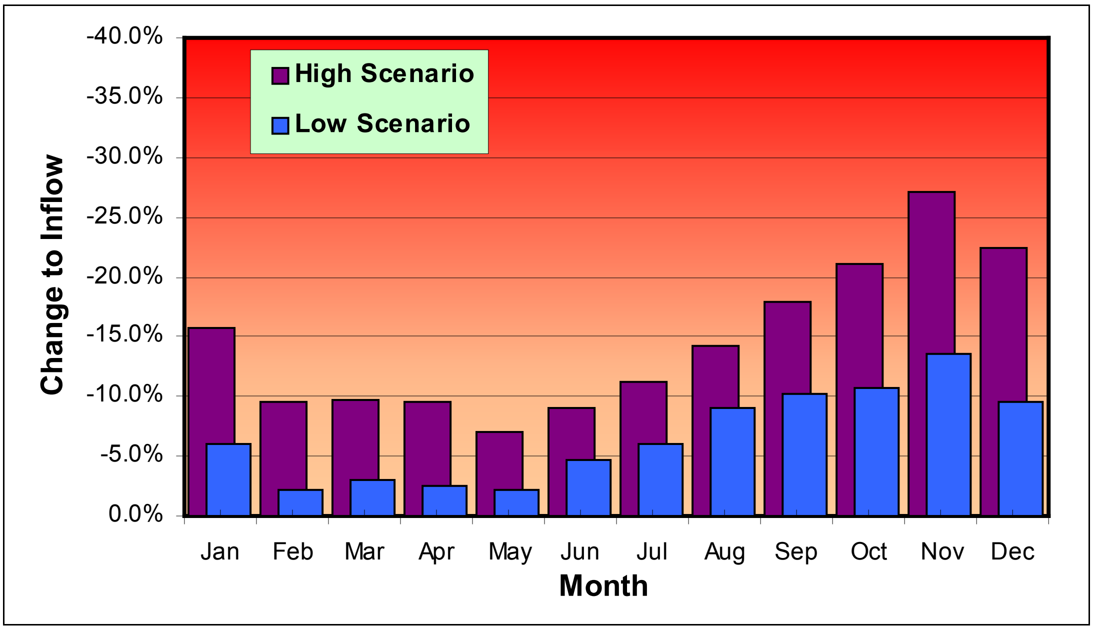

Figure 5.1: Monthly Change to Leslie Dam Inflows (High & Low Case)

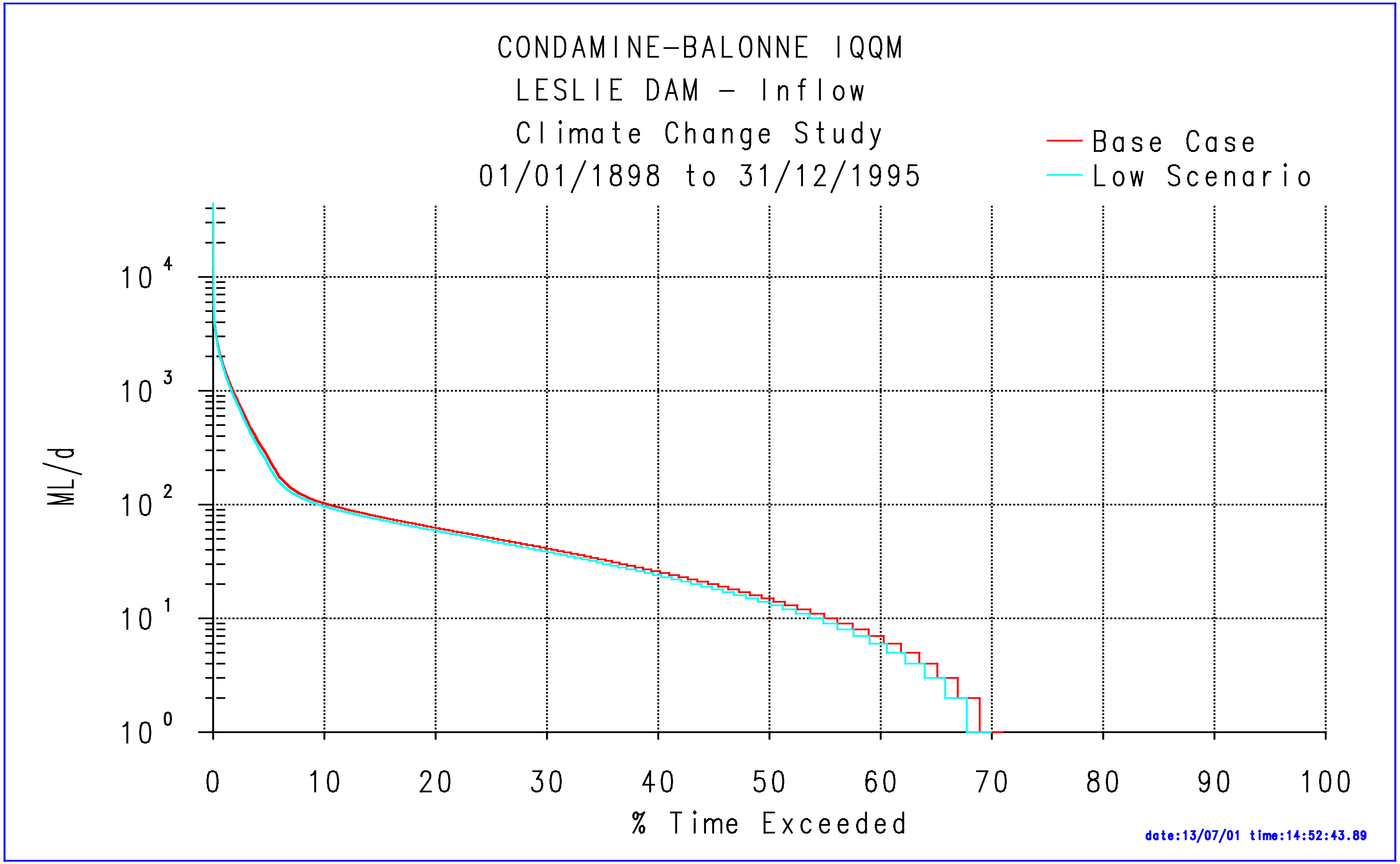

**Figure 5.2: Inflows to Leslie Dam (Base vs Low Case)**

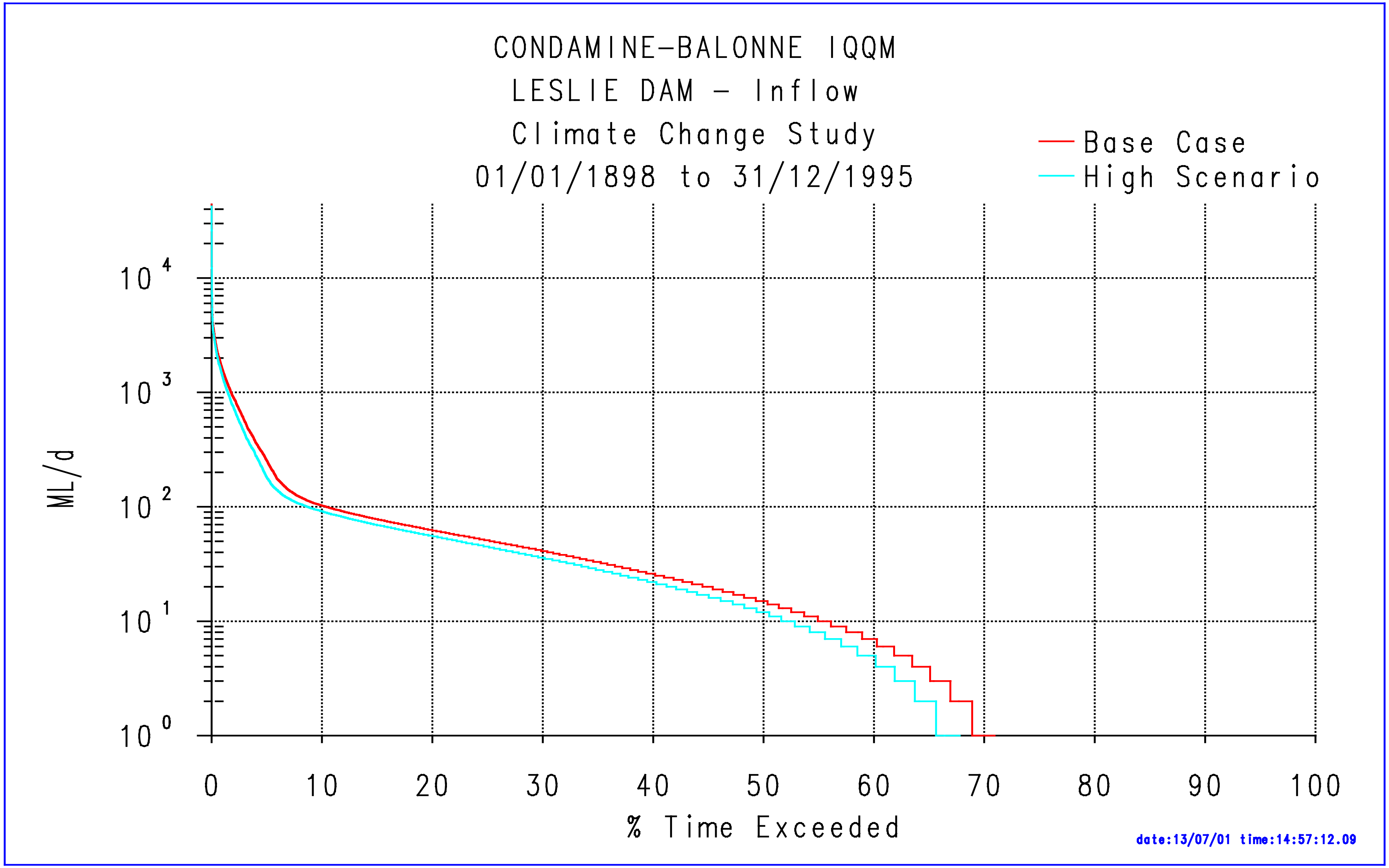

Figure 5.3: Inflows to Leslie Dam (Base vs High Case)

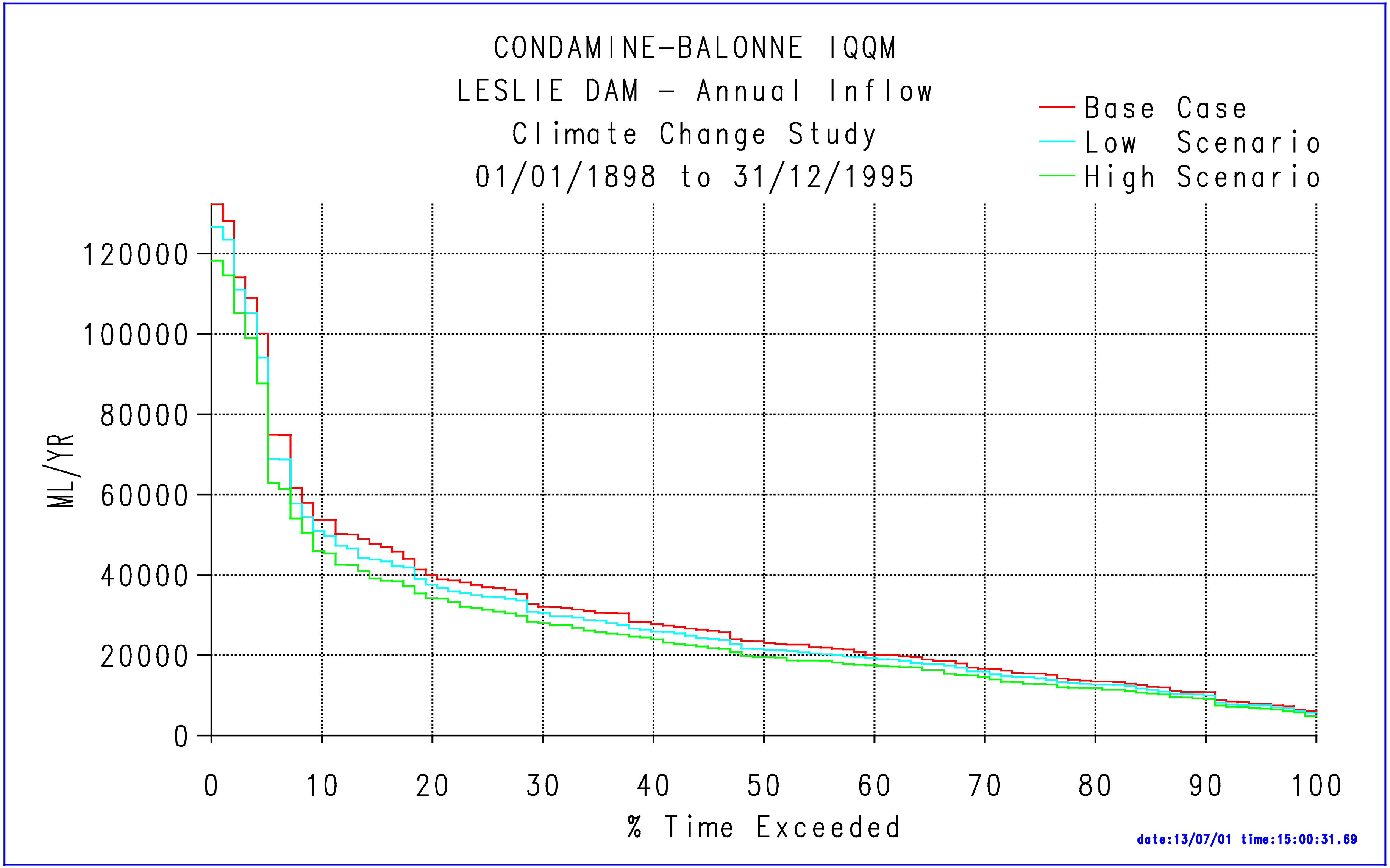

**Figure 5.4: Annual Inflows to Leslie Dam**

## Table 5.3: Monthly Statistics for Chinchilla Weir Inflows

| Month | Draft WAMP Scenario-A (ML/Month) | Low Case* | High Case* |
|---|---|---|---|
| January | 52676 | -6.4% | -17.6% |
| February | 95475 | -3.5% | -11.4% |
| March | 25922 | -3.3% | -10.7% |
| April | 37863 | -3.4% | -12.1% |
| May | 29106 | -0.2% | -5.4% |
| June | 31633 | -3.1% | -8.7% |
| July | 25634 | -6.8% | -12.1% |
| August | 14819 | -9.6% | -16.5% |
| September | 3742 | -12.6% | -21.6% |
| October | 9662 | -14.1% | -28.5% |
| November | 24224 | -19.0% | -38.5% |
| December | 35868 | -9.9% | -24.0% |
| **Annual Total** | **386625** | **-6.2%** | **-15.6%** |

* The inflows are shown as a percentage change from the Base Case

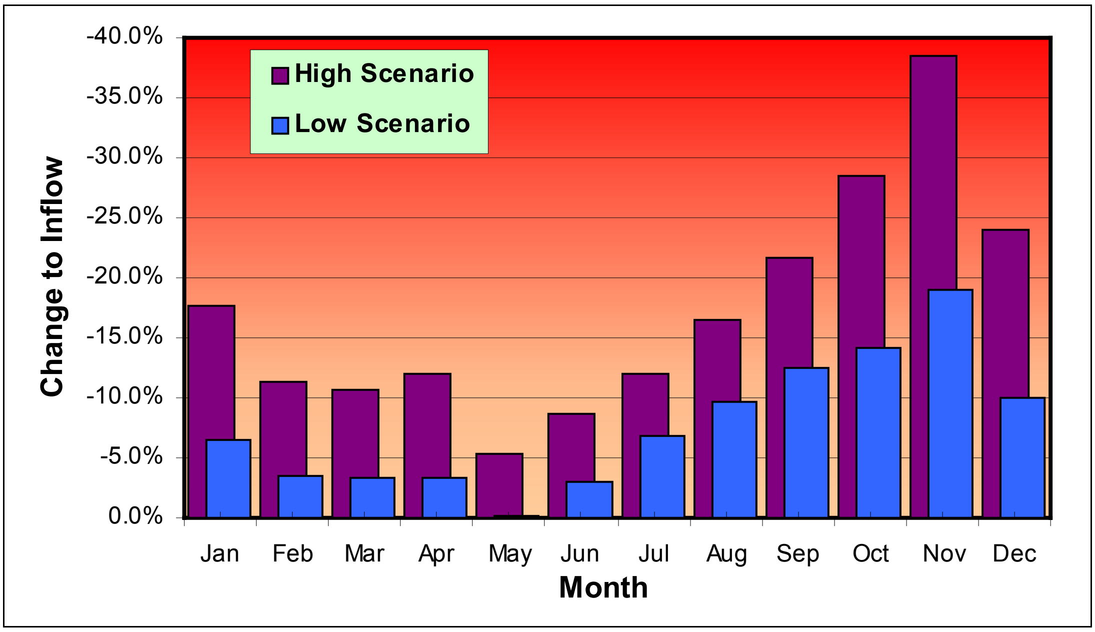

Figure 5.5: Monthly Change to Chinchilla Weir Inflows (High & Low Case)

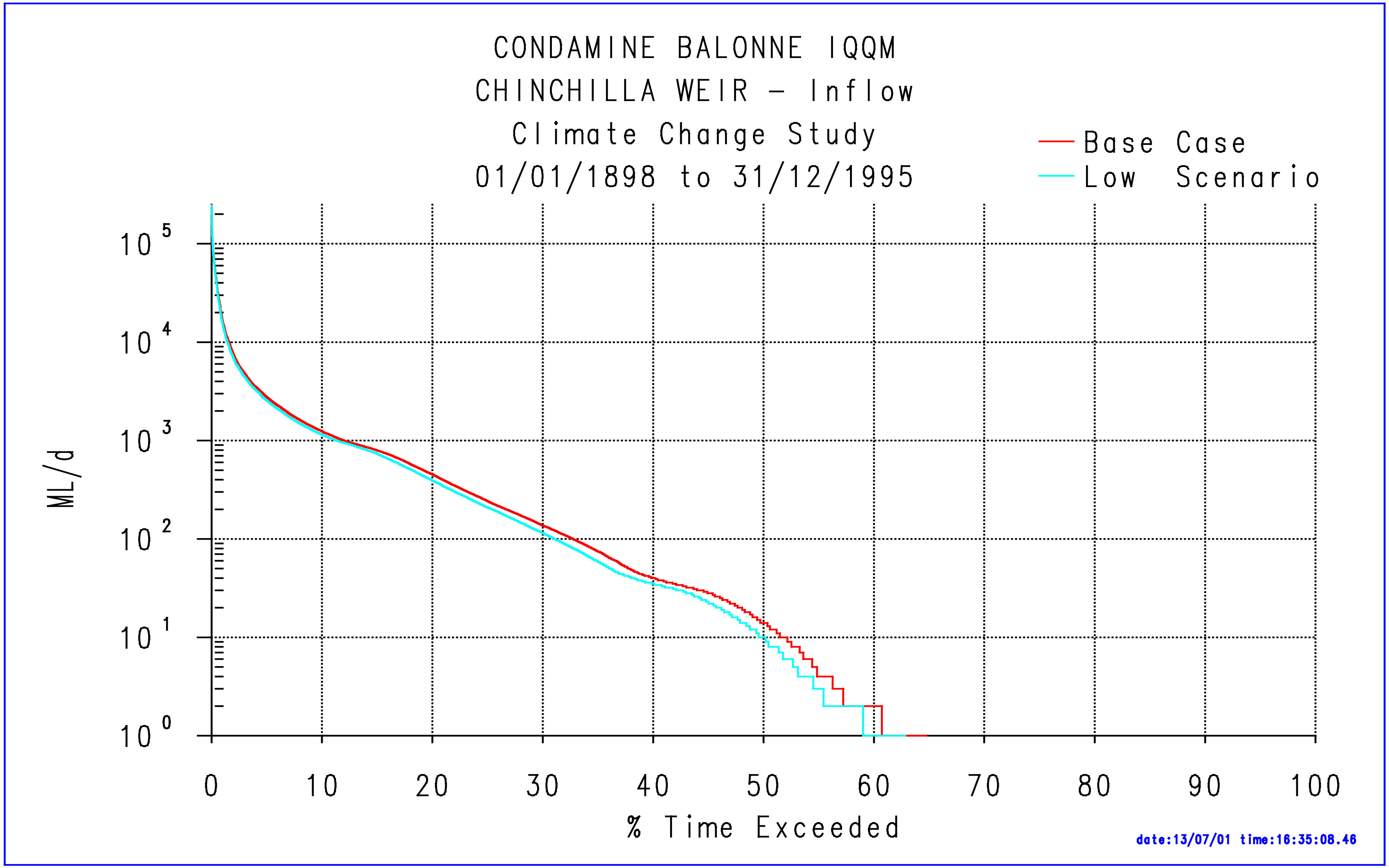

Figure 5.6: Inflows to Chinchilla Weir (Base vs Low Case)

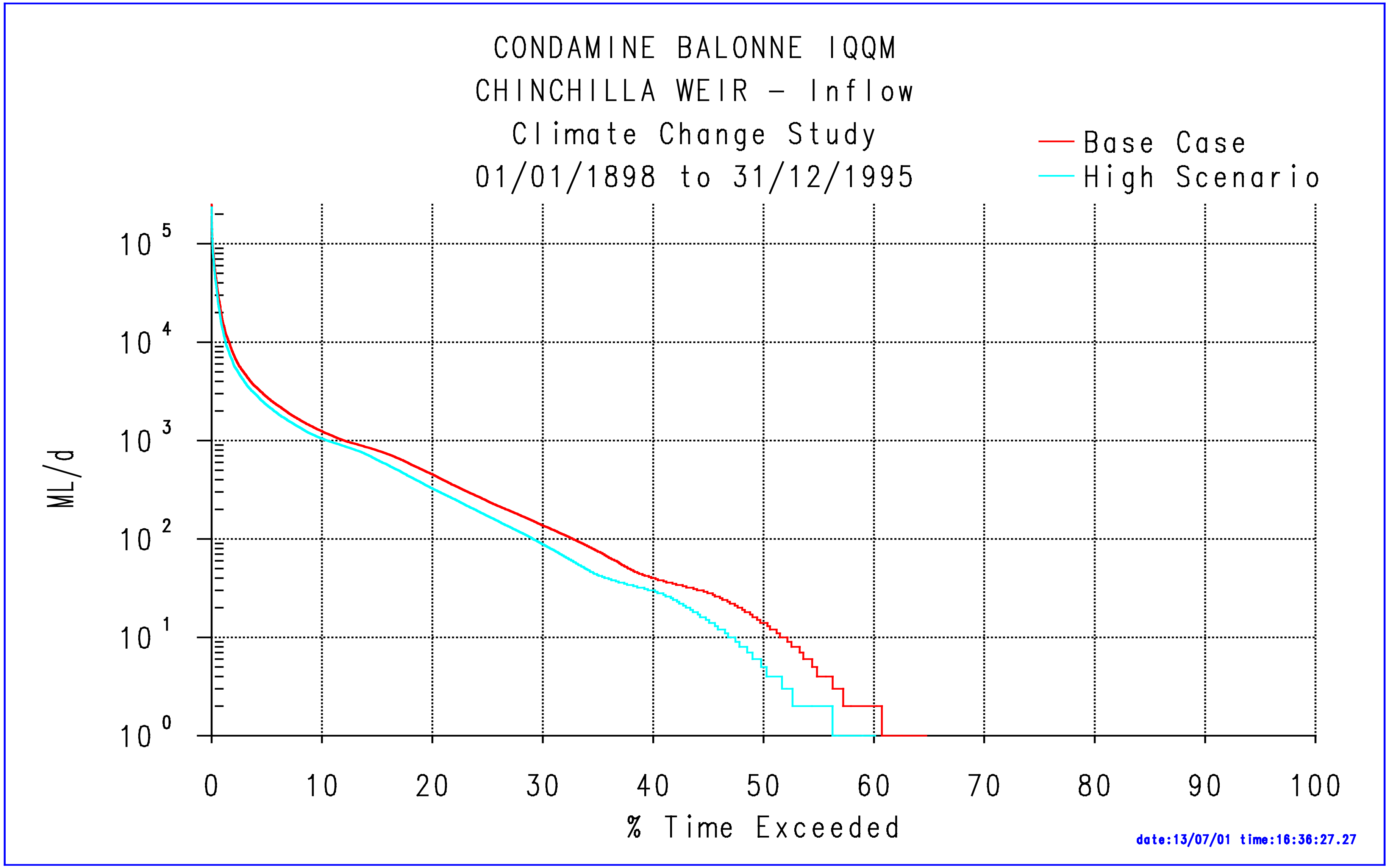

Figure 5.7: Inflows to Chinchilla Weir (Base vs High Case)

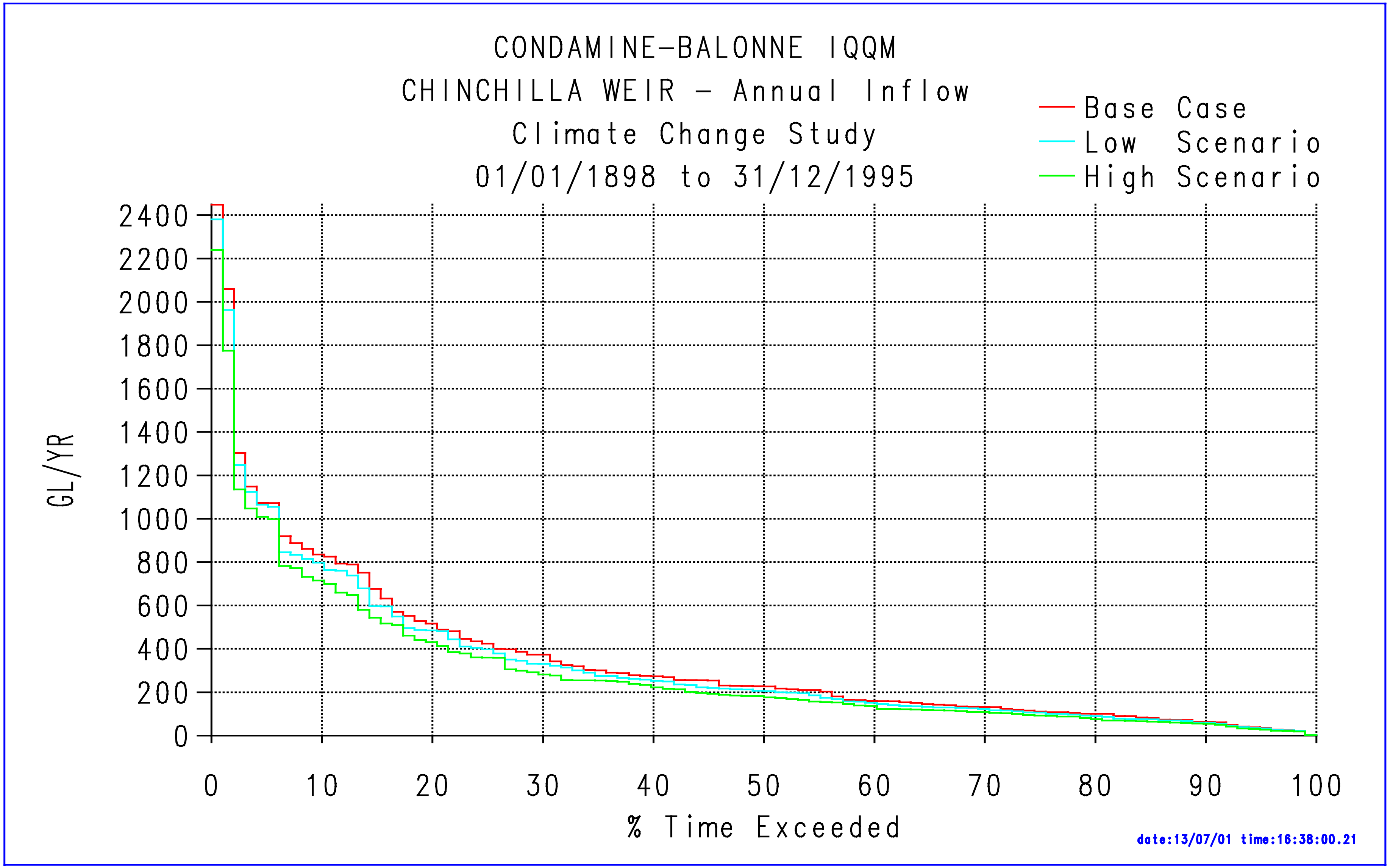

**Figure 5.8: Annual Inflows to Chinchilla Weir**

### Table 5.4: Monthly Statistics for Beardmore Dam Inflows

| Month | Draft WAMP Scenario-A (ML/Month) | Low Case* | High Case* |
|---|---|---|---|
| January | 151824 | -6.4% | -15.6% |
| February | 263717 | -5.6% | -13.1% |
| March | 153805 | -3.1% | -8.4% |
| April | 117808 | -1.7% | -8.2% |
| May | 69441 | 4.0% | -0.4% |
| June | 57551 | 2.4% | -1.7% |
| July | 85823 | -1.4% | -5.3% |
| August | 47316 | -5.6% | -9.8% |
| September | 7876 | -8.7% | -15.8% |
| October | 33999 | -8.9% | -18.9% |
| November | 66065 | -15.9% | -31.9% |
| December | 108328 | -9.9% | -23.1% |
| **Annual Total** | **1163554** | **-4.4%** | **-11.7%** |

* The inflows are shown as a percentage change from the Base Case

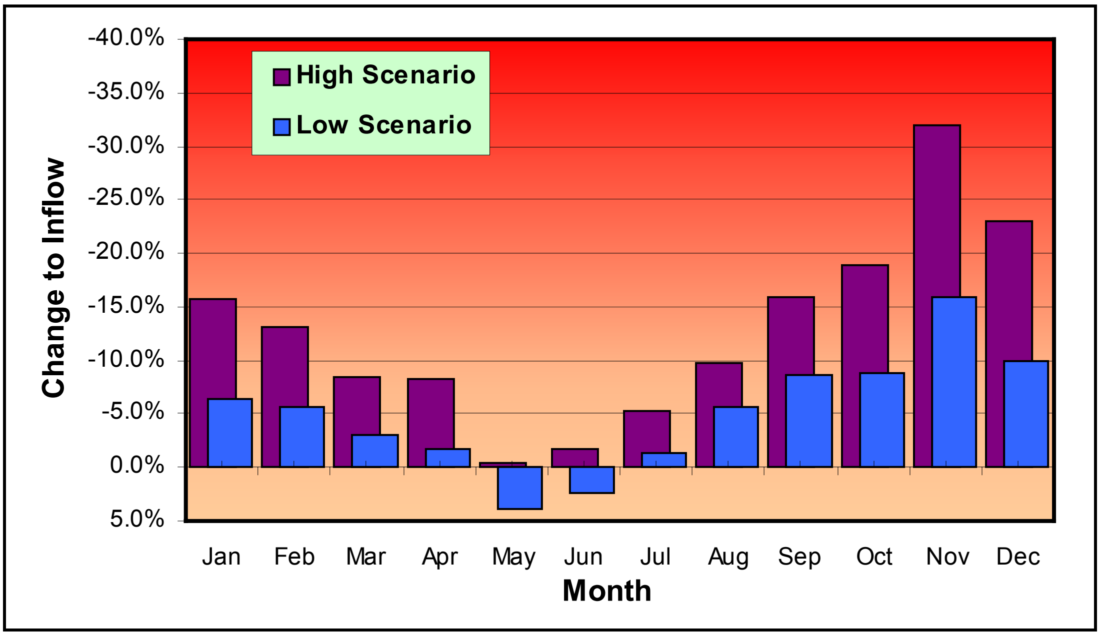

Figure 5.9: Monthly Change to Beardmore Dam Inflows (High & Low Case)

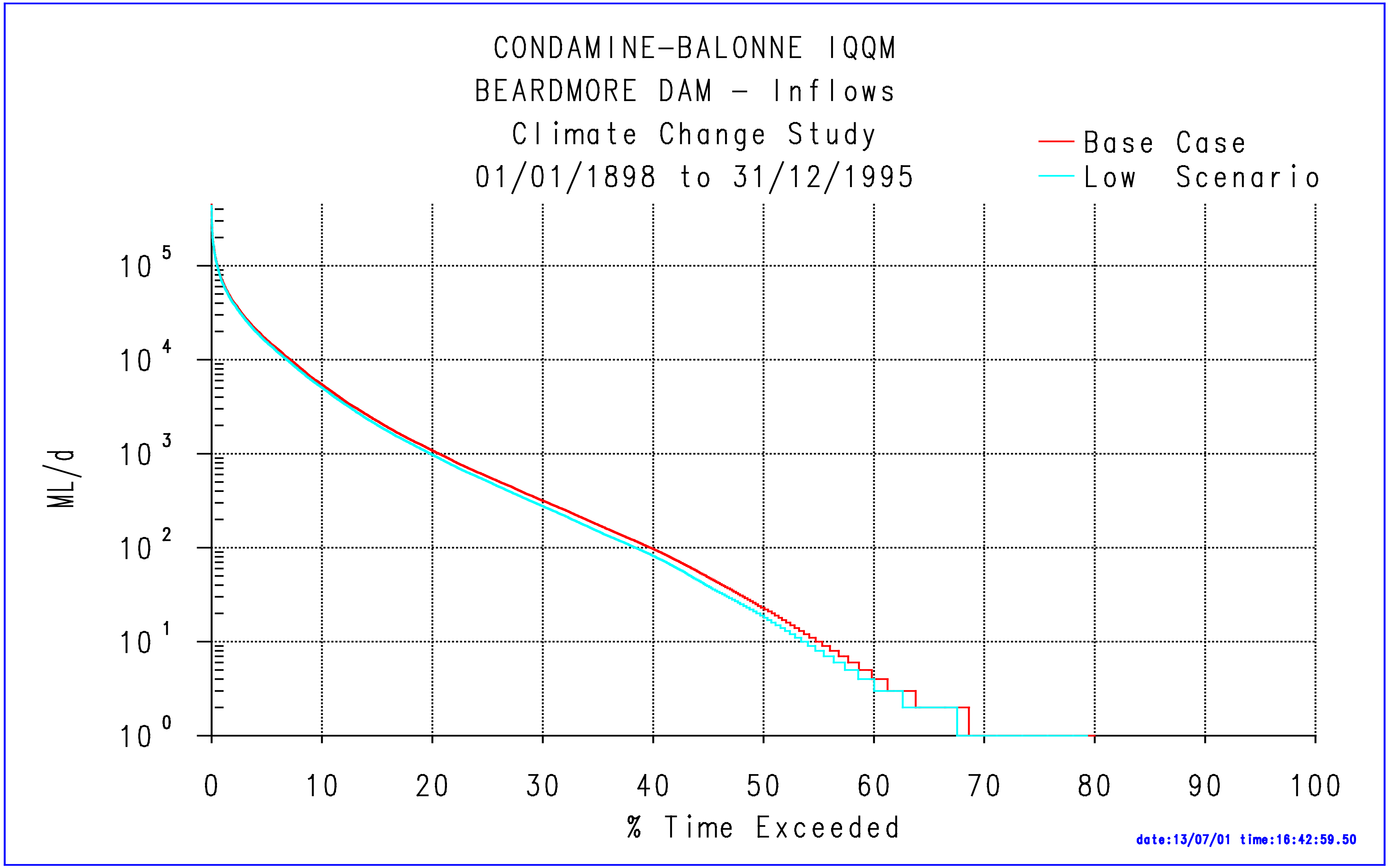

**Figure 5.10: Inflows to Beardmore Dam (Base vs Low Case)**

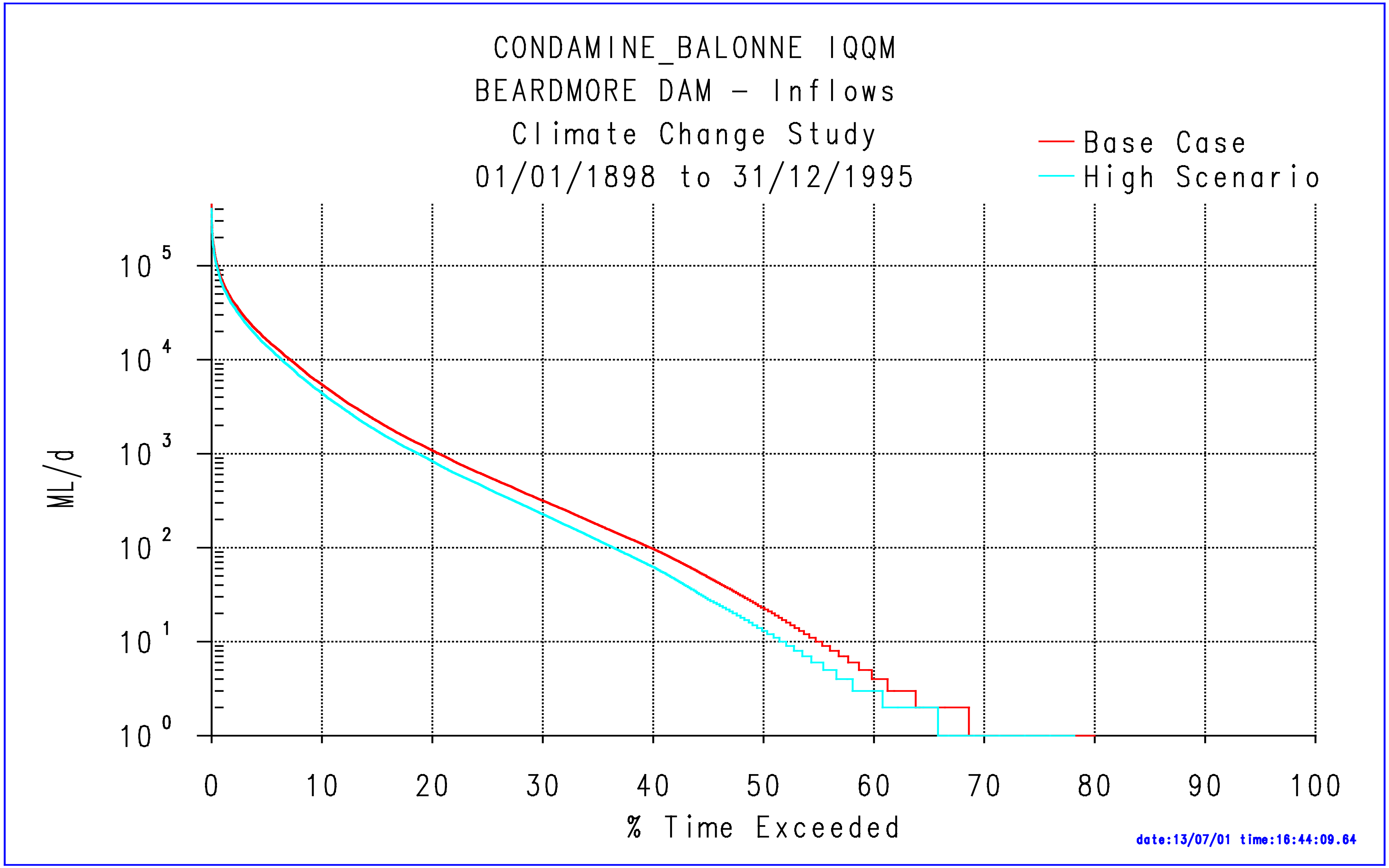

**Figure 5.11: Inflows to Beardmore Dam (Base vs High Case)**

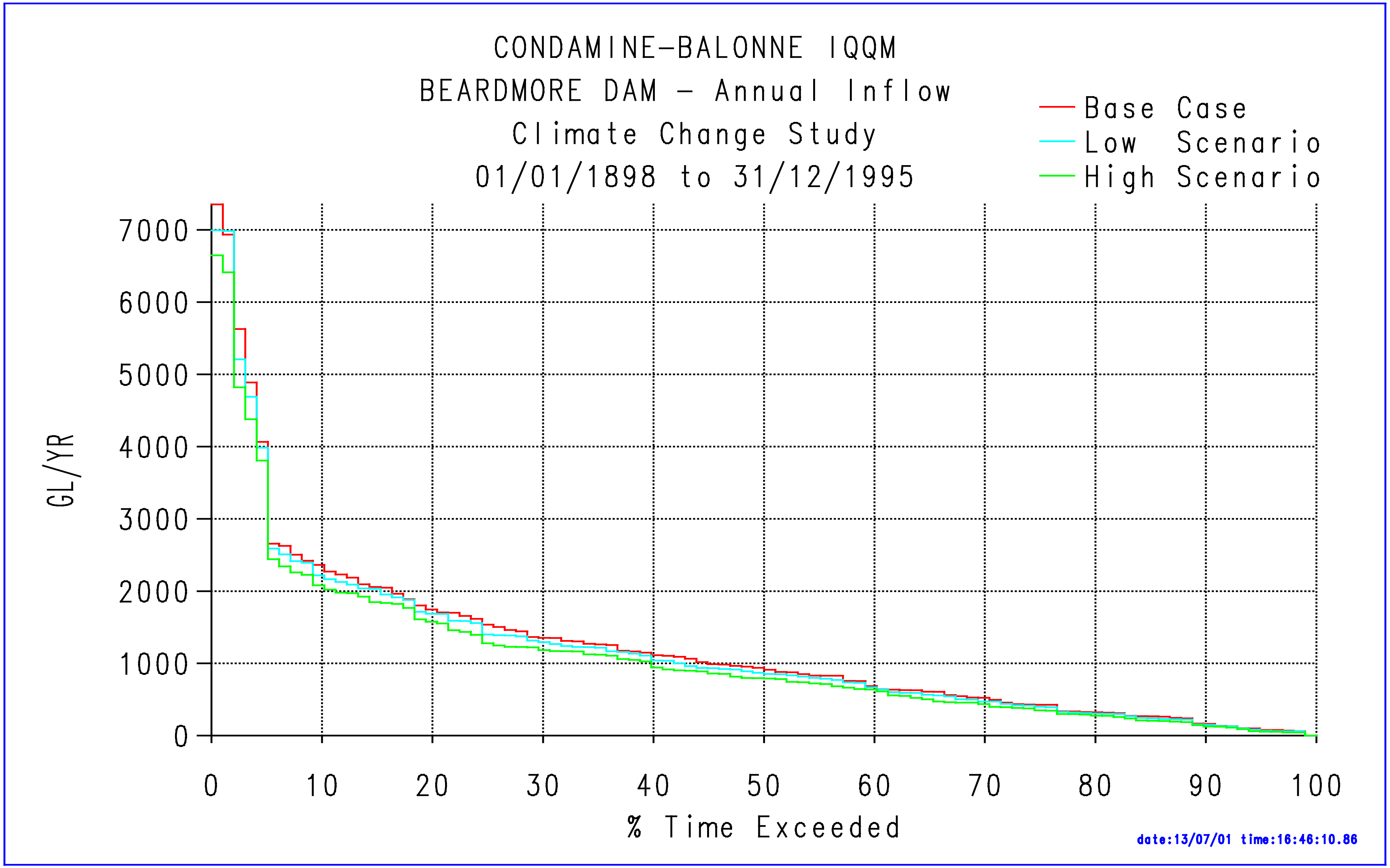

**Figure 5.12: Annual Inflows to Beardmore Dam**

## Table 5.5: Monthly Statistics for Streamflow at GS 422205A Hastings

| Month | Draft WAMP Scenario-A (ML/Month) | Low Case* | High Case* |
|---|---|---|---|
| January | 49005 | -7.9% | -17.7% |
| February | 111168 | -6.8% | -15.5% |
| March | 64558 | -5.4% | -12.6% |
| April | 54990 | -3.1% | -10.1% |
| May | 31481 | 3.1% | -3.3% |
| June | 28365 | 2.1% | -2.2% |
| July | 45008 | -1.8% | -6.5% |
| August | 26245 | -5.0% | -9.4% |
| September | 6626 | -7.1% | -12.7% |
| October | 13441 | -10.3% | -21.5% |
| November | 21708 | -19.1% | -36.6% |
| December | 41150 | -13.3% | -28.8% |
| **Annual Total** | **493744** | **-5.4%** | **-13.5%** |

* The inflows are shown as a percentage change from the Base Case

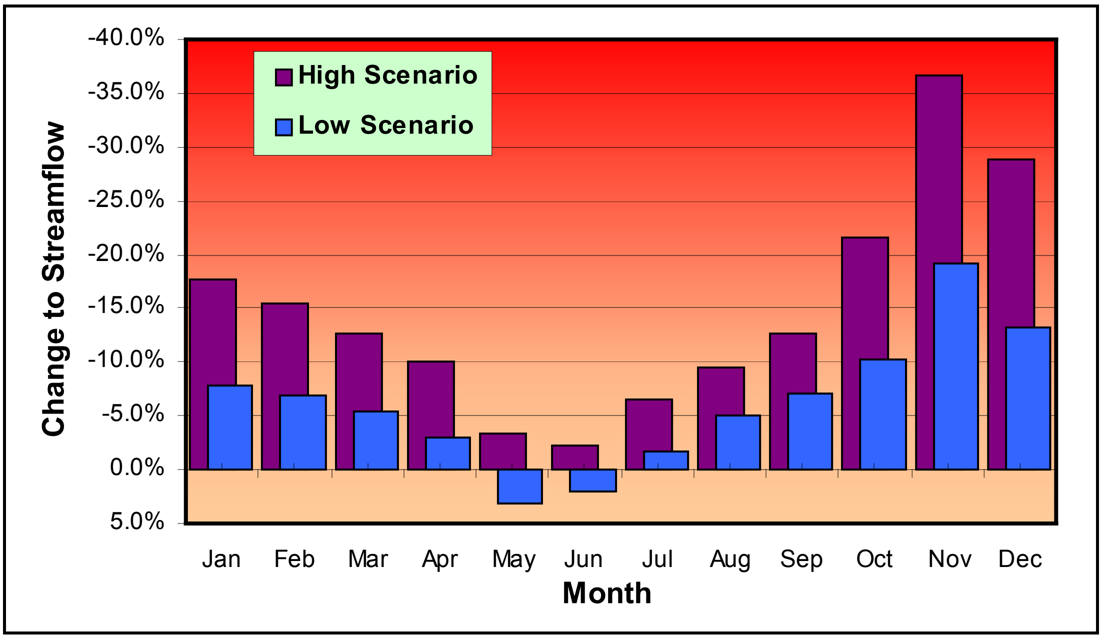

Figure 5.13: Monthly Change to Streamflow at GS 422205A Hastings (High & Low Case)

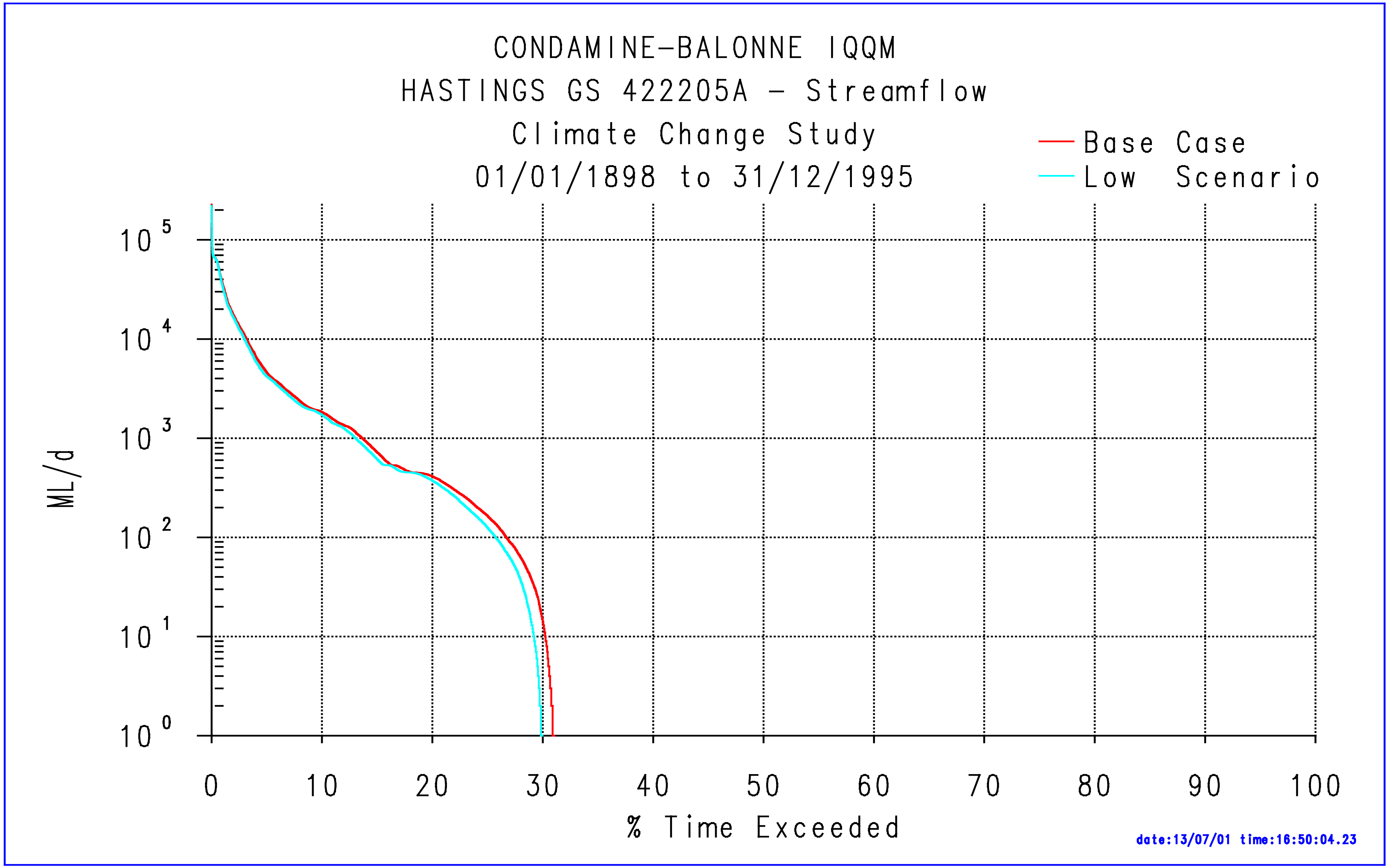

**Figure 5.14: Streamflow at GS 422205A Hastings (Base vs Low Case)**

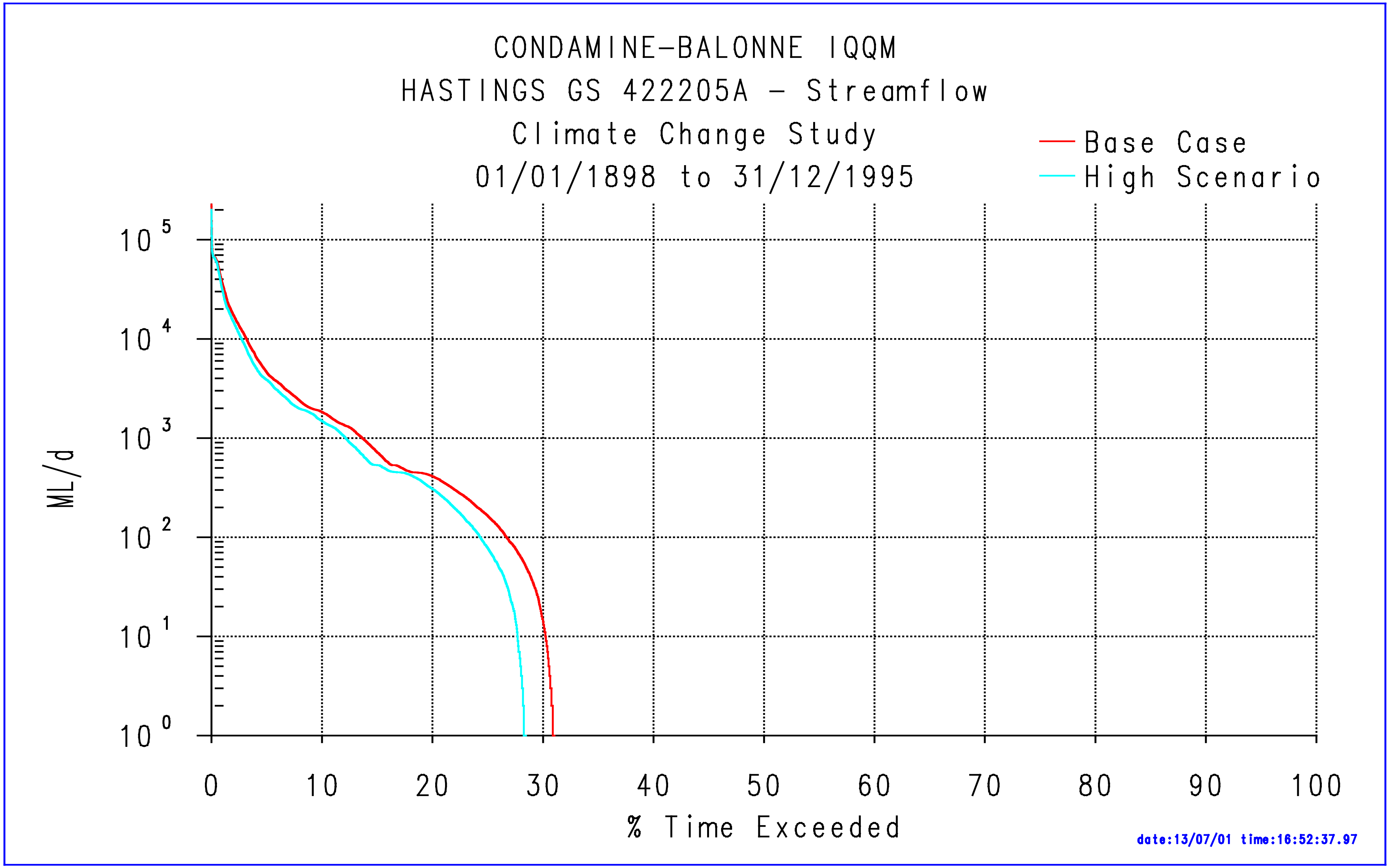

Figure 5.15: Streamflow at GS 422205A Hastings (Base vs High Case)

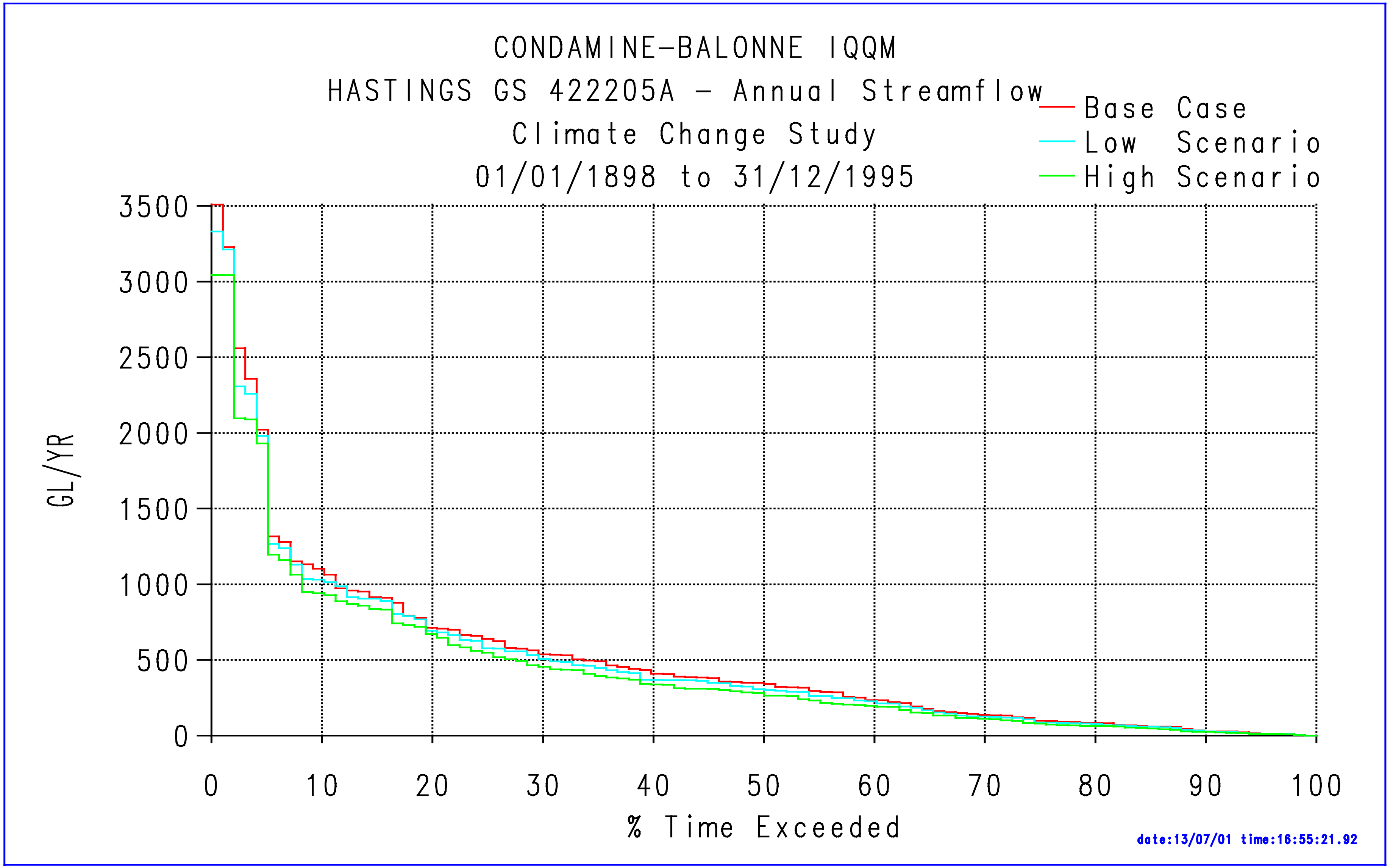

**Figure 5.16: Annual Streamflow at GS 422205A Hastings**

### Table 5.6: Monthly Statistics for Streamflow at GS 422204A Whyenbah

| Month | Draft WAMP Scenario-A (ML/Month) | Low Case* | High Case* |
|---|---|---|---|
| January | 41193 | -8.6% | -18.7% |
| February | 72822 | -5.7% | -13.2% |
| March | 54621 | -5.2% | -12.1% |
| April | 37785 | -1.7% | -7.5% |
| May | 22917 | 1.6% | -4.5% |
| June | 22115 | 1.4% | -2.9% |
| July | 29690 | -2.2% | -6.5% |
| August | 17335 | -5.2% | -9.1% |
| September | 4282 | -6.3% | -11.9% |
| October | 10311 | -10.1% | -20.2% |
| November | 19549 | -18.5% | -37.2% |
| December | 30260 | -12.3% | -27.4% |
| **Annual Total** | **362881** | **-5.4%** | **-13.2%** |

* The inflows are shown as a percentage change from the Base Case

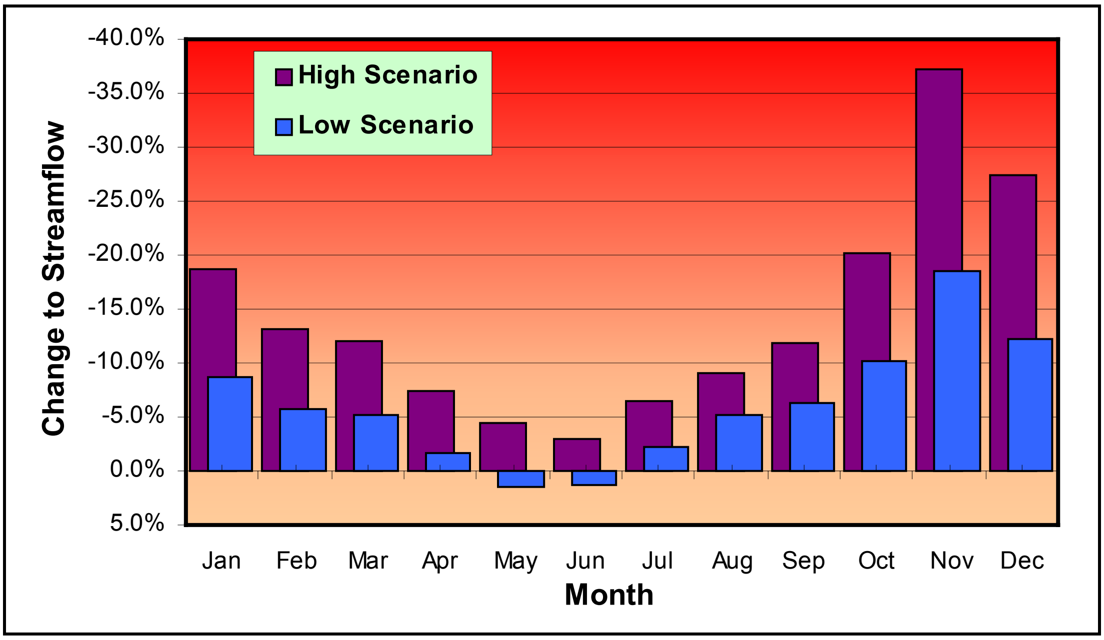

Figure 5.17: Monthly Change to Streamflow at GS 422204A Whyenbah (High & Low Case)

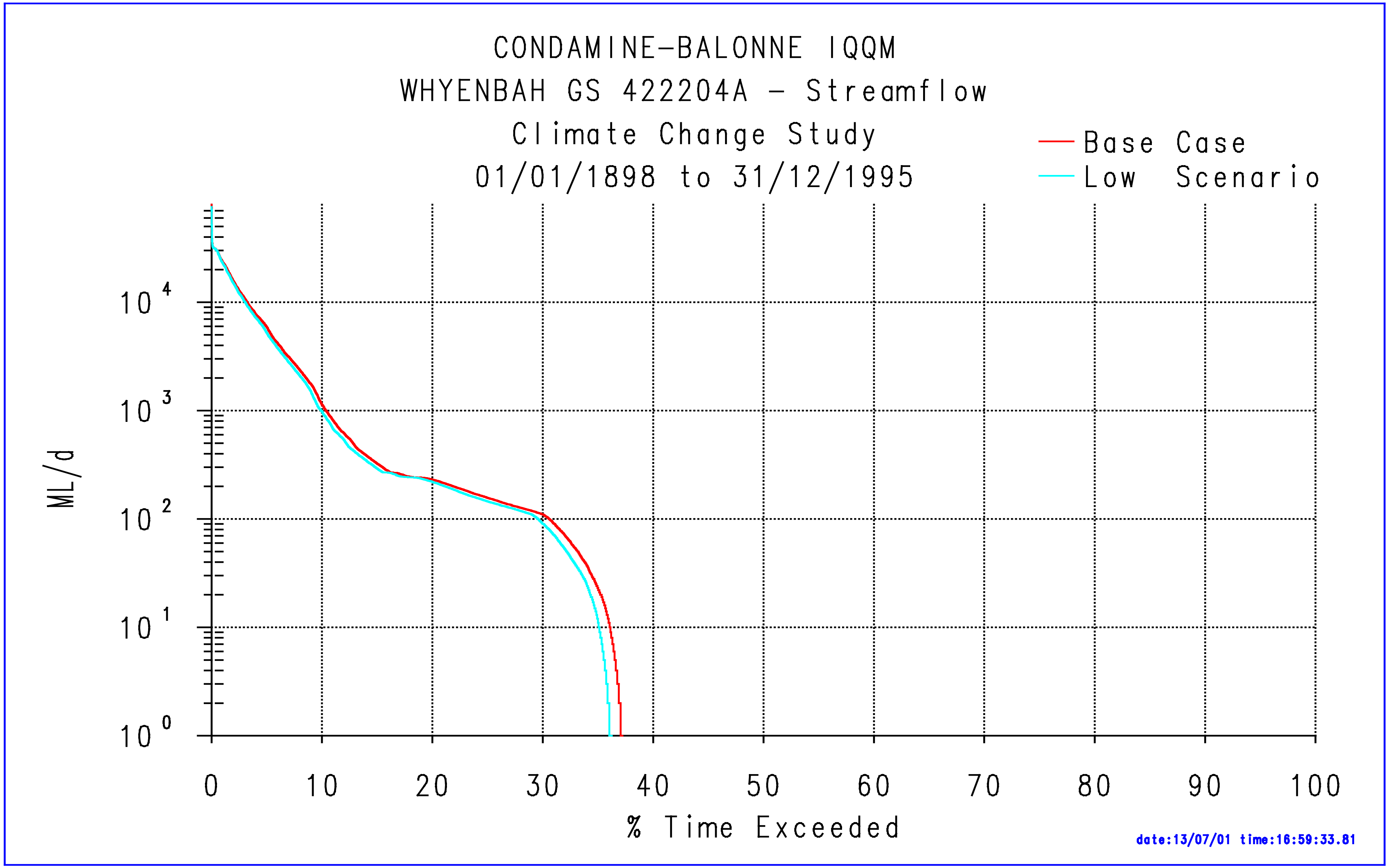

Figure 5.18: Streamflow at GS 422204A Whyenbah (Base vs Low Case)

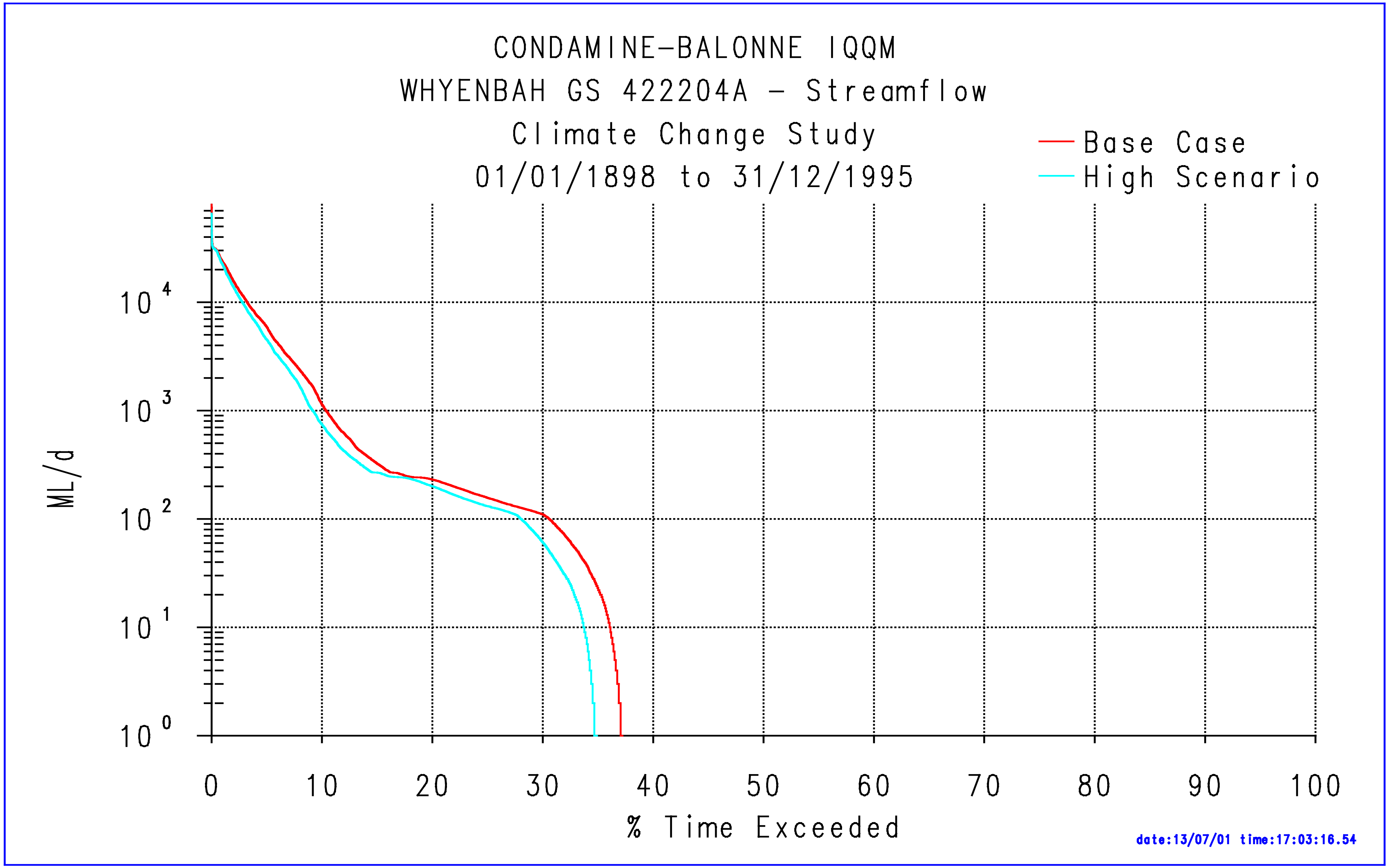

**Figure 5.19: Streamflow at GS 422204A Whyenbah (Base vs High Case)**

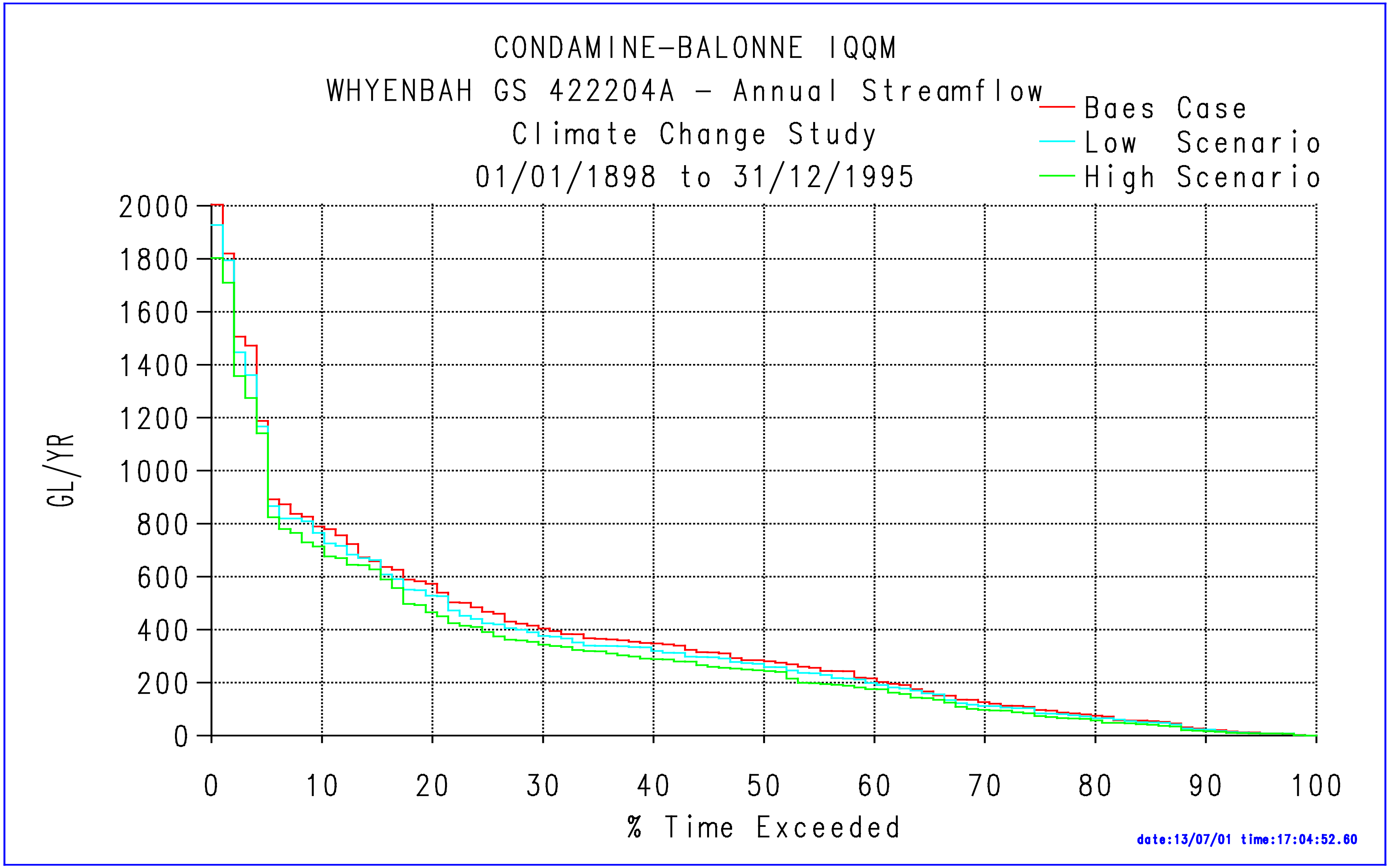

Figure 5.20: Annual Streamflow at GS 422204A Whyenbah

## *6 CHANGES TO IRRIGATION DEMANDS (FROM IQQM)*

In this section the statistics of water usage have been summarised. The mean annual diversion and reliabilities have been compared for the following areas of the Condamine-Balonne system:

- Leslie Dam Irrigation Scheme
- Chinchilla Weir Irrigation Scheme
- St George Irrigation Area
- Unregulated Irrigation downstream of Beardmore Dam

High priority demands are usually town water supply and industrial demands that have a higher reliability than the other demands in the system. The higher reliability is achieved through the announced allocation rule, which sets aside a carry-over reserve for the high priority demands. The higher the reserve, the higher the reliability of the high priority demands and the lower the reliability of the medium priority demand.

Medium priority demand represents mainly irrigation demand. The demand in the IQQM has been set to the Nominal Allocation and does not change from year to year even if the announced allocation is below 100 per cent. In other words, the crop demand model has been turned off. A deficit will occur when the cumulative demand for the water year exceeds the current allocation (which is the product of the announced allocation and the Nominal Allocation). For example, if the announced allocation at the beginning of the year is 30 per cent, there will not be a deficit in supply until the total demand reaches 30 per cent of the Nominal Allocation. Depending on the demand pattern, this may take several months. If there is a significant inflow in the meantime, the announced allocation may be increased to allow irrigation to continue for a few more months. The announced allocation has to reach 100 per cent before the cumulative demand reaches 100 per cent for no deficit to occur For water harvesters, the crop demand model was used to estimate the crop demand from rainfall and potential evaporation. The planted areas were estimated by dividing the on-farm storage capacity by the mean annual crop demand. The surface area of the on-farm storages was estimated by assuming a mean depth of 3m. The flow thresholds in the IQQM have been adjusted to maintain the river flow downstream of the extraction location.

Water harvesters in the St George and Distributary System used a crop demand that did not take into account rainfall and did not vary year to year. The crop demand was estimated using a demand pattern and an annual average crop demand shown in Table 6.1. The planted area was calculated by dividing the on-farm storage capacity by 12 megalitres per hectare. The surface area of the on-farm storages was estimated by assuming a mean depth of 4m.

**Table 6.1: Monthly Demand Pattern for Water Harvesting Demand (St George and Distributary System only)**

| Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|
| St George - Annual Average Crop Demand = 6.3 ML/ha/annum | | | | | | | | | | | |
| 19.9 | 17.7 | 6.8 | 1.1 | 0.2 | 0.5 | 0.2 | 3.2 | 16.9 | 5.1 | 4.7 | 23.7 |
| Distributary System - Annual Average Crop Demand = 6.0 ML/ha/annum | | | | | | | | | | | |
| 23.1 | 20.6 | 7.0 | 2.2 | 0 | 0.1 | 0.5 | 2.7 | 12.1 | 6.3 | 4.2 | 21.2 |

Stock and domestic demands were represented as demands with a uniform daily demand pattern

### 6.1 Leslie Dam Irrigation Scheme

Leslie Dam is situated on Sandy Creek in the upper reaches of the Condamine River. The storage has a capacity of 106,250 megalitres and a dead storage level of 3,300 megalitres. The Leslie Dam Irrigation Scheme or Upper Condamine Irrigation Project (UCIP) extends from Leslie Dam to Cecil Weir and includes the North Branch. The management system consists of two components, namely the operating levels in the weirs downstream of Leslie Dam and the announced allocation system. A summary for water use in the Leslie Dam Irrigation Scheme for the climate change scenarios is shown in Table 6.2. The results of the Draft WAMP Scenario-A case have been presented for comparison.

**Table 6.2: Water Use - Leslie Dam Irrigation Scheme**

| | | | Draft WAMP Scenario-A | Low Case[*] | High Case[*] |
|---|---|---|---|---|---|
| **Regulated Users (High Priority)**<br>Killarney TWS<br>Warwick TWS<br>Cecil Plains TWS | Mean Annual Diversion (ML) | | 5917 | -1.3% | -2.9% |
| | Reliability | Annual | 94.5% | -1.1% | -1.1% |
| | | Monthly | 98.5% | -0.2% | -0.1% |
| **Regulated Users (Medium Priority)**<br>Regulated Irrigation | Mean Annual Diversion (ML) | | 17448 | -7.7% | -18.4% |
| | Reliability | Annual | 57.5% | -9.3% | -18.6% |
| | | Monthly | 77.9% | -6.2% | -14.1% |
| **Water Harvesting** | Mean Annual Diversion (ML) | | 26992 | +0.6%[♣] | -1.7% |
| **Stock & Domestic** | Mean Annual Diversion (ML) | | 261 | -1.3% | -3.0% |

[*] The Mean Annual Diversion and Reliabilities have been shown as percentage change from the Base Case

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[♣] The IQQM scenarios predicted a decrease in diversions for both cases except for the water harvesting. The increased evaporation caused an increase in crop demand and losses from the on-farm-storages, so that the despite the decrease in streamflow there was an increase in water harvesting diversions.

### 6.2 Chinchilla Weir Irrigation Scheme

The Lower Condamine IQQM includes the Chinchilla Weir Water Supply Scheme based on Chinchilla Weir. The model represents the management system of this regulated section of the Condamine River. The medium priority demands have been represented as three nodes with different access to the weir. Because of the high transmission losses involved in releasing water to the downstream irrigators during dry periods, releases are not made to these users when the storage is low. The system is managed using cut-off levels. A summary for water use in the Chinchilla Weir Irrigation Scheme for the climate change scenarios is show in Table 6.3. The results of the Draft WAMP Scenario-A case have been presented for comparison.

**Table 6.3: Water Use - Chinchilla Weir Irrigation Scheme**

| | | | **Draft WAMP Scenario-A** | **Low Case*** | **High Case*** |
|---|---|---|---|---|---|
| **Regulated Users (High Priority)**<br>Chinchilla TWS<br>BrigalowTWS<br>Condamine TWS | Mean Annual Diversion (ML) | | 1285 | -0.1% | -0.3% |
| | Reliability | Annual | 89.0% | -1.0% | -1.0% |
| | | Monthly | 97.4% | -0.2% | -0.3% |
| **Regulated Users (Medium Priority)**<br>Regulated Irrigation | Mean Annual Diversion (ML) | | 2367 | -1.0% | -2.5% |
| | Reliability | Annual | 63.0% | 0.0% | -7.2% |
| | | Monthly | 86.9% | -0.4% | -2.1% |
| **Water Harvesting**** | Mean Annual Diversion (ML) | | 41997 | +1.0%♣ | -2.2% |
| **Stock & Domestic**** | Mean Annual Diversion (ML) | | 276 | -3.2% | -7.7% |

*The Mean Annual Diversion and Reliabilities have been shown as percentage change from the Base Case
**Only diversions on the main River from Cecil Plains to Weribone

### 6.3 St George Irrigation Area and Distributary System

The St George system has been modelled using the SGOS12 program, a daily simulation program developed by the Department of Natural Resources (Harding,2000). The SGOS12 model represents the dam and weirs in the St George System as a single storage. The details of the storages are presented in Table 6.4. Because the model does not represent the individual storages, it cannot represent the operation of the weirs. However, the storage-area curve was developed on the assumption that Buckinbah and Moolabah Weirs would be dawn down first and that Jack Taylor Weir would be kept full until Beardmore Dam was drawn down to its dead storage level. The start of the water year is the beginning of October. The announced allocation is calculated at the beginning of every month and when the storage overflows. In this case, the carryover of unused allocation and forward draws

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♣ The IQQM scenarios predicted a decrease in diversions for both cases except for the water harvesting. The increased evaporation caused an increase in crop demand and losses from the on-farm-storages, so that the despite the decrease in streamflow there was an increase in water harvesting diversions.

on the next year's allocation were not allowed. The use of off-allocation water by the medium priority users when the storage overflowed was not allowed.

The monthly potential evaporation expected to the end of the cotton-growing season in March was used. The announced allocation was not revised from April until the end of the water year. A summary for regulated water use in the St George Irrigation Scheme for the climate change scenarios is show in Table 6.5. The results of the Draft WAMP Scenario-A case have been presented for comparison.

The Distributary system is an unregulated system and has been modelled as such. However, the distribution of low flows though the system has been controlled by a series of weirs called the bifurcation weirs. The effect of the weirs on the flow distribution were calibrated to recorded flows.

A summary for unregulated water use downstream of Beardmore Dam is shown in Table 6.6. The results of the Draft WAMP Scenario-A case have been presented for comparison.

**Table 6.4: St George System Storages**

| Storage | Capacity (ML) | Surface Area at Full Supply Level (ha) | Dead Storage (ML) |
|---|---|---|---|
| Beardmore Dam | 81700 | 2862 | 4000 |
| Jack Taylor Weir | 10100 | 316 | 3000 |
| Moolabah Weir | 3950 | 185 | 800 |
| Buckinbah Weir | 5120 | 205 | 2200 |
| **Total** | **100870** | **3568** | **10000** |

**Table 6.5: Water Use - St George Irrigation Area**

| | | | Draft WAMP Scenario-A | Low Case* | High Case* |
|---|---|---|---|---|---|
| **Regulated Users (High Priority)**<br>St George TWS | Mean Annual Diversion (ML) | | 2960 | -0.2% | -0.5% |
| | Reliability | Annual | 94.5% | 0.0% | 0.0% |
| | | Monthly | 99.5% | 0.0% | 0.0% |
| **Regulated Users (Medium Priority)**<br>Regulated Irrigation | Mean Annual Diversion (ML) | | 63013 | -0.9% | -2.8% |
| | Reliability | Annual | 52.1% | -3.1% | -11.4% |
| | | Monthly | 87.0% | -1.7% | -3.9% |

* The Mean Annual Diversion and Reliabilities have been shown as percentage change from the Base Case

## Table 6.6: Water Use - Unregulated Irrigation Downstream of Beardmore Dam

| | | **Draft WAMP Scenario-A** | **Low Case**[*] | **High Case**[*] |
|---|---|---|---|---|
| **Water Harvesting**<br>St George | Mean Annual Diversion (ML) | 125791 | -1.1% | -4.8% |
| **Water Harvesting**<br>QLD Distributary Stystem | Mean Annual Diversion (ML) | 209450 | -6.3% | -13.8% |
| **Water Harvesting**<br>Downstream of Beardmore | Mean Annual Diversion (ML) | 335241 | -4.0% | -9.3% |

[*] The Mean Annual Diversion and Reliabilities have been shown as percentage change from the Base Case

# *7 CONCLUSIONS*

Hydrologic models were used to analyse the effects of the climate change scenarios. GCM data used to modify the rainfall and potential evaporation data used by both the Sacramento and IQQM models. The Sacramento model was used to generate the modified streamflows for the Condamine-Balonne sub-catchments. To analyse the behaviour and impacts on irrigation, the modified streamflows were incorporated as inflows for the 'Scenario A' IQQM models (Developed for the Draft Condamine-Balonne Water Allocation Management Plan). The Sacramento and IQQM models were designed to simulate the large-scale behaviour of the catchment and were calibrated to give the closest representation of actual catchment behaviour at a daily time step. As the models have been based on the large-scale catchment behaviour, they may not reproduce all of the changes caused by climate change.

Irrigation demand in the model has been based on entitlements so the model does not fully represent irrigator response to climate change. In the regulated sections the demand for each year has been set to the nominal allocation on the licence and is independent of rainfall and potential evaporation. The change in the diversions associated with these licences is caused by the change in flow. The unregulated demands use the crop model and are affected by the changes to rainfall and potential evaporation. However, the planted areas used in these simulations did not change from year to year. This should be kept in mind when interpreting these results.

Water harvesting in the Leslie Dam Irrigation Scheme and Chinchilla Weir Irrigation Scheme showed slight increases in diversion for the low case. The increased potential evaporation caused an increase in crop demand and losses from the on-farm-storages, so that despite the decrease in streamflow, there was an increase in water harvesting diversion.

Despite these limitations, the modelling provides an estimate of the impact of climate change on the hydrology and water resources of the Condamine System. The high case was predicted to cause between 7.5 and 18.3 percent reduction in the inflows, which was predicted to cause a reduction in streamflow at the downstream gauges of Hastings and Whyenbah of approximately 13.5 percent. The greatest reductions were predicted to occur during the period from November to January.

The reduction in streamflow was predicted to cause a reduction of up to 18.4 percent in regulated irrigation upstream of Cecil Plains, but only 2.8 percent at St George. Water harvesting diversions were predicted to decrease by only 1.7 percent upstream of Cecil Plains. In the more developed section downstream of Beardmore Dam, the predicted diversion decrease was 9.3 percent. A similar decrease was predicted for overland flow water harvesting. Unregulated irrigation upstream of Cecil Plains was predicted to increase by 1.0 percent because of the higher demand from higher expected potential evaporation. Even though the flows had decreased, there was still sufficient flow to meet some of the extra demand.

The modelling suggests that the high case would have significant impact on the hydrology and water resources of the Condamine-Balonne system.

## *8 REFERENCES*

Burnash, R.J.E., Ferral, R.L. and McGuire (1984), “A Generalised Streamflow Simulation System”, Joint Federal-State River Forecast Centre, Sacramento, California.

Chaseling McGiffin PTY LTD (1998) “St George Irrigation Area, Water Resource Simulation Model, ‘SGOS10, Version 11.0 03-02-00’”, Prepared for DNR, April 1998

Department of Land & Water Conservation (1995), “Intergrated Quantity-Quality Model (IQQM) Reference Manual”, NSW.

## *9 Monthly Climate Change Factors - Provided by CSIRO*

**Epot 50%**

| Station | Lat | Lon | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 035093 | -25 | 147.95 | 5.3 | 5.4 | 4.6 | 3.8 | 3.0 | 3.3 | 3.6 | 3.9 | 4.3 | 4.7 | 5.1 | 5.2 |
| 040170 | -27.3 | 152.05 | 4.3 | 3.9 | 4.0 | 4.0 | 4.1 | 4.3 | 4.5 | 4.8 | 4.9 | 5.1 | 5.3 | 4.8 |
| 041005 | -26.95 | 151.45 | 4.4 | 4.1 | 4.0 | 4.0 | 3.9 | 4.2 | 4.4 | 4.7 | 4.9 | 5.0 | 5.2 | 4.8 |
| 041007 | -26.85 | 150.8 | 4.6 | 4.2 | 4.1 | 4.0 | 3.8 | 4.1 | 4.3 | 4.6 | 4.8 | 5.0 | 5.2 | 4.9 |
| 041013 | -28.25 | 152.05 | 4.2 | 3.7 | 3.9 | 4.0 | 4.2 | 4.4 | 4.6 | 4.8 | 5.0 | 5.1 | 5.3 | 4.8 |
| 041014 | -28.35 | 151.7 | 4.2 | 3.7 | 3.9 | 4.0 | 4.2 | 4.4 | 4.6 | 4.8 | 5.0 | 5.1 | 5.3 | 4.7 |
| 041018 | -27.5 | 151.9 | 4.3 | 3.9 | 3.9 | 4.0 | 4.1 | 4.3 | 4.6 | 4.8 | 4.9 | 5.1 | 5.3 | 4.8 |
| 041022 | -28.5 | 151.95 | 4.2 | 3.6 | 3.8 | 4.0 | 4.2 | 4.4 | 4.6 | 4.9 | 5.0 | 5.1 | 5.3 | 4.7 |
| 041023 | -27.2 | 151.25 | 4.4 | 4.1 | 4.0 | 4.0 | 3.9 | 4.2 | 4.5 | 4.7 | 4.9 | 5.0 | 5.2 | 4.8 |
| 041035 | -28.1 | 152.1 | 4.2 | 3.7 | 3.9 | 4.0 | 4.2 | 4.4 | 4.6 | 4.8 | 5.0 | 5.1 | 5.3 | 4.8 |
| 041037 | -27.3 | 151.85 | 4.4 | 3.9 | 4.0 | 4.0 | 4.1 | 4.3 | 4.5 | 4.8 | 4.9 | 5.1 | 5.3 | 4.8 |
| 041041 | -28.25 | 151.75 | 4.2 | 3.7 | 3.9 | 4.0 | 4.2 | 4.4 | 4.6 | 4.8 | 5.0 | 5.1 | 5.3 | 4.8 |
| 041044 | -28.2 | 152.1 | 4.2 | 3.7 | 3.9 | 4.0 | 4.2 | 4.4 | 4.6 | 4.8 | 5.0 | 5.1 | 5.3 | 4.8 |
| 041046 | -28.3 | 152.4 | 4.2 | 3.6 | 3.8 | 4.1 | 4.3 | 4.5 | 4.7 | 4.9 | 5.0 | 5.2 | 5.3 | 4.8 |
| 041050 | -26.8 | 151.1 | 4.5 | 4.2 | 4.1 | 4.0 | 3.9 | 4.1 | 4.4 | 4.6 | 4.8 | 5.0 | 5.2 | 4.9 |
| 041051 | -26.95 | 151.2 | 4.5 | 4.1 | 4.0 | 4.0 | 3.9 | 4.2 | 4.4 | 4.7 | 4.9 | 5.0 | 5.2 | 4.8 |
| 041053 | -27.35 | 151.6 | 4.4 | 3.9 | 4.0 | 4.0 | 4.0 | 4.3 | 4.5 | 4.8 | 4.9 | 5.1 | 5.2 | 4.8 |
| 041056 | -28.35 | 152.3 | 4.2 | 3.6 | 3.8 | 4.1 | 4.3 | 4.5 | 4.7 | 4.9 | 5.0 | 5.2 | 5.3 | 4.8 |
| 041061 | -27.65 | 151.2 | 4.4 | 4.0 | 4.0 | 4.0 | 4.0 | 4.2 | 4.5 | 4.8 | 4.9 | 5.1 | 5.2 | 4.8 |
| 041063 | -28 | 151.6 | 4.3 | 3.8 | 3.9 | 4.0 | 4.1 | 4.3 | 4.6 | 4.8 | 5.0 | 5.1 | 5.2 | 4.8 |
| 041069 | -27.85 | 151.25 | 4.3 | 3.9 | 3.9 | 4.0 | 4.0 | 4.3 | 4.5 | 4.8 | 4.9 | 5.1 | 5.2 | 4.8 |
| 041082 | -27.7 | 151.65 | 4.3 | 3.9 | 3.9 | 4.0 | 4.1 | 4.3 | 4.6 | 4.8 | 4.9 | 5.1 | 5.2 | 4.8 |
| 041083 | -28.1 | 151.8 | 4.3 | 3.8 | 3.9 | 4.0 | 4.2 | 4.4 | 4.6 | 4.8 | 5.0 | 5.1 | 5.3 | 4.8 |
| 041086 | -26.65 | 151.4 | 4.5 | 4.2 | 4.1 | 4.0 | 3.9 | 4.1 | 4.4 | 4.7 | 4.8 | 5.0 | 5.2 | 4.9 |
| 041103 | -27.6 | 151.95 | 4.3 | 3.8 | 3.9 | 4.0 | 4.1 | 4.3 | 4.6 | 4.8 | 4.9 | 5.1 | 5.3 | 4.8 |
| 041107 | -27.9 | 152.1 | 4.3 | 3.8 | 3.9 | 4.0 | 4.2 | 4.4 | 4.6 | 4.8 | 5.0 | 5.1 | 5.3 | 4.8 |
| 041120 | -28.2 | 152.2 | 4.2 | 3.7 | 3.9 | 4.1 | 4.2 | 4.4 | 4.6 | 4.8 | 5.0 | 5.2 | 5.3 | 4.8 |
| 041126 | -27.6 | 151.85 | 4.3 | 3.9 | 3.9 | 4.0 | 4.1 | 4.3 | 4.6 | 4.8 | 4.9 | 5.1 | 5.3 | 4.8 |
| 041134 | -28.3 | 152.4 | 4.2 | 3.6 | 3.8 | 4.1 | 4.3 | 4.5 | 4.7 | 4.9 | 5.0 | 5.2 | 5.3 | 4.8 |
| 041140 | -27.2 | 151.25 | 4.4 | 4.1 | 4.0 | 4.0 | 3.9 | 4.2 | 4.5 | 4.7 | 4.9 | 5.0 | 5.2 | 4.8 |
| 041191 | -27.25 | 151.35 | 4.4 | 4.0 | 4.0 | 4.0 | 4.0 | 4.2 | 4.5 | 4.7 | 4.9 | 5.0 | 5.2 | 4.8 |
| 041197 | -27.3 | 150.85 | 4.5 | 4.1 | 4.0 | 4.0 | 3.9 | 4.1 | 4.4 | 4.7 | 4.8 | 5.0 | 5.2 | 4.8 |
| 041261 | -27.1 | 150.8 | 4.5 | 4.2 | 4.1 | 4.0 | 3.9 | 4.1 | 4.4 | 4.6 | 4.8 | 5.0 | 5.2 | 4.8 |
| 041271 | -27.1 | 151.65 | 4.4 | 4.0 | 4.0 | 4.0 | 4.0 | 4.2 | 4.5 | 4.7 | 4.9 | 5.1 | 5.2 | 4.8 |

| | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 041283 | -27.25 | 151.3 | 4.4 | 4.0 | 4.0 | 4.0 | 4.0 | 4.2 | 4.5 | 4.7 | 4.9 | 5.0 | 5.2 | 4.8 |
| 041332 | -28.05 | 152.35 | 4.2 | 3.7 | 3.9 | 4.1 | 4.2 | 4.4 | 4.6 | 4.8 | 5.0 | 5.2 | 5.3 | 4.8 |
| 041359 | -27.4 | 151.75 | 4.3 | 3.9 | 4.0 | 4.0 | 4.1 | 4.3 | 4.5 | 4.8 | 4.9 | 5.1 | 5.2 | 4.8 |
| 041445 | -28.2 | 151.9 | 4.2 | 3.7 | 3.9 | 4.0 | 4.2 | 4.4 | 4.6 | 4.8 | 5.0 | 5.1 | 5.3 | 4.8 |
| 041504 | -27.75 | 151.4 | 4.3 | 3.9 | 3.9 | 4.0 | 4.1 | 4.3 | 4.5 | 4.8 | 4.9 | 5.1 | 5.2 | 4.8 |
| 042012 | -27.25 | 149.7 | 4.6 | 4.4 | 4.2 | 3.9 | 3.7 | 4.0 | 4.2 | 4.5 | 4.7 | 4.9 | 5.1 | 4.9 |
| 042016 | -27.35 | 150.05 | 4.6 | 4.3 | 4.1 | 3.9 | 3.8 | 4.0 | 4.3 | 4.6 | 4.8 | 5.0 | 5.2 | 4.9 |
| 042023 | -26.65 | 150.2 | 4.7 | 4.5 | 4.2 | 3.9 | 3.7 | 3.9 | 4.2 | 4.5 | 4.7 | 4.9 | 5.2 | 4.9 |
| 042078 | -26.9 | 150.45 | 4.6 | 4.3 | 4.1 | 3.9 | 3.8 | 4.0 | 4.3 | 4.6 | 4.8 | 5.0 | 5.2 | 4.9 |
| 042091 | -26.45 | 150.9 | 4.6 | 4.3 | 4.1 | 4.0 | 3.8 | 4.0 | 4.3 | 4.6 | 4.8 | 5.0 | 5.2 | 4.9 |
| 043000 | -26.55 | 148.2 | 4.9 | 4.9 | 4.3 | 3.8 | 3.3 | 3.6 | 4.0 | 4.3 | 4.5 | 4.8 | 5.0 | 5.0 |
| 043009 | -25.95 | 147.85 | 5.1 | 5.1 | 4.5 | 3.8 | 3.2 | 3.5 | 3.8 | 4.1 | 4.4 | 4.7 | 5.0 | 5.1 |
| 043014 | -26.3 | 148.6 | 4.9 | 4.9 | 4.4 | 3.8 | 3.3 | 3.6 | 3.9 | 4.3 | 4.5 | 4.8 | 5.1 | 5.0 |
| 043020 | -26.5 | 148 | 4.9 | 4.9 | 4.4 | 3.8 | 3.3 | 3.6 | 3.9 | 4.3 | 4.5 | 4.8 | 5.0 | 5.0 |
| 043029 | -25.85 | 147.4 | 5.1 | 5.2 | 4.5 | 3.8 | 3.1 | 3.4 | 3.8 | 4.1 | 4.4 | 4.7 | 5.0 | 5.1 |
| 043039 | -27.35 | 148.9 | 4.7 | 4.5 | 4.2 | 3.9 | 3.6 | 3.9 | 4.2 | 4.5 | 4.7 | 4.9 | 5.1 | 4.9 |
| 043043 | -26.6 | 149.4 | 4.8 | 4.6 | 4.3 | 3.9 | 3.5 | 3.8 | 4.1 | 4.4 | 4.6 | 4.9 | 5.1 | 5.0 |
| 043050 | -25.5 | 148 | 5.2 | 5.3 | 4.5 | 3.8 | 3.1 | 3.4 | 3.7 | 4.0 | 4.4 | 4.7 | 5.1 | 5.1 |
| 043053 | -28 | 148.6 | 4.6 | 4.3 | 4.1 | 3.9 | 3.6 | 3.9 | 4.3 | 4.6 | 4.7 | 4.9 | 5.0 | 4.8 |
| 043060 | -26.1 | 147.9 | 5.0 | 5.1 | 4.4 | 3.8 | 3.2 | 3.5 | 3.8 | 4.2 | 4.5 | 4.7 | 5.0 | 5.0 |
| 043082 | -27.15 | 148.6 | 4.7 | 4.6 | 4.2 | 3.8 | 3.5 | 3.8 | 4.1 | 4.4 | 4.6 | 4.8 | 5.1 | 4.9 |
| 043090 | -27.9 | 148.65 | 4.6 | 4.4 | 4.1 | 3.9 | 3.6 | 3.9 | 4.2 | 4.6 | 4.7 | 4.9 | 5.0 | 4.8 |
| 044011 | -26.8 | 147.65 | 4.9 | 4.9 | 4.3 | 3.8 | 3.3 | 3.6 | 4.0 | 4.3 | 4.5 | 4.8 | 5.0 | 4.9 |
| 044075 | -27.25 | 148.1 | 4.8 | 4.6 | 4.2 | 3.8 | 3.4 | 3.8 | 4.1 | 4.4 | 4.6 | 4.8 | 5.0 | 4.9 |

**Precip 50%**

| Station | Lat | Lon | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 035093 | -25 | 147.95 | -1.9 | -2.0 | 0.2 | 2.3 | 4.5 | 3.7 | 2.8 | 2.0 | 0.7 | -0.5 | -1.8 | -1.8 |
| 040170 | -27.3 | 152.05 | 0.1 | 1.0 | 1.0 | 1.0 | 1.0 | 0.3 | -0.4 | -1.1 | -1.3 | -1.6 | -1.8 | -0.9 |
| 041005 | -26.95 | 151.45 | -0.1 | 0.8 | 1.0 | 1.2 | 1.5 | 0.7 | -0.1 | -0.8 | -1.1 | -1.4 | -1.8 | -0.9 |
| 041007 | -26.85 | 150.8 | -0.2 | 0.5 | 1.0 | 1.5 | 1.9 | 1.1 | 0.3 | -0.5 | -0.9 | -1.3 | -1.7 | -1.0 |
| 041013 | -28.25 | 152.05 | 0.4 | 1.5 | 1.3 | 1.0 | 0.8 | 0.1 | -0.6 | -1.3 | -1.4 | -1.6 | -1.8 | -0.7 |
| 041014 | -28.35 | 151.7 | 0.5 | 1.6 | 1.4 | 1.2 | 1.0 | 0.2 | -0.5 | -1.2 | -1.4 | -1.5 | -1.7 | -0.6 |
| 041018 | -27.5 | 151.9 | 0.2 | 1.1 | 1.1 | 1.1 | 1.1 | 0.3 | -0.4 | -1.1 | -1.3 | -1.5 | -1.8 | -0.8 |
| 041022 | -28.5 | 151.95 | 0.5 | 1.6 | 1.3 | 1.1 | 0.8 | 0.1 | -0.6 | -1.3 | -1.4 | -1.6 | -1.7 | -0.6 |
| 041023 | -27.2 | 151.25 | 0.0 | 0.9 | 1.1 | 1.3 | 1.5 | 0.8 | -0.1 | -0.8 | -1.1 | -1.4 | -1.7 | -0.9 |
| 041035 | -28.1 | 152.1 | 0.4 | 1.4 | 1.2 | 1.0 | 0.8 | 0.1 | -0.6 | -1.2 | -1.4 | -1.6 | -1.8 | -0.7 |
| 041037 | -27.3 | 151.85 | 0.1 | 1.0 | 1.0 | 1.1 | 1.1 | 0.4 | -0.3 | -1.0 | -1.3 | -1.5 | -1.8 | -0.9 |
| 041041 | -28.25 | 151.75 | 0.4 | 1.5 | 1.3 | 1.1 | 1.0 | 0.2 | -0.5 | -1.2 | -1.4 | -1.5 | -1.7 | -0.6 |
| 041044 | -28.2 | 152.1 | 0.4 | 1.5 | 1.2 | 1.0 | 0.8 | 0.1 | -0.6 | -1.3 | -1.4 | -1.6 | -1.8 | -0.7 |
| 041046 | -28.3 | 152.4 | 0.4 | 1.5 | 1.2 | 0.9 | 0.6 | 0.0 | -0.7 | -1.3 | -1.5 | -1.6 | -1.8 | -0.7 |
| 041050 | -26.8 | 151.1 | -0.2 | 0.6 | 1.0 | 1.4 | 1.7 | 1.0 | 0.2 | -0.6 | -1.0 | -1.4 | -1.7 | -1.0 |
| 041051 | -26.95 | 151.2 | -0.1 | 0.7 | 1.0 | 1.3 | 1.6 | 0.9 | 0.1 | -0.7 | -1.1 | -1.4 | -1.7 | -0.9 |
| 041053 | -27.35 | 151.6 | 0.1 | 1.0 | 1.1 | 1.2 | 1.3 | 0.5 | -0.2 | -1.0 | -1.2 | -1.5 | -1.7 | -0.8 |
| 041056 | -28.35 | 152.3 | 0.4 | 1.5 | 1.2 | 0.9 | 0.6 | 0.0 | -0.7 | -1.3 | -1.5 | -1.6 | -1.8 | -0.7 |
| 041061 | -27.65 | 151.2 | 0.2 | 1.1 | 1.2 | 1.3 | 1.4 | 0.7 | -0.2 | -0.9 | -1.2 | -1.4 | -1.7 | -0.7 |
| 041063 | -28 | 151.6 | 0.4 | 1.4 | 1.3 | 1.2 | 1.1 | 0.4 | -0.4 | -1.1 | -1.3 | -1.5 | -1.7 | -0.7 |
| 041069 | -27.85 | 151.25 | 0.3 | 1.3 | 1.3 | 1.3 | 1.4 | 0.6 | -0.2 | -1.0 | -1.2 | -1.5 | -1.7 | -0.7 |
| 041082 | -27.7 | 151.65 | 0.2 | 1.2 | 1.2 | 1.2 | 1.2 | 0.4 | -0.4 | -1.1 | -1.3 | -1.5 | -1.7 | -0.7 |
| 041083 | -28.1 | 151.8 | 0.4 | 1.4 | 1.3 | 1.1 | 1.0 | 0.2 | -0.5 | -1.2 | -1.4 | -1.5 | -1.7 | -0.7 |
| 041086 | -26.65 | 151.4 | -0.2 | 0.6 | 0.9 | 1.2 | 1.6 | 0.8 | 0.0 | -0.7 | -1.1 | -1.4 | -1.8 | -1.0 |
| 041103 | -27.6 | 151.95 | 0.2 | 1.2 | 1.1 | 1.0 | 1.0 | 0.3 | -0.4 | -1.1 | -1.3 | -1.6 | -1.8 | -0.8 |
| 041107 | -27.9 | 152.1 | 0.3 | 1.3 | 1.2 | 1.0 | 0.8 | 0.2 | -0.5 | -1.2 | -1.4 | -1.6 | -1.8 | -0.8 |
| 041120 | -28.2 | 152.2 | 0.4 | 1.5 | 1.2 | 1.0 | 0.7 | 0.1 | -0.6 | -1.3 | -1.4 | -1.6 | -1.8 | -0.7 |

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 041126 | -27.6 | 151.85 | 0.2 | 1.2 | 1.1 | 1.1 | 1.1 | 0.3 | -0.4 | -1.1 | -1.3 | -1.5 | -1.8 | -0.8 |
| 041134 | -28.3 | 152.4 | 0.4 | 1.5 | 1.2 | 0.9 | 0.6 | 0.0 | -0.7 | -1.3 | -1.5 | -1.6 | -1.8 | -0.7 |
| 041140 | -27.2 | 151.25 | 0.0 | 0.9 | 1.1 | 1.3 | 1.5 | 0.8 | -0.1 | -0.8 | -1.1 | -1.4 | -1.7 | -0.9 |
| 041191 | -27.25 | 151.35 | 0.1 | 0.9 | 1.1 | 1.3 | 1.5 | 0.7 | -0.1 | -0.9 | -1.2 | -1.4 | -1.7 | -0.8 |
| 041197 | -27.3 | 150.85 | 0.0 | 0.8 | 1.1 | 1.5 | 1.8 | 1.0 | 0.1 | -0.7 | -1.0 | -1.3 | -1.7 | -0.9 |
| 041261 | -27.1 | 150.8 | -0.1 | 0.7 | 1.1 | 1.5 | 1.9 | 1.1 | 0.2 | -0.6 | -0.9 | -1.3 | -1.7 | -0.9 |
| 041271 | -27.1 | 151.65 | 0.0 | 0.9 | 1.0 | 1.2 | 1.3 | 0.6 | -0.2 | -0.9 | -1.2 | -1.5 | -1.8 | -0.9 |
| 041283 | -27.25 | 151.3 | 0.1 | 0.9 | 1.1 | 1.3 | 1.5 | 0.7 | -0.1 | -0.9 | -1.1 | -1.4 | -1.7 | -0.8 |
| 041332 | -28.05 | 152.35 | 0.3 | 1.4 | 1.1 | 0.9 | 0.7 | 0.0 | -0.6 | -1.3 | -1.4 | -1.6 | -1.8 | -0.8 |
| 041359 | -27.4 | 151.75 | 0.1 | 1.1 | 1.1 | 1.1 | 1.2 | 0.4 | -0.3 | -1.0 | -1.3 | -1.5 | -1.8 | -0.8 |
| 041445 | -28.2 | 151.9 | 0.4 | 1.5 | 1.3 | 1.1 | 0.9 | 0.2 | -0.5 | -1.2 | -1.4 | -1.6 | -1.7 | -0.7 |
| 041504 | -27.75 | 151.4 | 0.3 | 1.2 | 1.2 | 1.3 | 1.3 | 0.5 | -0.3 | -1.0 | -1.2 | -1.5 | -1.7 | -0.7 |
| 042012 | -27.25 | 149.7 | -0.3 | 0.4 | 1.1 | 1.9 | 2.6 | 1.7 | 0.8 | 0.0 | -0.6 | -1.1 | -1.6 | -1.0 |
| 042016 | -27.35 | 150.05 | -0.2 | 0.6 | 1.1 | 1.7 | 2.3 | 1.5 | 0.6 | -0.2 | -0.7 | -1.2 | -1.6 | -0.9 |
| 042023 | -26.65 | 150.2 | -0.5 | 0.1 | 0.9 | 1.6 | 2.4 | 1.6 | 0.8 | 0.0 | -0.6 | -1.1 | -1.7 | -1.1 |
| 042078 | -26.9 | 150.45 | -0.3 | 0.4 | 1.0 | 1.6 | 2.2 | 1.4 | 0.5 | -0.3 | -0.7 | -1.2 | -1.7 | -1.0 |
| 042091 | -26.45 | 150.9 | -0.4 | 0.3 | 0.8 | 1.4 | 2.0 | 1.2 | 0.4 | -0.4 | -0.8 | -1.3 | -1.8 | -1.1 |
| 043000 | -26.55 | 148.2 | -0.7 | -0.3 | 1.0 | 2.4 | 3.7 | 2.7 | 1.7 | 0.7 | 0.0 | -0.8 | -1.5 | -1.1 |
| 043009 | -25.95 | 147.85 | -1.1 | -0.9 | 0.8 | 2.5 | 4.2 | 3.2 | 2.2 | 1.2 | 0.3 | -0.7 | -1.6 | -1.4 |
| 043014 | -26.3 | 148.6 | -0.9 | -0.5 | 0.8 | 2.2 | 3.6 | 2.7 | 1.7 | 0.8 | 0.0 | -0.8 | -1.6 | -1.3 |
| 043020 | -26.5 | 148 | -0.7 | -0.3 | 1.1 | 2.5 | 3.9 | 2.9 | 1.8 | 0.8 | 0.0 | -0.8 | -1.5 | -1.1 |
| 043029 | -25.85 | 147.4 | -1.2 | -1.0 | 0.8 | 2.7 | 4.5 | 3.5 | 2.4 | 1.4 | 0.4 | -0.6 | -1.6 | -1.4 |
| 043039 | -27.35 | 148.9 | -0.2 | 0.5 | 1.3 | 2.2 | 3.0 | 2.1 | 1.1 | 0.1 | -0.4 | -1.0 | -1.5 | -0.9 |
| 043043 | -26.6 | 149.4 | -0.7 | -0.2 | 0.8 | 1.9 | 3.0 | 2.1 | 1.3 | 0.4 | -0.3 | -1.0 | -1.7 | -1.2 |
| 043050 | -25.5 | 148 | -1.5 | -1.4 | 0.5 | 2.4 | 4.3 | 3.4 | 2.4 | 1.5 | 0.5 | -0.6 | -1.7 | -1.6 |
| 043053 | -28 | 148.6 | 0.2 | 1.0 | 1.7 | 2.3 | 3.0 | 1.9 | 0.8 | -0.2 | -0.6 | -1.0 | -1.4 | -0.6 |
| 043060 | -26.1 | 147.9 | -1.0 | -0.8 | 0.8 | 2.5 | 4.1 | 3.1 | 2.1 | 1.1 | 0.2 | -0.7 | -1.6 | -1.3 |
| 043082 | -27.15 | 148.6 | -0.3 | 0.3 | 1.3 | 2.3 | 3.3 | 2.3 | 1.3 | 0.3 | -0.3 | -0.9 | -1.5 | -0.9 |
| 043090 | -27.9 | 148.65 | 0.2 | 0.9 | 1.6 | 2.3 | 3.0 | 2.0 | 0.9 | -0.2 | -0.6 | -1.0 | -1.4 | -0.6 |
| 044011 | -26.8 | 147.65 | -0.5 | 0.0 | 1.3 | 2.7 | 4.0 | 2.9 | 1.7 | 0.6 | 0.0 | -0.7 | -1.4 | -1.0 |
| 044075 | -27.25 | 148.1 | -0.2 | 0.4 | 1.4 | 2.5 | 3.5 | 2.5 | 1.3 | 0.3 | -0.3 | -0.9 | -1.4 | -0.8 |

**Epot 95%**

| Station | Lat | Lon | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 035093 | -25 | 147.95 | 7.4 | 7.4 | 6.7 | 5.9 | 5.2 | 5.5 | 5.8 | 6.1 | 6.5 | 6.9 | 7.4 | 7.4 |
| 040170 | -27.3 | 152.05 | 6.4 | 5.9 | 6.0 | 6.1 | 6.2 | 6.4 | 6.7 | 7.0 | 7.1 | 7.2 | 7.3 | 6.9 |
| 041005 | -26.95 | 151.45 | 6.5 | 6.1 | 6.1 | 6.1 | 6.0 | 6.3 | 6.6 | 6.9 | 7.1 | 7.2 | 7.4 | 6.9 |
| 041007 | -26.85 | 150.8 | 6.6 | 6.3 | 6.1 | 6.0 | 5.9 | 6.2 | 6.5 | 6.8 | 7.0 | 7.2 | 7.3 | 7.0 |
| 041013 | -28.25 | 152.05 | 6.2 | 5.8 | 5.9 | 6.1 | 6.3 | 6.5 | 6.7 | 7.0 | 7.1 | 7.1 | 7.2 | 6.7 |
| 041014 | -28.35 | 151.7 | 6.2 | 5.8 | 5.9 | 6.1 | 6.2 | 6.5 | 6.7 | 7.0 | 7.1 | 7.1 | 7.2 | 6.7 |
| 041018 | -27.5 | 151.9 | 6.4 | 5.9 | 6.0 | 6.1 | 6.2 | 6.4 | 6.7 | 7.0 | 7.1 | 7.2 | 7.3 | 6.8 |
| 041022 | -28.5 | 151.95 | 6.2 | 5.7 | 5.9 | 6.1 | 6.3 | 6.5 | 6.7 | 7.0 | 7.0 | 7.1 | 7.2 | 6.7 |
| 041023 | -27.2 | 151.25 | 6.5 | 6.1 | 6.1 | 6.0 | 6.0 | 6.3 | 6.6 | 6.9 | 7.1 | 7.2 | 7.3 | 6.9 |
| 041035 | -28.1 | 152.1 | 6.3 | 5.8 | 5.9 | 6.1 | 6.3 | 6.5 | 6.7 | 7.0 | 7.1 | 7.2 | 7.2 | 6.8 |
| 041037 | -27.3 | 151.85 | 6.4 | 6.0 | 6.0 | 6.1 | 6.1 | 6.4 | 6.7 | 7.0 | 7.1 | 7.2 | 7.3 | 6.9 |
| 041041 | -28.25 | 151.75 | 6.3 | 5.8 | 5.9 | 6.1 | 6.2 | 6.5 | 6.7 | 7.0 | 7.1 | 7.1 | 7.2 | 6.7 |
| 041044 | -28.2 | 152.1 | 6.2 | 5.8 | 5.9 | 6.1 | 6.3 | 6.5 | 6.7 | 7.0 | 7.1 | 7.1 | 7.2 | 6.7 |
| 041046 | -28.3 | 152.4 | 6.2 | 5.7 | 5.9 | 6.1 | 6.3 | 6.5 | 6.8 | 7.0 | 7.0 | 7.1 | 7.2 | 6.7 |
| 041050 | -26.8 | 151.1 | 6.6 | 6.2 | 6.1 | 6.0 | 6.0 | 6.3 | 6.6 | 6.9 | 7.0 | 7.2 | 7.4 | 7.0 |
| 041051 | -26.95 | 151.2 | 6.5 | 6.1 | 6.1 | 6.0 | 6.0 | 6.3 | 6.6 | 6.9 | 7.0 | 7.2 | 7.4 | 6.9 |
| 041053 | -27.35 | 151.6 | 6.4 | 6.0 | 6.0 | 6.1 | 6.1 | 6.4 | 6.7 | 7.0 | 7.1 | 7.2 | 7.3 | 6.9 |
| 041056 | -28.35 | 152.3 | 6.2 | 5.7 | 5.9 | 6.1 | 6.3 | 6.5 | 6.7 | 7.0 | 7.0 | 7.1 | 7.2 | 6.7 |
| 041061 | -27.65 | 151.2 | 6.4 | 6.0 | 6.0 | 6.0 | 6.1 | 6.4 | 6.6 | 6.9 | 7.1 | 7.2 | 7.3 | 6.9 |
| 041063 | -28 | 151.6 | 6.3 | 5.9 | 6.0 | 6.1 | 6.2 | 6.4 | 6.7 | 7.0 | 7.1 | 7.2 | 7.2 | 6.8 |

| | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 041069 | -27.85 | 151.25 | 6.4 | 5.9 | 6.0 | 6.0 | 6.1 | 6.4 | 6.7 | 7.0 | 7.0 | 7.2 | 7.3 | 6.8 |
| 041082 | -27.7 | 151.65 | 6.4 | 5.9 | 6.0 | 6.1 | 6.1 | 6.4 | 6.7 | 7.0 | 7.1 | 7.2 | 7.3 | 6.8 |
| 041083 | -28.1 | 151.8 | 6.3 | 5.8 | 5.9 | 6.1 | 6.2 | 6.5 | 6.7 | 7.0 | 7.1 | 7.1 | 7.2 | 6.8 |
| 041086 | -26.65 | 151.4 | 6.6 | 6.2 | 6.1 | 6.1 | 6.0 | 6.3 | 6.6 | 6.9 | 7.1 | 7.2 | 7.4 | 7.0 |
| 041103 | -27.6 | 151.95 | 6.3 | 5.9 | 6.0 | 6.1 | 6.2 | 6.4 | 6.7 | 7.0 | 7.1 | 7.2 | 7.3 | 6.8 |
| 041107 | -27.9 | 152.1 | 6.3 | 5.8 | 5.9 | 6.1 | 6.2 | 6.5 | 6.7 | 7.0 | 7.1 | 7.2 | 7.3 | 6.8 |
| 041120 | -28.2 | 152.2 | 6.2 | 5.8 | 5.9 | 6.1 | 6.3 | 6.5 | 6.7 | 7.0 | 7.1 | 7.1 | 7.2 | 6.7 |
| 041126 | -27.6 | 151.85 | 6.4 | 5.9 | 6.0 | 6.1 | 6.2 | 6.4 | 6.7 | 7.0 | 7.1 | 7.2 | 7.3 | 6.8 |
| 041134 | -28.3 | 152.4 | 6.2 | 5.7 | 5.9 | 6.1 | 6.3 | 6.5 | 6.8 | 7.0 | 7.0 | 7.1 | 7.2 | 6.7 |
| 041140 | -27.2 | 151.25 | 6.5 | 6.1 | 6.1 | 6.0 | 6.0 | 6.3 | 6.6 | 6.9 | 7.1 | 7.2 | 7.3 | 6.9 |
| 041191 | -27.25 | 151.35 | 6.5 | 6.0 | 6.0 | 6.0 | 6.1 | 6.3 | 6.6 | 6.9 | 7.1 | 7.2 | 7.3 | 6.9 |
| 041197 | -27.3 | 150.85 | 6.5 | 6.1 | 6.1 | 6.0 | 6.0 | 6.3 | 6.6 | 6.9 | 7.0 | 7.2 | 7.3 | 6.9 |
| 041261 | -27.1 | 150.8 | 6.6 | 6.2 | 6.1 | 6.0 | 5.9 | 6.2 | 6.5 | 6.8 | 7.0 | 7.2 | 7.3 | 6.9 |
| 041271 | -27.1 | 151.65 | 6.5 | 6.0 | 6.0 | 6.1 | 6.1 | 6.4 | 6.7 | 7.0 | 7.1 | 7.2 | 7.4 | 6.9 |
| 041283 | -27.25 | 151.3 | 6.5 | 6.1 | 6.0 | 6.0 | 6.0 | 6.3 | 6.6 | 6.9 | 7.1 | 7.2 | 7.3 | 6.9 |
| 041332 | -28.05 | 152.35 | 6.2 | 5.8 | 5.9 | 6.1 | 6.3 | 6.5 | 6.7 | 7.0 | 7.1 | 7.2 | 7.2 | 6.8 |
| 041359 | -27.4 | 151.75 | 6.4 | 5.9 | 6.0 | 6.1 | 6.1 | 6.4 | 6.7 | 7.0 | 7.1 | 7.2 | 7.3 | 6.9 |
| 041445 | -28.2 | 151.9 | 6.3 | 5.8 | 5.9 | 6.1 | 6.2 | 6.5 | 6.7 | 7.0 | 7.1 | 7.1 | 7.2 | 6.7 |
| 041504 | -27.75 | 151.4 | 6.4 | 5.9 | 6.0 | 6.1 | 6.1 | 6.4 | 6.7 | 7.0 | 7.1 | 7.2 | 7.3 | 6.8 |
| 042012 | -27.25 | 149.7 | 6.7 | 6.4 | 6.2 | 6.0 | 5.8 | 6.1 | 6.4 | 6.7 | 6.9 | 7.1 | 7.3 | 7.0 |
| 042016 | -27.35 | 150.05 | 6.6 | 6.3 | 6.2 | 6.0 | 5.8 | 6.1 | 6.4 | 6.7 | 6.9 | 7.1 | 7.3 | 6.9 |
| 042023 | -26.65 | 150.2 | 6.8 | 6.5 | 6.2 | 6.0 | 5.8 | 6.1 | 6.4 | 6.7 | 6.9 | 7.1 | 7.3 | 7.0 |
| 042078 | -26.9 | 150.45 | 6.7 | 6.3 | 6.2 | 6.0 | 5.9 | 6.2 | 6.5 | 6.8 | 6.9 | 7.1 | 7.3 | 7.0 |
| 042091 | -26.45 | 150.9 | 6.7 | 6.3 | 6.2 | 6.0 | 5.9 | 6.2 | 6.5 | 6.8 | 7.0 | 7.2 | 7.4 | 7.0 |
| 043000 | -26.55 | 148.2 | 7.0 | 6.8 | 6.4 | 5.9 | 5.5 | 5.8 | 6.1 | 6.5 | 6.7 | 7.0 | 7.3 | 7.1 |
| 043009 | -25.95 | 147.85 | 7.2 | 7.1 | 6.5 | 5.9 | 5.3 | 5.7 | 6.0 | 6.3 | 6.7 | 7.0 | 7.3 | 7.2 |
| 043014 | -26.3 | 148.6 | 7.0 | 6.9 | 6.4 | 5.9 | 5.5 | 5.8 | 6.1 | 6.4 | 6.7 | 7.0 | 7.3 | 7.2 |
| 043020 | -26.5 | 148 | 7.0 | 6.9 | 6.4 | 5.9 | 5.4 | 5.8 | 6.1 | 6.5 | 6.7 | 7.0 | 7.3 | 7.1 |
| 043029 | -25.85 | 147.4 | 7.2 | 7.2 | 6.5 | 5.9 | 5.2 | 5.6 | 5.9 | 6.3 | 6.6 | 7.0 | 7.3 | 7.3 |
| 043039 | -27.35 | 148.9 | 6.7 | 6.5 | 6.2 | 5.9 | 5.7 | 6.0 | 6.3 | 6.6 | 6.8 | 7.0 | 7.2 | 7.0 |
| 043043 | -26.6 | 149.4 | 6.9 | 6.7 | 6.3 | 6.0 | 5.6 | 5.9 | 6.2 | 6.5 | 6.8 | 7.0 | 7.3 | 7.1 |
| 043050 | -25.5 | 148 | 7.3 | 7.2 | 6.6 | 5.9 | 5.3 | 5.6 | 5.9 | 6.2 | 6.6 | 7.0 | 7.4 | 7.3 |
| 043053 | -28 | 148.6 | 6.6 | 6.4 | 6.1 | 5.9 | 5.7 | 6.0 | 6.4 | 6.7 | 6.9 | 7.0 | 7.2 | 6.9 |
| 043060 | -26.1 | 147.9 | 7.1 | 7.0 | 6.5 | 5.9 | 5.4 | 5.7 | 6.0 | 6.4 | 6.7 | 7.0 | 7.3 | 7.2 |
| 043082 | -27.15 | 148.6 | 6.8 | 6.6 | 6.3 | 5.9 | 5.6 | 5.9 | 6.3 | 6.6 | 6.8 | 7.0 | 7.2 | 7.0 |
| 043090 | -27.9 | 148.65 | 6.6 | 6.4 | 6.1 | 5.9 | 5.7 | 6.0 | 6.4 | 6.7 | 6.9 | 7.0 | 7.2 | 6.9 |
| 044011 | -26.8 | 147.65 | 7.0 | 6.8 | 6.3 | 5.9 | 5.4 | 5.8 | 6.2 | 6.5 | 6.8 | 7.0 | 7.3 | 7.1 |
| 044075 | -27.25 | 148.1 | 6.8 | 6.6 | 6.3 | 5.9 | 5.5 | 5.9 | 6.3 | 6.6 | 6.8 | 7.0 | 7.2 | 7.0 |

**Precip 95%**

| Station | Lat | Lon | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 035093 | -25 | 147.95 | -3.7 | -3.0 | -0.5 | 2.1 | 4.6 | 3.7 | 2.9 | 2.0 | -0.3 | -2.7 | -5.0 | -4.3 |
| 040170 | -27.3 | 152.05 | -2.3 | -0.3 | -0.2 | 0.0 | 0.2 | -0.4 | -0.9 | -1.5 | -3.1 | -4.7 | -6.3 | -4.3 |
| 041005 | -26.95 | 151.45 | -2.4 | -0.6 | -0.2 | 0.3 | 0.7 | 0.1 | -0.5 | -1.1 | -2.7 | -4.4 | -6.1 | -4.3 |
| 041007 | -26.85 | 150.8 | -2.5 | -0.8 | -0.1 | 0.6 | 1.3 | 0.7 | 0.0 | -0.7 | -2.4 | -4.1 | -5.8 | -4.1 |
| 041013 | -28.25 | 152.05 | -1.8 | 0.3 | 0.2 | 0.1 | 0.0 | -0.6 | -1.2 | -1.8 | -3.2 | -4.6 | -5.9 | -3.9 |
| 041014 | -28.35 | 151.7 | -1.6 | 0.4 | 0.3 | 0.2 | 0.2 | -0.4 | -1.1 | -1.7 | -3.0 | -4.4 | -5.7 | -3.7 |
| 041018 | -27.5 | 151.9 | -2.2 | -0.2 | -0.1 | 0.1 | 0.2 | -0.3 | -0.9 | -1.5 | -3.0 | -4.6 | -6.1 | -4.2 |
| 041022 | -28.5 | 151.95 | -1.6 | 0.5 | 0.3 | 0.1 | 0.0 | -0.6 | -1.3 | -1.9 | -3.2 | -4.5 | -5.8 | -3.7 |
| 041023 | -27.2 | 151.25 | -2.2 | -0.4 | 0.0 | 0.4 | 0.8 | 0.2 | -0.5 | -1.1 | -2.7 | -4.3 | -5.9 | -4.1 |
| 041035 | -28.1 | 152.1 | -1.9 | 0.2 | 0.1 | 0.0 | 0.0 | -0.6 | -1.2 | -1.8 | -3.2 | -4.6 | -6.0 | -4.0 |
| 041037 | -27.3 | 151.85 | -2.3 | -0.3 | -0.1 | 0.1 | 0.3 | -0.2 | -0.8 | -1.4 | -3.0 | -4.6 | -6.2 | -4.3 |
| 041041 | -28.25 | 151.75 | -1.7 | 0.3 | 0.3 | 0.2 | 0.2 | -0.4 | -1.1 | -1.7 | -3.1 | -4.4 | -5.8 | -3.8 |

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 041044 | -28.2 | 152.1 | -1.8 | 0.3 | 0.2 | 0.1 | 0.0 | -0.6 | -1.2 | -1.8 | -3.2 | -4.6 | -6.0 | -3.9 |
| 041046 | -28.3 | 152.4 | -1.8 | 0.3 | 0.1 | -0.1 | -0.3 | -0.8 | -1.4 | -1.9 | -3.3 | -4.7 | -6.1 | -4.0 |
| 041050 | -26.8 | 151.1 | -2.5 | -0.8 | -0.2 | 0.4 | 1.1 | 0.4 | -0.2 | -0.8 | -2.5 | -4.3 | -6.0 | -4.3 |
| 041051 | -26.95 | 151.2 | -2.4 | -0.6 | -0.1 | 0.4 | 0.9 | 0.3 | -0.3 | -1.0 | -2.6 | -4.3 | -6.0 | -4.2 |
| 041053 | -27.35 | 151.6 | -2.2 | -0.3 | 0.0 | 0.2 | 0.5 | -0.1 | -0.7 | -1.3 | -2.9 | -4.5 | -6.0 | -4.1 |
| 041056 | -28.35 | 152.3 | -1.8 | 0.3 | 0.2 | 0.0 | -0.2 | -0.8 | -1.3 | -1.9 | -3.3 | -4.7 | -6.0 | -3.9 |
| 041061 | -27.65 | 151.2 | -2.0 | -0.1 | 0.2 | 0.4 | 0.7 | 0.1 | -0.6 | -1.3 | -2.7 | -4.2 | -5.7 | -3.9 |
| 041063 | -28 | 151.6 | -1.8 | 0.1 | 0.2 | 0.3 | 0.3 | -0.3 | -0.9 | -1.6 | -3.0 | -4.4 | -5.8 | -3.8 |
| 041069 | -27.85 | 151.25 | -1.8 | 0.0 | 0.2 | 0.4 | 0.6 | 0.0 | -0.7 | -1.4 | -2.8 | -4.2 | -5.6 | -3.8 |
| 041082 | -27.7 | 151.65 | -2.0 | -0.1 | 0.1 | 0.2 | 0.4 | -0.2 | -0.9 | -1.5 | -2.9 | -4.5 | -5.9 | -4.0 |
| 041083 | -28.1 | 151.8 | -1.8 | 0.2 | 0.2 | 0.2 | 0.2 | -0.4 | -1.1 | -1.7 | -3.1 | -4.5 | -5.9 | -3.9 |
| 041086 | -26.65 | 151.4 | -2.6 | -0.8 | -0.3 | 0.3 | 0.8 | 0.3 | -0.3 | -0.9 | -2.7 | -4.5 | -6.2 | -4.4 |
| 041103 | -27.6 | 151.95 | -2.1 | -0.1 | 0.0 | 0.1 | 0.2 | -0.4 | -1.0 | -1.5 | -3.1 | -4.6 | -6.1 | -4.2 |
| 041107 | -27.9 | 152.1 | -2.0 | 0.1 | 0.0 | 0.0 | 0.0 | -0.5 | -1.1 | -1.7 | -3.2 | -4.6 | -6.1 | -4.1 |
| 041120 | -28.2 | 152.2 | -1.8 | 0.2 | 0.1 | 0.0 | -0.1 | -0.7 | -1.3 | -1.8 | -3.2 | -4.7 | -6.0 | -4.0 |
| 041126 | -27.6 | 151.85 | -2.1 | -0.1 | 0.0 | 0.1 | 0.3 | -0.3 | -0.9 | -1.5 | -3.0 | -4.6 | -6.1 | -4.1 |
| 041134 | -28.3 | 152.4 | -1.8 | 0.3 | 0.1 | -0.1 | -0.3 | -0.8 | -1.4 | -1.9 | -3.3 | -4.7 | -6.1 | -4.0 |
| 041140 | -27.2 | 151.25 | -2.2 | -0.4 | 0.0 | 0.4 | 0.8 | 0.2 | -0.5 | -1.1 | -2.7 | -4.3 | -5.9 | -4.1 |
| 041191 | -27.25 | 151.35 | -2.2 | -0.4 | 0.0 | 0.3 | 0.7 | 0.1 | -0.5 | -1.2 | -2.7 | -4.4 | -5.9 | -4.1 |
| 041197 | -27.3 | 150.85 | -2.2 | -0.5 | 0.1 | 0.6 | 1.1 | 0.4 | -0.2 | -0.9 | -2.5 | -4.1 | -5.6 | -3.9 |
| 041261 | -27.1 | 150.8 | -2.3 | -0.6 | 0.0 | 0.6 | 1.2 | 0.6 | -0.1 | -0.8 | -2.4 | -4.1 | -5.7 | -4.0 |
| 041271 | -27.1 | 151.65 | -2.4 | -0.5 | -0.2 | 0.2 | 0.5 | -0.1 | -0.7 | -1.2 | -2.9 | -4.5 | -6.2 | -4.3 |
| 041283 | -27.25 | 151.3 | -2.2 | -0.4 | 0.0 | 0.4 | 0.8 | 0.1 | -0.5 | -1.1 | -2.7 | -4.3 | -5.9 | -4.1 |
| 041332 | -28.05 | 152.35 | -1.9 | 0.1 | 0.0 | -0.1 | -0.2 | -0.7 | -1.3 | -1.8 | -3.3 | -4.7 | -6.2 | -4.1 |
| 041359 | -27.4 | 151.75 | -2.2 | -0.3 | -0.1 | 0.2 | 0.4 | -0.2 | -0.8 | -1.4 | -2.9 | -4.5 | -6.1 | -4.2 |
| 041445 | -28.2 | 151.9 | -1.8 | 0.3 | 0.2 | 0.1 | 0.1 | -0.5 | -1.1 | -1.8 | -3.1 | -4.5 | -5.9 | -3.8 |
| 041504 | -27.75 | 151.4 | -1.9 | 0.0 | 0.2 | 0.3 | 0.5 | -0.1 | -0.8 | -1.4 | -2.8 | -4.3 | -5.8 | -3.9 |
| 042012 | -27.25 | 149.7 | -2.2 | -0.7 | 0.2 | 1.2 | 2.2 | 1.4 | 0.6 | -0.2 | -1.8 | -3.4 | -5.0 | -3.6 |
| 042016 | -27.35 | 150.05 | -2.1 | -0.6 | 0.2 | 1.0 | 1.8 | 1.1 | 0.3 | -0.5 | -2.0 | -3.6 | -5.2 | -3.7 |
| 042023 | -26.65 | 150.2 | -2.6 | -1.2 | -0.1 | 0.9 | 2.0 | 1.2 | 0.5 | -0.2 | -1.9 | -3.8 | -5.5 | -4.1 |
| 042078 | -26.9 | 150.45 | -2.4 | -0.9 | 0.0 | 0.8 | 1.6 | 0.9 | 0.2 | -0.5 | -2.2 | -3.9 | -5.6 | -4.0 |
| 042091 | -26.45 | 150.9 | -2.7 | -1.1 | -0.3 | 0.5 | 1.4 | 0.7 | 0.1 | -0.5 | -2.3 | -4.2 | -6.0 | -4.4 |
| 043000 | -26.55 | 148.2 | -2.4 | -1.4 | 0.2 | 1.9 | 3.5 | 2.6 | 1.7 | 0.8 | -1.0 | -2.7 | -4.5 | -3.5 |
| 043009 | -25.95 | 147.85 | -2.8 | -2.0 | 0.0 | 2.1 | 4.1 | 3.2 | 2.2 | 1.3 | -0.6 | -2.6 | -4.5 | -3.7 |
| 043014 | -26.3 | 148.6 | -2.7 | -1.7 | 0.0 | 1.7 | 3.4 | 2.5 | 1.6 | 0.8 | -1.1 | -3.0 | -4.8 | -3.8 |
| 043020 | -26.5 | 148 | -2.4 | -1.5 | 0.2 | 2.0 | 3.7 | 2.8 | 1.8 | 0.9 | -0.9 | -2.7 | -4.4 | -3.4 |
| 043029 | -25.85 | 147.4 | -2.9 | -2.1 | 0.0 | 2.3 | 4.5 | 3.5 | 2.5 | 1.6 | -0.4 | -2.4 | -4.3 | -3.6 |
| 043039 | -27.35 | 148.9 | -2.0 | -0.7 | 0.4 | 1.6 | 2.7 | 1.8 | 0.9 | 0.0 | -1.5 | -3.0 | -4.6 | -3.3 |
| 043043 | -26.6 | 149.4 | -2.6 | -1.4 | 0.0 | 1.3 | 2.7 | 1.9 | 1.1 | 0.3 | -1.5 | -3.3 | -5.1 | -3.9 |
| 043050 | -25.5 | 148 | -3.3 | -2.5 | -0.3 | 2.0 | 4.2 | 3.4 | 2.5 | 1.6 | -0.5 | -2.7 | -4.8 | -4.0 |
| 043053 | -28 | 148.6 | -1.4 | -0.1 | 0.8 | 1.7 | 2.6 | 1.7 | 0.7 | -0.3 | -1.5 | -2.8 | -4.1 | -2.8 |
| 043060 | -26.1 | 147.9 | -2.7 | -1.9 | 0.1 | 2.0 | 4.0 | 3.0 | 2.1 | 1.2 | -0.7 | -2.6 | -4.5 | -3.6 |
| 043082 | -27.15 | 148.6 | -2.0 | -0.8 | 0.4 | 1.7 | 3.0 | 2.1 | 1.1 | 0.2 | -1.3 | -2.9 | -4.5 | -3.3 |
| 043090 | -27.9 | 148.65 | -1.5 | -0.2 | 0.8 | 1.7 | 2.6 | 1.7 | 0.7 | -0.2 | -1.5 | -2.9 | -4.2 | -2.9 |
| 044011 | -26.8 | 147.65 | -2.1 | -1.2 | 0.5 | 2.1 | 3.8 | 2.8 | 1.8 | 0.8 | -0.8 | -2.5 | -4.1 | -3.1 |
| 044075 | -27.25 | 148.1 | -1.8 | -0.7 | 0.6 | 1.9 | 3.3 | 2.3 | 1.3 | 0.3 | -1.1 | -2.7 | -4.1 | -3.0 |

# Appendix 4: Border River System

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*NSW Department of Land and Water Conservation*

This appendix details the examination of factors contributing to the results for the Border River system.

***System Inputs:***

The Sacramento rainfall-runoff models used to generate the system inputs use rainfall and potential evaporation to generate streamflow. In both the 50th percentile and 95th percentile cases the generally decreased rainfall and increased potential evaporation would have the overall effect of decreasing both the dam inflows and the tributary inflows downstream of the dams.

***System Outputs:***

The net potential evaporation volume from the storages would be affected by two counter-balancing factors. The increased potential evaporation and decreased rainfall would produce a net increase in potential evaporation volume. However, because the storages are generally more empty, the average surface area is smaller and thus there would be less potential evaporation. The results for both cases indicate that there is only negligible net change in storage potential evaporation.

As with the storage potential evaporation, the irrigation diversions would be affected by two counter-balancing factors. The increased potential evaporation would produce a net increase in the crop water requirement and the reduced rainfall would produce a net increase in the required river extractions to meet the crop water requirements. This is evident in that the on-allocation diversions for both NSW and QLD have increased for both scenarios. However, the reduced inflows to the major storages would result in less regulated water available for irrigation. The reduced storage inflows would also produce less storage spills and, combined with the reduced unregulated inflows from tributaries, would have the effect of making less water available for off-allocation. Again, this reduction is somewhat counter-balanced by the fact that the increased crop water requirements and increased potential evaporation from on-farm storages would cause these storages to empty quicker, thus making more space available for extracting off-allocation water in events that occur close together. The net effect of all these factors is that there is actually a marginal increase in the total diversions for NSW (which has a much higher component of on-allocation water) and only a marginal reduction in the total diversions for QLD (which has a much higher component of off-allocation water).

Floodplain harvesting would also be reduced because there are less high flow events due to less spills from the major storages and less unregulated contributions from the downstream tributaries.

The transmission losses and effluent outflows would reduce significantly due the reduced unregulated higher flows, which generally incur large losses and contribute significant flows to the effluents, and a general trend towards a more regulated flow regime.

The end-of-system flows (Mungindi) would also reduce significantly due to the more regulated flow regime combined with the reduced catchment inflows.
In summary, although the total available water in the Border Rivers catchment would be reduced, the irrigation diversions would be only marginally affected, with the major impacts being on the system losses, effluent flows and end-of-system flows.

***Other:***

Flows at Goondiwindi are included as this is generally considered to be a key gauging station for the Border Rivers. Most of the inflows are upstream and most of the effluent outflows and bifurcations are downstream of this point.
The unaccounted difference in the system mass balance is also included as a sanity check that all components are presented in the preceding tables. The minor unaccounted differences are due to changes in storage volumes and volume of water stored in river reaches.

Table 1 summarises the factors contributing to the results for the Border River system.

**Table 1: factors contributing to the results for the Border River system**

**SYSTEM INPUTS**

| **Scenarios** | | Dam Inflows (ML) | | | Vol Ratio | Trib. Inflows | Vol Ratio | **Total Input** | Vol Ratio |
|---|---|---|---|---|---|---|---|---|---|
| | Coolmunda | Glenlyon | Pindari | Sub-total | (%) | (ML) | (%) | | (%) |
| Base Case 99-00 Conditions | 70987 | 72175 | 158117 | **301279** | | **1477789** | | **1779068** | |
| 50%ile Factors | 68069 | 68832 | 144893 | **281794** | **93.5** | **1394706** | **94.4** | **1676500** | **94.2** |
| 95%ile Factors | 62882 | 63746 | 131442 | **258070** | **85.7** | **1285528** | **87.0** | **1543598** | **86.8** |

**SYSTEM OUTPUTS**

| **Scenarios** | | Net Evap Volume (ML) | | | | | Vol Ratio |
|---|---|---|---|---|---|---|---|
| | Coolmunda | Glenlyon | Pindari | Flood-plains | Other Storages | Total | (%) |
| Base Case 99-00 Conditions | 12592 | 16205 | 6882 | 887 | 23313 | **59879** | |
| 50%ile Factors | 13248 | 15926 | 7029 | 928 | 23526 | **60657** | **101.3** |
| 95%ile Factors | 13419 | 15209 | 6539 | 948 | 22734 | **58849** | **98.3** |

**SYSTEM OUTPUTS (Cont.)**

| **Scenarios** | NSW Irrigator Diversions (ML) | | | | Vol Ratio | QLD Irrigator Diversions (ML) ) | | | | Vol Ratio | Total Diversions (ML) | Vol Ratio |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | ON | OFF | FPH* | Total | (%) | ON | OFF | FPH | Total | (%) | | (%) |
| Base Case 99-00 Conditions | 77291 | 111351 | 5479 | 194121 | | 12919 | 154601 | 2349 | 169869 | | 363990 | |
| 50%ile Factors | 82864 | 110397 | 5277 | 198538 | 102 | 13126 | 152560 | 2003 | 167689 | 99 | 366227 | 100.6 |
| 95%ile Factors | 82775 | 108642 | 4657 | 196074 | 101 | 14216 | 147979 | 1634 | 163829 | 96 | 359903 | 98.9 |

*FPH = Flood plain harvesting

**SYSTEM OUTPUTS (Cont.)**

| **Scenarios** | Other Extractions | Vol Ratio | Losses | Vol Ratio | EOS@ Mungindi | Vol Ratio | **Total Output** | Vol Ratio |
|---|---|---|---|---|---|---|---|---|
| | (ML) | (%) | (ML) | (%) | (ML) | (%) | **(ML)** | (%) |
| Base Case 99-00 Conditions | 2588 | | 986424 | | 365252 | | 1778133 | |
| 50%ile Factors | 2587 | 100.0 | 914643 | 92.7 | 331421 | 90.7 | 1675535 | 94.2 |
| 95%ile Factors | 2587 | 100.0 | 827059 | 83.8 | 294490 | 80.6 | 1542888 | 86.8 |

**OTHER OUTPUTS**

| **Scenarios** | Flow@ Goondiwindi | Vol Ratio |
|---|---|---|
| | (ML) | (%) |
| Base Case 99-00 Conditions | **831775** | |
| 50%ile Factors | **765937** | **92.1** |
| 95%ile Factors | **698365** | **84.0** |

| Unaccounted | Vol Ratio |
|---|---|
| (ML) | (%) |
| **-935** | **-0.05** |
| **-965** | **-0.06** |
| **-710** | **-0.05** |

## Appendix 5: Time sequence data for the Gwydir River

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*Under contract to Hassall & Associates Pty Ltd*

This appendix contains the results to support the discussion in Section 3.4 and demonstrate that the number of years of low river flow would increase under the climate change scenarios.

The annual flow at Yarraman for each of the three scenarios, showing "low" years is contained in Table 1. Table 2 shows the low allocation sequence analysis, with the allocation threshold of 40%. Table 3 shows the analysis for Yarraman flows, using the median for the Base Case as the comparison threshold.

The number of low flow years increased by 14%.

The data in Tables 2 and 3 indicates which sequences of both allocation and flow join to become longer ones in the climate change scenarios. The results show that the sequences have increased in length – e.g. one year increased to 3 yr duration between the base and "dry" scenarios. There are also more severe sequences in the climate change scenarios. This indicates that dry years that were previously separated by a wetter year have now become sequences of dry years joined together.

### Table 1: Annual flow at Yarraman for each of the three scenarios, showing "low" years compared to the median of 236 GL

| Year | Base | freq<med | 50th %ile | freq<med | 95th %ile | freq<med |
|---|---|---|---|---|---|---|
| 1892 | 588095 | | 338859 | | 267246 | |
| 1893 | 528458 | | 458772 | | 462232 | |
| 1894 | 291824 | | 275591 | | 264341 | |
| 1895 | 285460 | | 264926 | | 248915 | |
| 1896 | 295276 | | 268582 | | | LOW |
| 1897 | 88431 | LOW | 36083 | LOW | 34824 | LOW |
| 1898 | 87041 | LOW | 86530 | LOW | 80891 | LOW |
| 1899 | | LOW | 139697 | LOW | 129303 | LOW |
| 1900 | 232546 | LOW | | LOW | 197181 | LOW |
| 1901 | 79250 | LOW | 52251 | LOW | 27848 | LOW |
| 1902 | 364258 | | 334092 | | 308996 | |
| 1903 | 384820 | | 319192 | | 309517 | |
| 1904 | 284237 | | 250039 | | 231988 | LOW |
| 1905 | 236739 | | 189679 | LOW | 169249 | LOW |
| 1906 | 137071 | LOW | 123659 | LOW | | LOW |
| 1907 | 305605 | | 301937 | | 291889 | |
| 1908 | 227448 | LOW | 240710 | | 215263 | LOW |
| 1909 | 1086144 | | 1014779 | | 969506 | |
| 1910 | 378559 | | 339207 | | 319394 | |

| Year | Base | freq<med | 50th %ile | freq<med | 95th %ile | freq<med |
|---|---|---|---|---|---|---|
| 1911 | 280720 | | 275117 | | 265892 | |
| 1912 | 274967 | | 246121 | | 181461 | LOW |
| 1913 | 207331 | LOW | 208743 | | 203917 | |
| 1914 | 100038 | | 92079 | LOW | 76092 | |
| 1915 | 280231 | | 275446 | | 259862 | |
| 1916 | 434570 | | 393931 | | 348328 | |
| 1917 | 871766 | | 645230 | | 483811 | |
| 1918 | 162846 | LOW | 125528 | LOW | 108759 | LOW |
| 1919 | 400888 | | 393979 | | 382300 | |
| 1920 | 756451 | | 760278 | | 744617 | |
| 1921 | 411150 | | | | 192917 | LOW |
| 1922 | 176098 | LOW | 179142 | LOW | | LOW |
| 1923 | 118276 | LOW | 103390 | LOW | 60670 | LOW |
| | 110154 | LOW | 94547 | LOW | 79915 | LOW |
| 1925 | 139071 | LOW | 93840 | LOW | 77884 | |
| 1926 | 34723 | | 34301 | LOW | 31725 | LOW |
| 1927 | 307431 | | 292524 | | 263472 | |
| 1928 | 294916 | | 305852 | | 304781 | |
| 1929 | 192250 | LOW | 158521 | LOW | 129648 | LOW |
| 1930 | 866117 | | 859756 | | 805740 | |
| 1931 | 265684 | | 278286 | | 260067 | |
| 1932 | 313157 | | 302093 | | 263939 | |
| 1933 | 419935 | | 377715 | | 334261 | |
| 1934 | 248639 | | 222880 | LOW | 196398 | LOW |
| 1935 | 137351 | LOW | 67761 | LOW | 61836 | LOW |
| 1936 | 152357 | LOW | 146505 | LOW | 143220 | LOW |
| 1937 | 228836 | LOW | 219828 | LOW | 206236 | LOW |
| 1938 | 98579 | LOW | 90581 | LOW | 83548 | LOW |
| 1939 | 39978 | LOW | 40665 | LOW | 38544 | LOW |
| 1940 | 225887 | LOW | 222759 | LOW | 204637 | LOW |
| 1941 | 205320 | LOW | 188691 | LOW | 175569 | LOW |
| 1942 | 290740 | | 257226 | | 225801 | LOW |
| 1943 | 242920 | | 215483 | LOW | 199268 | LOW |
| 1944 | 150817 | LOW | 131738 | LOW | 122727 | LOW |
| 1945 | 221493 | LOW | 223971 | LOW | 212332 | LOW |
| 1946 | 287557 | | 275553 | | 250009 | |
| 1947 | 280806 | | 246181 | | 212739 | LOW |
| 1948 | 180605 | LOW | 186264 | LOW | 171481 | LOW |
| 1949 | 1150116 | | 904792 | | 789888 | |
| 1950 | 1235167 | | 1162474 | | 1097170 | |
| 1951 | 344831 | | 317679 | | 299249 | |
| 1952 | 284485 | | 269434 | | 186728 | LOW |

| Year | Base | freq<med | 50th %ile | freq<med | 95th %ile | freq<med |
|---|---|---|---|---|---|---|
| 1953 | 155177 | LOW | 104828 | LOW | 125131 | LOW |
| 1954 | 766466 | | 723087 | | 660458 | |
| 1955 | 1866210 | | 1780591 | | 1601781 | |
| 1956 | 133818 | LOW | 157418 | LOW | 177599 | LOW |
| 1957 | 150158 | LOW | 135607 | LOW | 118901 | LOW |
| 1958 | 125558 | LOW | 114285 | LOW | | LOW |
| 1959 | 104595 | LOW | 105122 | LOW | 93752 | LOW |
| 1960 | 112436 | LOW | 73533 | LOW | 58296 | LOW |
| 1961 | 193604 | LOW | 178121 | LOW | 156549 | LOW |
| 1962 | 173341 | LOW | | LOW | 165967 | LOW |
| 1963 | 421186 | | 404880 | | 376340 | |
| 1964 | 173405 | LOW | 134847 | LOW | 124882 | LOW |
| 1965 | 85294 | LOW | 83000 | LOW | 75381 | LOW |
| 1966 | 150175 | LOW | 146364 | LOW | 133069 | LOW |
| 1967 | 206402 | LOW | 193202 | LOW | 180428 | LOW |
| 1968 | 89630 | | | LOW | 74634 | LOW |
| 1969 | 235405 | LOW | 200527 | LOW | 180240 | LOW |
| 1970 | 1883925 | | 1733267 | | 1603233 | |
| 1971 | 151905 | LOW | 160195 | LOW | 170899 | LOW |
| 1972 | 331381 | | 336944 | | 309752 | |
| 1973 | 431198 | | 373592 | | 336852 | |
| 1974 | 493528 | | 478878 | | 444802 | |
| 1975 | 508953 | | 511840 | | 445473 | |
| 1976 | 525489 | | 520529 | | 471452 | |
| 1977 | 338545 | | 316094 | | 270759 | |
| 1978 | 207953 | | | LOW | 210040 | LOW |
| 1979 | 160384 | LOW | 38689 | LOW | 21955 | LOW |
| 1980 | 141670 | | | LOW | 138714 | LOW |
| 1981 | 153324 | LOW | 147385 | LOW | 140098 | LOW |
| 1982 | 382765 | | 368031 | | 345114 | |
| 1983 | 642313 | | 595755 | | 541739 | |
| 1984 | 197495 | | | LOW | 190184 | LOW |
| 1985 | 267848 | | | LOW | 149930 | LOW |
| 1986 | 163433 | | | LOW | 87516 | LOW |
| 1987 | 258200 | | | | 224207 | LOW |
| 1988 | | | | LOW | 206549 | LOW |
| 1989 | 278722 | | 277627 | | 242023 | |
| 1990 | 264184 | | | | 265232 | |
| 1991 | 149088 | LOW | 138320 | | 117079 | LOW |
| 1992 | 71497 | | | LOW | 59780 | LOW |
| 1993 | 66267 | | 56471 | LOW | 52803 | LOW |
| 1994 | 128123 | | | LOW | 121570 | LOW |

| Year | Base | freq<med | 50th %ile | freq<med | 95th %ile | freq<med |
|---|---|---|---|---|---|---|
| 1995 | 441444 | | 407139 | | 364922 | |
| 1996 | 284733 | | 300485 | | 279084 | |
| 1997 | 1037395 | | 810143 | | 772789 | |
| 1998 | 195526 | LOW | 206212 | LOW | 194216 | LOW |
| 1999 | 203917 | LOW | 203917 | LOW | 203917 | LOW |

### Table 2: Low allocation sequence analysis, with the allocation threshold of 40%

| | No. of sequences that last for the defined number of years, with maximum % allocation < 40% | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 1Yr | 2Yr | 3 Yr | 4 Yr | 5Yr | 6Yr | 7Yr | 8Yr | Total no. of Low Years | % |
| Base Case | 7 | 4 | 5 | 1 | 1 | | | | 39 | 36.1 |
| Scenario-1 (50th %ile) | 3 | 4 | 3 | 3 | 2 | | | 1 | 50 | 46.3 |
| Scenario-2 (95th %ile) | 3 | 5 | 1 | 5 | 2 | | | 1 | 54 | 50.0 |

### Table 3: Low flow sequence analysis for Yarraman flows, using the median for the Base Case as the comparison threshold

| | No. of sequences that last for the defined number of years, with flow < Median | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1Yr | 2Yr | 3 Yr | 4 Yr | 5Yr | 6Yr | 7Yr | 8Yr | 9Yr | 10Yr | 11Yr | 12Yr | Total no. of Low Years | % |
| Base Case | 10 | 3 | 0 | 2 | 2 | 1 | 2 | 0 | | | | | 54 | 50.0 |
| Scenario-1 (50th %ile) | 6 | 3 | 2 | 2 | 2 | 1 | 1 | 1 | | | | | 57 | 52.8 |
| Scenario-2 (95th %ile) | 4 | 3 | 2 | 2 | 1 | 3 | 1 | 0 | | | | 1 | 66 | 61.1 |

## Appendix 6: Cotton growth under climate change

Two impacts on crop yield are discussed: higher $CO_2$ concentrations and higher temperatures. For the purposes of the simplified analysis, it is assumed that the two impacts are additive. That is, the yield increases can be added together. More research on this is warranted.

Other potential production impacts from climate change not considered include:

- increases in pest and weed pressures[4];
- increases in water use efficiency (higher photosynthesis and reduced stomatal conductivity, such as described in Samarakoon and Gifford, 1996);
- increases in radiation levels; and
- shorter growing periods because of increased temperatures (counterbalancing this is that higher temperatures may become limiting).

There is uncertainty associated with the degree to which farmers and research workers will be able to adapt their management to changes in climate by crop breeding, cultivation and irrigation practices. These factors are kept constant for the purposes of this study.

### ***Higher $CO_2$ concentrations and plant growth***

> "Considerable literature has developed examining the effects of increased carbon dioxide on plant growth, much of which has been concerned with the responses of individual plants, leaves, or stomata. The benefit that a high $CO_2$ environment appears to derive from the ability of plants to gain more $CO_2$ while losing less water by increasing stomatal resistance. It follows that the benefits should be greater in agricultural systems where more water is transpired in total evapotranspiration and less where the reverse is the case. It also follows that other adjustments to agricultural systems which increase transpiration over potential evaporation will have additional benefits in enhanced $CO_2$ environments" (Hassall & Associates 1998).

One study that has specifically looked at cotton growth is in Arizona, where free-air $CO_2$ enrichment (FACE) open field experiments were conducted from 1989 to 1991 (Hendry and Kimball, 1994) on cotton (Mauney et al., 1994). In these experiments crops were grown in the field with $CO_2$ supplementation of the atmosphere to maintain a level of 550 ppm and compared to current levels of 362 ppm. In cotton, the harvestable yield increased due to the FACE treatment by 43 percent.

Yield response to $CO_2$ concentration is shown as a linear increase between 362 and 550 ppm (and possibly up to about 600ppm). Saturation is estimated to occur at about 900ppm (R. Gifford pers. comm.). The $CO_2$ concentrations for the 50% and 95% are 430ppm and 455ppm respectively. This translates to potential yield increases of between 16 and 21%.

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[4] Coviella *et al*. (2002) suggest that higher $CO_2$ concentrations, in conjunction with lower Nitrogen levels, will affect the defensive mechanisms (e.g. Bt lines).

## ***Higher temperatures and plant growth***

Cotton yields are particularly sensitive to temperature, particularly low temperatures. Constable *et al.* (1976) proposed a relationship between lint yield potential and heat units, namely:

> Yield = 2350*(1- EXP(-0.00267*DYLD)) , where DYLD = DSUM - DDFL - 800
>
> Where:-
> DYLD = Yield depression coefficient due to temperature;
> DSUM = Sum of degree days required to produce a crop; and
> DDFL = Degree days required for flowering.

Hassall & Associates (1998) uses this relationship to estimate the yield increases associated with temperature increases in the Macquarie River valley. For temperature increases of 0.4 and 1.2 degrees Celsius, yield potential is likely to be increased by 4.7 and 8.1 % respectively.

The temperature increases for the three cotton rivers, for 2030, are 0.9 to 1.2°C for the average and dry scenarios. It is reasonable to assume that the yield potential will increase by a similar extent to that in the Macquarie, namely between 6 and 8%.

Reddy *et al*. (1999) indicate that changes in temperature will impact boll set and fibre diameter, with a critical threshold being 32°C. This may become a bigger constraint when considering the climate change scenarios for 2070, where temperature increases may be in the order of 6°C.

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