Enabling Community Access to NSW Climate Change Rainfall and Runoff Projections; a spatial perspective

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SUMMARY

Future Climate and Runoff Projections (~2030) for NSW and the Australian Capital Territory (Vaze *et al*, 2008) has provided estimates of future rainfall, areal potential evopotranspiration and daily runoff projections for climate conditions in about 2030. Results are based on fifteen global climate models (GCMs) and 32 runoff projections modelled by the SIMHYD and Sacramento lumped conceptual daily rainfall-runoff models. The study provided a consistent future rainfall-runoff dataset that can be used by state government agencies, industry and community to plan for and adapt to the future climate change impact.

However, the key challenge for these outputs to be made publicly available is the size of the dataset, which contains 112 years of daily time series data (40907 days) at ~5 km grids across NSW and ACT (30696 cells). In pure binary form the dataset is about 300 GB and in readable but unreferenced format it is greater than 3TB.

This paper describes *The Climate Projection 2030 Portal* website and how it provides access to these critical modelling projections. The data set structure, the methods, processes and tools that have been used to make the dataset available are discussed.

The Climate Projection 2030 Portal has a 4 level access protocol, with both an ARC-GIS web service interface directly to pre-processed data (spatial data) and an information resource and data mining tool for the various climate models (vector data).

The significance of climate change planning using the best available projections is becoming more and more evident, with impacts needing to be factored into many aspects of planning and decision making throughout all levels of government, industry, and the wider community. *The Climate Projection 2030 Portal* provides the interface that allows these impacts to be locally analysed using extracts from the master dataset and then communicated to the general public through a public education interface in more easily understood formats and techniques using actual site specific data.

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1. INTRODUCTION

The significance of climate change is becoming more and more evident, with impacts needing to be factored into many aspects of planning and decision making throughout all levels of government, industry, and the wider community. However, currently available climate change projections provided by global climate models (GCMs) are generally at a broad scale from approximately 175 to 400 km pixels. Such projections may be suitable for continent scale analysis but are too broad for community and government to formulate climate change adaptation policies at regional or catchment scale.

To meet such information needs in New South Wales (NSW), the NSW Office of Water (formally Department of Water and Energy) carried out a study on the *Future Climate and Runoff Projections (~2030) for NSW and the Australian Capital Territory* project (Vaze *et al*, 2008). The study was initally aimed at providing information for modelling water resource management and planning for NSW Office of Water. However, in a workshop (2009), it was identified that the data generated by the study may be useful to a boarder number of stakeholders, including all government agencies and community in NSW and ACT.

The NSW Office of Water recently developed an internet based data dissemination service, *The Climate Projection 2030 Portal,* to enable wider stakeholders access to this dataset. This paper details information to assist users in accessing, extracting and using the data within this very large and important dataset. Specifically the paper includes information about:

- the original modelling methodology used to generate the data;
- the methods used in preparing the data to act as a shared resource;
- setting up the community portal to access the data;
- wizards, tools and techinques that are provided by the portal for accessing and extracting the data; and
- a case study example of catchment scale analysis based on extracted data.

2. MODELLING METHODOLOGY USED TO GENERATE THE DATASET

2.1 Study Area and Data

The rainfall-runoff modelling was carried out for the entire NSW and ACT region. Full details of the methods used are described in Vaze *et al*, 2008. In summary, 219 catchments across southeast Australia were used to calibrate the SIMHYD and Sacramento rainfall-runoff models. The catchments used for model calibration all have daily observed runoff records for 1975 to 2006 with less than 20 percent missing runoff data and have catchment areas between 50 and 2000 km^2. The source of the climate data used in the study was the 'SILO Data Drill' of the Queensland Department of Natural Resources and Water (www.nrw.qld.gov.au/silo; Jeffrey *et al*, 2001). The SILO Data Drill provides 0.05^o grid data of daily rainfall and other climate variables for across Australia. The potential evapotranspiration (PET) data was calculated from the SILO climate data using Morton's wet environment evapotranspiration algorithms (www.bom.gov.au/averages; Morton, 1983).

2.2 Rainfall and runoff modelling

Two widely used conceptual rainfall-runoff models; SIMHYD and Sacramento were used in the study. SIMHYD is a simple lumped conceptual daily rainfall-runoff model with seven parameters (Chiew *et al*, 2002). SIMHYD has been used successfully across Australia for various applications, including the estimation of runoff in the National Land and Water Resources Audit, the estimation of climate change impacts on runoff and in various regionalisation studies. The Sacramento model is also a lumped conceptual daily rainfall-runoff model (Burnash *et al*, 1973), but it is considerably more complex than SIMHYD. The Sacramento model has 18 parameters, but in the application here, only 14 parameters are optimised. The Sacramento model has been used widely across the world and in Australia, in particular as part of the Integrated Quanity and Quality Model (IQQM) used in river system model implementations in NSW and Queensland. The Sacramento model has also been used in regionalisation studies with various degrees of success.

For each of the 219 catchments, the two rainfall-runoff models are calibrated for all the 0.05^o grids (~ 5 km x 5 km) within the catchment, against observed streamflow data at the catchment outlet. The use of 0.05^o grids allows a good representation of the spatial patterns and gradients in rainfall. The rainfall-runoff models are calibrated against 1975 to 2006 streamflow data from all the 219 calibration catchments. The calibration period is a compromise between a shorter period that would better represent current development and a longer period that would better account for climatic variability.

The runoff for grid cells that are not within a calibration catchment is modelled using optimised parameter values from the geographically closest grid cell which lies within a calibration catchment. As the parameter values come from calibration against streamflow from 50 to 2000 km^2 catchments, the runoff defined here is different to (and can be much higher than) streamflow recorded over very large catchments where there can be significant transmission losses (particularly in the western region). Almost all the catchments available for model calibration are in the higher runoff areas in the eastern parts of the region. Runoff estimates are therefore generally good in the eastern parts of the NSW and are comparatively poor elsewhere.

The same set of parameter values are used to model runoff across the whole region for both the historical climate and future climate scenarios using 112 years of daily climate inputs described in the next section. The rainfall-runoff modelling approach (using SIMHYD and Sacramento models) used for the purpose of the study provides a consistent basis (that is automated and reproducible) for modelling historical runoff across the entire region and for assessing the potential impacts of climate change on future runoff.

2.3 Climate scenarios

Daily rainfall and potential evapotranspiration (PET) are required to run the SIMHYD and Sacramento rainfall-runoff models. The methodology used in the study to derive future climate data is similar to the one used in the Murray Darling Basin Sustainable Yields (MDBSY) Project (http://www.csiro.au/partnerships/MDBSY.html). The climate data and their derivation for the hydrologic scenario modelling across NSW are described in detail in Vaze *et al*, 2008.

The historical climate (1895-2006) is the baseline against which the future climate is compared. The future climate is used to assess the range of likely climate around the year 2030. Fifteen future climate variants, each with 112 years of daily climate sequences, are used. The future climate variants are developed by scaling the 1895 to 2006 climate data to reflect ~2030 climate, based on the analyses of 15 global climate models (GCMs) and the IPCC SRES A1B global warming scenario (IPCC, 2007). The SRES A1B scenario describes a future world of very rapid economic growth, global population that peaks in mid-century and declines thereafter, and the rapid introduction of new and more efficient technologies with a balance across all energy sources (IPCC, 2007). There is little difference in global warming between the different emission scenarios by 2030 although they diverge after the mid-21st century. The GCM data are obtained from the Program for Climate Model Diagnosis and Intercomparison (PCMDI) website (http://www-pcmdi.llnl.gov).

As the future climate series (A1B scenario) is obtained by scaling the historical daily climate series from 1895 to 2006, the daily climate series for the historical and future climate have the same length of data (112 years) and the same sequence of daily climate. The future climate scenario is therefore not a forecast climate at 2030, but a 112-year daily climate series based on 1895 to 2006 data for projected global temperatures at ~2030 relative to ~1990.

The method used to obtain the future climate series also takes into account different changes in each of the four seasons as well as changes in the daily rainfall distribution. The consideration of changes in the daily rainfall distribution is important because many GCMs indicate that future extreme rainfall is likely to be more intense, even in some regions where projections indicate a decrease in mean seasonal or annual rainfall. As the high rainfall events generate large runoff, the use of traditional methods that assume the entire rainfall distribution to change in the same way would lead to an underestimation of the extreme runoff as well as the mean annual runoff.

The 15 variants of 112 years of future daily rainfall and PET series, each informed by a different GCM (see Table 1), are used to run the SIMHYD and Sacramento rainfall-runoff models to estimate future daily runoff for all the 0.05^{o} grid cells across the study area. The same optimised parameter values obtained from the model calibration against historical streamflow data are used to model the future runoff.

2.4 Global Climate Models

The following table defines the Global Climate Models (GCM) used in Vaze *et al* (2008). The column naming convention used in the creation of the master table described in section 3 uses the Ref number defined in this table as a suffix for all columns associated with a GCM, i.e. SAC_5 represents the Sacramento flow associated with the CSIRO- MK3.0 GCM.

Ref	GCM	DESCRIPTION	SCALE (Km)
1	SILO	SILO Actual data	
2	CCCMA T47	Canadian Climate Centre, Canada	~250
3	CCCMA T63	Canadian Climate Centre, Canada	~175
4	CNRM	Meteo-France, France	~175
5	CSIRO-MK3.0	CSIRO, Australia	~175
6	GFDL 2.0	Geophysical Fluid, Dynamics Lab, USA	~200
7	GISS-AOM	NASA/Goddard Institute for Space Studies, USA	~300
8	IAP	LASG/Institute of Atmospheric Physics, China	~300
9	INMCM	Institute of Numerical Mathematics, Russia	~400
10	IPSL	Institute Pierre Simon Laplace, France	~275
11	MIROC-M	Centre for Climate Research, Japan	~250
12	MIUB	Meteorological Institute of the University of Bonn, Germany - Meteorological Research Institute of KMA, Korea	~400
13	MPI-ECHAM5	Max Planck Institute for Meteorology DKRZ, Germany	~175
14	MRI	Meteorological Research Institute, Japan	~250
15	NCAR-CCSM	National Center for Atmospheric Research, USA	~125
16	NCAR-PCM1	National Center for Atmospheric Research, USA	~250

Table 1 Global Climate Model references

3. PREPARING THE DATA AS A SHARED RESOURCE

3.1 Original data format

The climate data was in 16 binary files, one for historic and one each for the 15 GCMs. Flow data was contained in 32 binary files, two for historic and two each for the 15 GCMs, with separate files for the runoff from the SIMHYD and Sacramento models (named SIM-scenario and SAC-scenario). Each file has data for the 30696 cells covering all of NSW/ACT and each cell has one time-series of 40907 points from 1 January 1895 to 31 December 2006. The values (mm/day) are stored in 32bit IEEE reals. The data was arranged as follows:

16 files <Rainfall for first cell><Areal PET for first cell><Rainfall for 2nd cell><Areal PET for 2nd cell>......<Rainfall for last cell><Areal PET for last cell> (appox. 149GB)
32 files <Runoff for first cell><Runoff - 2nd cell>......<Runoff - last cell> (approx 149 GB)

3.2 Data transformations

Using a Perl script, these binary data files were opened simultaneously and progressively the data for each cell and date was extracted, converted and imported into a master database table of 67 columns and 1.255 billion rows (about 450GB) of data within MYSQL (see Table 2). This data was indexed and partitioned into 112 sub-tables, for each year of data.

Col 1	Col 2	Col 3	Col 4-19	Col 20-35	Col 36-52	Col 52-67
ID	DATEID	CELLID	Sacramento SAC_1-16	SIMHYD SIM_1-16	Rainfall RAI_1-16	PET PET_1-16
1	1	1	0	1.0095	0	0
2	2	1	0	0.9664	1	1
…	…	…	…	…	…	…
1255681271	40906	30696	0	0.2407	0	0
1255681272	40907	30696	0	0.1316	0	0

Table 2 Master table general configuration

Given the storage space required and the expected uses of the data the following data amalgamation process was implemented. It should be noted that all calculation for the time series merged table are done with four (4) significant figures but only stored as two (2) significant figures to minimise both database storage requirements and to reduce the output file download size.

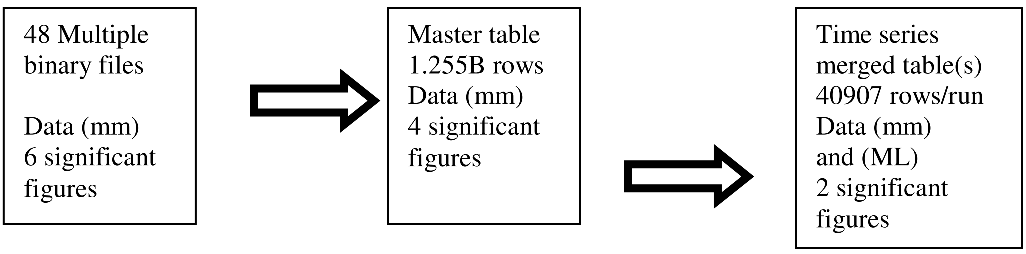


Figure 1 Data amalgamation process

3.3 Notes about data checking and validation

The original authors of the data provided raw data files, a FORTRAN binary conversion file to check the raw data conversion process, and selected extracted time series data files of runoff depths and volumes for some calibration and regional planning catchments. The polygon representation of these catchments have been converted to raster. With the standard ARC-GIS raster conversion rules for the boundary edges of a polygon is linked to the raster grid cell that covers the most area. Rainfall, PET and runoff depths for each of the cells grouped by this raster conversion were calculated from the master table.

The average depth of runoff for the catchments was multiplied by the area of the original polygon to convert the runoff depth into a volume discharge. A summary of the consistency between the original author's data and the results from the master table is presented in Table 3 which demonstrates an exact match of the grouped calculated runoff depth.

There are three different reasons why the calculated runoff volume from any grouping of cells is not exactly the same as the runoff volumes estimated by the original authors. These include;

- a slight variation between the area of the grid cells used and the actual size of the polygon (polygon to raster conversion),
- the alteration of the significant figures used to store the amalgamated depth, and
- the actual cell size generating a depth changes for every row within the grid.

Volumes are calculated for an east and west catchment due to the transmission losses defined in section 2.2. The numbers presented represent maximum percentage differences from the catchment runoff volumes estimated by the original authors. The time series merged table can be used to calculate any of these runoff volumes.

Data checking process	Runoff Depth calculation	West Vol	East Vol	Runoff Volume comments
Raw data conversion	Exact match	-	-	Not calculated on original dataset
Single Cell (mm)	100% match (4 sig)	-	-	Not calculated on original dataset
Multiple Cells				
Totals (mm) (vol by polygon)	100% match (2 sig)	-33.9% to +99.8% Average(2%)	-33.7% to +100.1% Average(4%)	Significant figures only (rounding with very low runoff depths has significant impact on runoff volumes
Totals (mm) (vol by calculated grid area)	100% match (2 sig)	-5.62%	-2.89%	Significant figures and polygon to raster conversion
Totals (mm) (vol by individual cell area and runoff depth	100% match (2 sig)	-5.63%	-2.89%	Significant figures and polygon to raster conversion and actual size of grid cell

Table 3 Consistency between original extracted data files and Time series merged table

4. SETTING UP A COMMUNITY PORTAL TO ALLOW ACCESS TO THE DATA

4.1 The vision for *The Climate Projection 2030 Portal*

The Climate Projection 2030 Portal is built on the work of Vaze *et al* (2008) and is designed to deliver this data to all decision makers to enable them to plan and adapt to the impacts of climate change. As the wider community is potentially impacted by these decisions and plans to adapt for climate change, public education was considered an important outcome of the project. Therefore, to maximise the knowledge sharing benefits of this dataset, a community of interested stakeholders has been established, so that as the dataset is used and further analysed, the whole community knowledge is increased.

4.2 Sharing the vision

The steering group for the project was made up of interested stakeholders representatives, researchers and decision makers from universities and government agencies. This consultation identified;

- a preferred list of tools and products, and
- that many decision makers using the information contained in the dataset will engage consultants to investigate case specific scenarios on their behalf.

This has resulted in the 4 level data access protocol conceptual model detailed in Figure 2 and Table 4.

Community Access Level	Description
Level 1 Full access (Information custodian NSW Office of Water)	Access all tables and prepare content for public education interface
Level 2 Steering Group representatives	Access all tables and enable consultants for specific projects
Level 3 Consultants for level 1 and 2	Access wizards and tables needed to deliver projects for steering group representatives
Level 4 Public Education interface	Prepared information from within the community Levels 1-3 that has both data and summary of outcome of analysis.

Table 4 Community Levels of Data Access Protocals

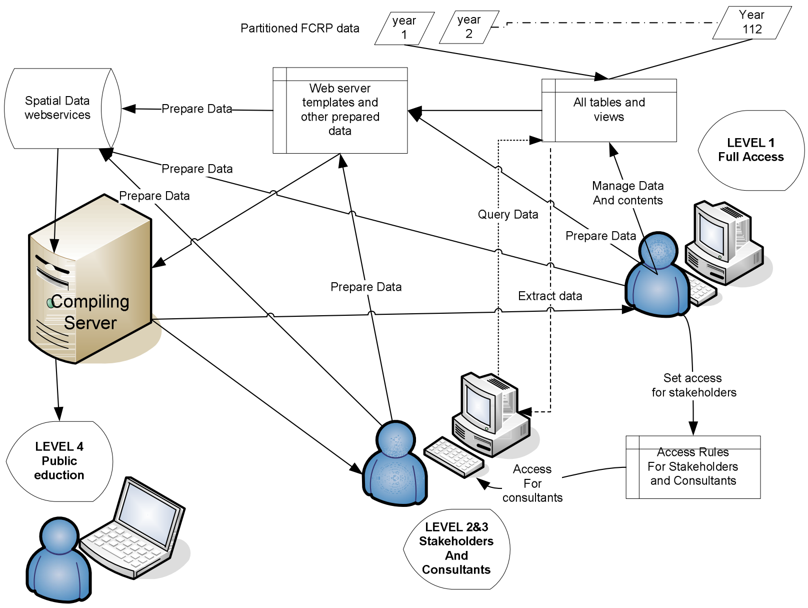


Figure 2 Conceptual model of 4 Community Levels of Access into portal

4.2.1 Types of data analysis identified by steering group

The steering group specified that the structure of the data and supporting tables and resources needed to be setup so that the data could be delivered as;

- Time series data for grouped cells for direct importing into existing models,
- Raster representations of any combinations time dependent parameters, and
- Methods and views that allow dry sequence analysis to be completed.

The following additional tables and resources allow the data to be summarized and viewed according to any combination of parameters and categories to match the analysis needs identified.

Time Dependent Parameters		Spatial Grouping categories	
Interval	**No**	**Scale**	**No**
Day	40907	Regional planning catchments	24
Month	1344	Catchment Management Area (CMA)	13
Season	448	Stream flow Gauges	138*
Year	112	Basins	45*
Decade	11	Inflow to Water Storages	12*
		Water Sharing Plan areas	25*
		* Categories at 1/1/2010	

Table 5 Parameters and Categories used to summarise data

Any combination of polygons can be prepared as a spatial grouping category by intersecting the polygons with a base NSW polygon, converting the merged polygon to a 253x186 cell raster using standard ARC Map tools. This raster is exported to ASCII using the raster to ASCII tool. The resulting txt files are imported into Microsoft Excel where a macro restructures the file to provide a tabular index of the merged polygon against all cells in the cell listing. This index is added as a new column in the spatial grouping categories table.

5. WIZARDS, TOOLS AND TECHINQUES TO ACCESS THE DATA

5.1 Community based web products and information workflows

The master table that contains all of the data associated with the report Vaze *et al* (2008) is very large. This data source is positioned as a shared resource for the whole community. Wizard based tools have been provided that define the scale, location, GCMs and time specific parameters of the exact limits of extracts of the data. Each data analysis extraction is given a unique identifier so that the outcomes of the analysis can be noted in the *Data Analysis Register* for the whole community.

5.2 Common features of all tools

All tools within *The Climate Projection 2030 Portal* are built on the www.nrmoptions.nsw.gov.au knowledge management framework. This system is designed to provide secure remote user access to data mining tools and content generation and management applications. The framework uses the ARC-GIS JavaScript API for delivering mapping services over the web. All tools have similar look, feel and functionality and all products and activities are secured and logged to ensure the appropriate levels of access defined by the steering group are maintained.

5.2.1 Typical data analysis extraction operational workflow

Each of the wizards described in section 5.3 have been designed around the same process and steps the user though the following process after the user has selected to create a data analysis export;

1. The system checks that the user has appropriate level access to extract data.
2. The system creates a record in the *Data Analysis Register* and creates a unique code that allows outcomes of the analysis to be managed.
3. The system creates a directory on the systems File Transfer Protocol (FTP) server for the storage of output files from the data preparation. This directory is named the same as the unique code for the data analysis.
4. The wizard then steps through a process that allows parameters to be collected that identify the exact data that needs to be prepared. Typically this is;
   4.1. What type of analysis do you want to undertake? (Time series, raster, sequence analysis).
   4.2. What is the timescale of the analysis? (daily, monthly, seasonally, annually, decade).
   4.3. What is the start date and end date of the analysis?
   4.4. Which of the grouping parameters is relevant to the data analysis?
   4.5. Which of the data types are required? (Sacramento runoff, SIMHYD – runoff, GCM rainfall or GCM PET).
   4.6. What type of aggregating function is required? (average, minimum, sum, etc)

4.7. Which of the GCM are to be included in the analysis?
5. All parameters selected by the users are stored and, the system amalgamates them to calculate a description of the data analysis. An email is sent to the user specifying the systems description of the data analysis and FTP subdirectory when the prepared files can be found. This email also contains the data analysis unique code, estimate delivery date and expiry dates.
6. The system will then schedule the data extraction scripts to run when the system is not heavily loaded.
7. At completion of the scripts another email is sent to the user to notify that the files are ready to download.

The actual data analysis occurs at the user's local machine. After the user publishes the results of the data analysis they are requested to summarise the outcome of the analysis back to the *Data Analysis Register*.

5.3 Exporting Wizards for data analysis with other tools

Users with Community Access levels 1, 2, or 3 can export selected data from the master table using export wizards. Each use of the wizard is given a unique identifier that allows the user to review and summarise the outcomes of the analysis.

5.3.1 Modelling tools

The modelling export wizard of *The Climate Projection 2030 Portal* prepares data from the time series merged table. It will create either a single file with multiple attributes or multiple comma separated variables (CSV) files with a single attribute for the whole or a specific time series.

These files can then be manipulated by the modeller according to the requirement of the model to be used for the analysis.

5.3.2 Spatial analysis tools

The spatial export wizard will summarize all data within the master table dataset according to the parameters selected in the wizard and deliver a series of ASCII files that can be imported as raster files into GIS programs. The GIS program can then be used to complete the map algebra comparisons between various raster datasets exported from the system. In preliminary testing the spatial export wizard has been used to complete the map algebra before generating the raster output.

The spatial export wizard has been used in association with the animation toolbar within ARC-GIS to create animation files that are accessible within the public education interface of *The Climate Projection 2030 Portal*.

5.3.3 Other Database tools for sequence analysis

The contents of the time series merged table are only maintained on the system for a limited period. Therefore, to allow more detailed analysis of the time series merged table information for a particular analysis, the data needs to be exported. *The Climate Projection 2030 Portal* has a prepared Microsoft Access Database file that can be downloaded and has been setup with all of the supporting tables for this type of analysis. The particular time series merged table run is exported from the site in CSV or equivalent format and imported into the prepared database using the standard database tools and queries for analysis.

5.4 Outcome Wizard for Summarizing the results of Data Analysis

Using the unique identifier created when the data was exported, users are requested to summarize the outcomes of their analysis for the benefit of the whole community and potentially for inclusion on the public education interface. All inclusions in the public education interface are accredited to the original user completing the analysis.

5.5 Public Education Interface

One of the primary reasons for setting up *The Climate Projection 2030 Portal* was to make the future climate and runoff projections work by Vaze *et al* (2008) more accessible. A supporting aim is to assist decision makers with communicating with the general public about the potential impacts of climate change. This is done by adding support to the map and diagrams within the document with more dynamic and direct outcomes of analysis of the actual site specific data that relates to the decision that affects them.

This interface will be based on all types of analyses of the data conducted by users with Community access Levels 1 to 3. Typically, this information is presented in plain English text and in as simple form as possible (such as AVI video files, charts and prepared SQL data captures).

This public education interface has been designed to continue to grow as more research/analysis is conducted with this and other climate data. An equivalent spatial and temporary scale dataset for temperature and other climate data has been identified and will be added to the framework during 2010.

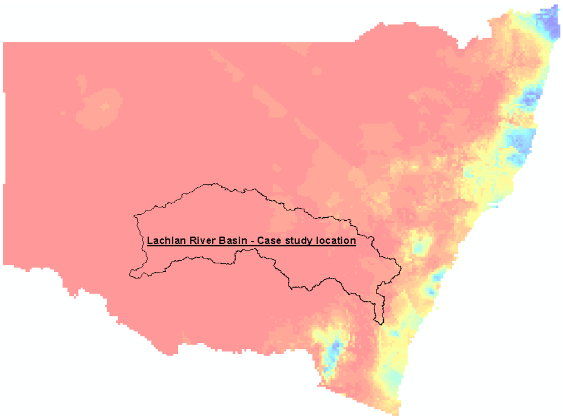


Figure 3 Video of annual Sacramento runoff (historic) 1896 -2006

YEAR	AvgOFSAC_1	AvgOfSIM_1	AvgOfRAI_1	AvgOfPET_1
1895	107794.65060000	110768.59575000	744410.95875000	867315.06832500
1896	110614.11187500	101579.54917500	787349.72677500	819569.67210000
1897	87860.67795000	66692.15752500	917910.95872500	919349.31487500
1898	232467.34207500	206619.54525000	656736.11100000	696022.72717500
1899	102788.56282500	86207.35027500	663488.02395000	622679.64052500
1900	52947.30127500	48184.90402500	621410.95890000	520678.08202500
1901	62756.78760000	52963.18492500	393006.84930000	448726.02727500
1902	4951.80135000	11641.25340000	531945.20542500	595863.01350000
1903	109571.68485000	97110.76005000	626171.23282500	549965.75332500
1904	55717.68442500	44831.48895000	545928.96172500	584310.10927500
1905	28934.84227500	37732.09567500	585164.38342500	552541.09567500
1906	75672.49297500	76932.07515000	536226.02730000	520417.80810000
1907	32766.14362500	43313.31495000	513678.08205000	615267.12307500
1908	70842.90285000	59384.79495000	480157.10370000	471762.29497500
1909	4104.38340000	22877.49307500	526445.20530000	525287.67120000

Figure 4 Tabular volume data annual for grouping of cells Sacramento, SYMHYD, rainfall & PET (historic) 1896-2006

6. CASE STUDY - CLIMATE CHANGE ANALYSIS USING THE DATA

6.1 Climate Change Impact on Water Resource Management in Lachlan Basin

The Lachlan River Basin (see Figure 3) is located within central western NSW and covers 85,532 km^2. The region's topography varies from tableland in the east, through the central slopes to western plains where the Lachlan River essentially terminates in the extensive wetlands of the Great Cumbung Swamp. Major water resources in the region include the Lachlan River and its tributaries. The mean annual rainfall for the region is 461mm, varying from around 1000 mm in the east to 200 mm in the west. Rainfall varies considerably between years and is generally higher in the summer months in the north, tending to winter dominant rainfall in the south. The dominant land use is dryland pasture used for broadacre grazing. Dry land cropping is a major enterprise and almost 20 percent of the region is covered with native vegetation. There are 47,900 ha of irrigated cropping, which varies depending on water availability.

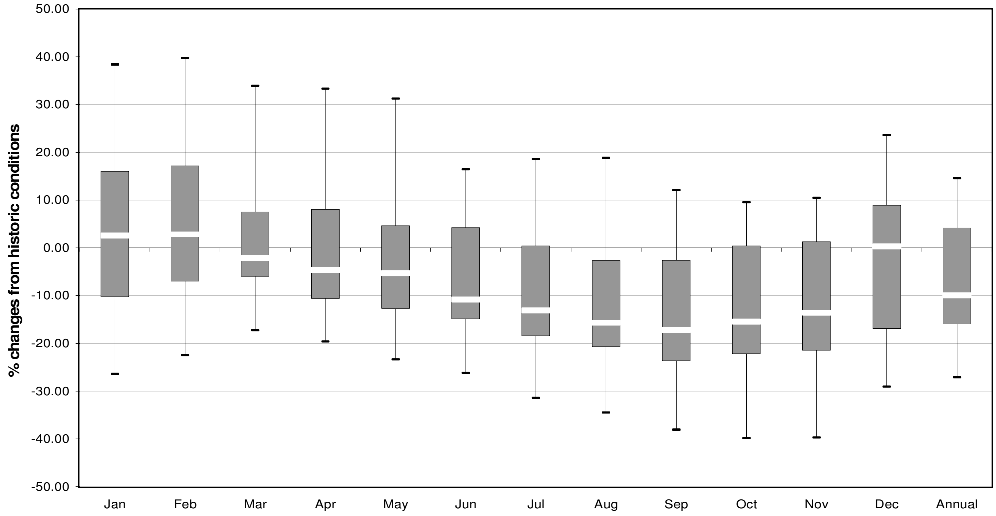
The impact of future climate change on water availability was analysed using the IQQM river system model. Input data included projected rainfall data for 15 GCMs and runoff data modelled by both SIMHYD and Sacramento rainfall-runoff models for all available 15 GCMs. As there is a relatively high level of uncertainty for rainfall projections, probabilities of future changes were calculated from modelling results for all 30 runoff series. A paired two sample test was conducted to ensure that there was not a systematic bias between the two rainfall-runoff models.

The monthly and annual potential ranges of future climate change impact on various water resources management indicators are shown in Figure 5. The bottom of the box is the 25th percentile (25% of values fall below this point), and the top is the 75th percentile. The bar across the middle of the box is the 50th percentile (or median) value. Extending out from each end of the box are the whiskers. The bottom whisker is the 5th percentile, whilst the top whisker is the 95th percentile.

6.2 Projected Changes in Total Inflows

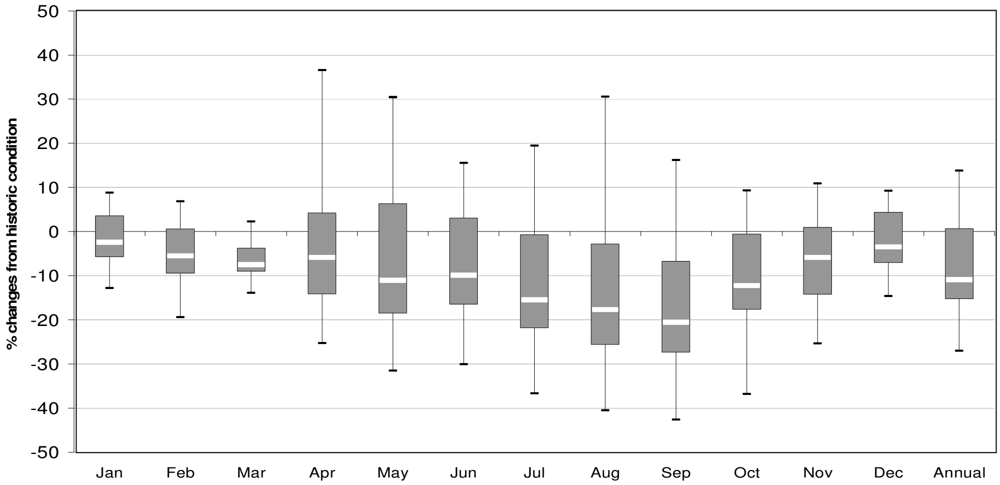
Most models (21 out of 30) estimated that total inflows to Lachlan Basin will be reduced under ~2030 climate projections. The projected median total inflow will be 9.96% lower than the historical climate (Figure 5). Inflows of 5th, 25th, 75th and 95th percentile projected changes were -27.1%, -15.99%, 4.15%, and 14.56%, respectively. The reduction in total flows will happen in March to November. For summer months, it was estimated a slight increase but with a larger range of variations.

Figure 5 Projected changes in total Inflows to Lachlan River Basin.



6.3 Projected Changes in Inflows to Wyangala Dam

Figure 6 Projected changes in Inflow to Wyangala Dam under ~2030 climate



The projected inflow to Wyangala Dam is similar to the projected basin wide inflows with a projected change of -10.98% in inflows. The projected changes of 5th, 25th, 75th and 95th percentile of inflows were -27.28%, -14.29%, 13.42%, and 0.64%, respectively. The reduction in total flows will happen in all months.

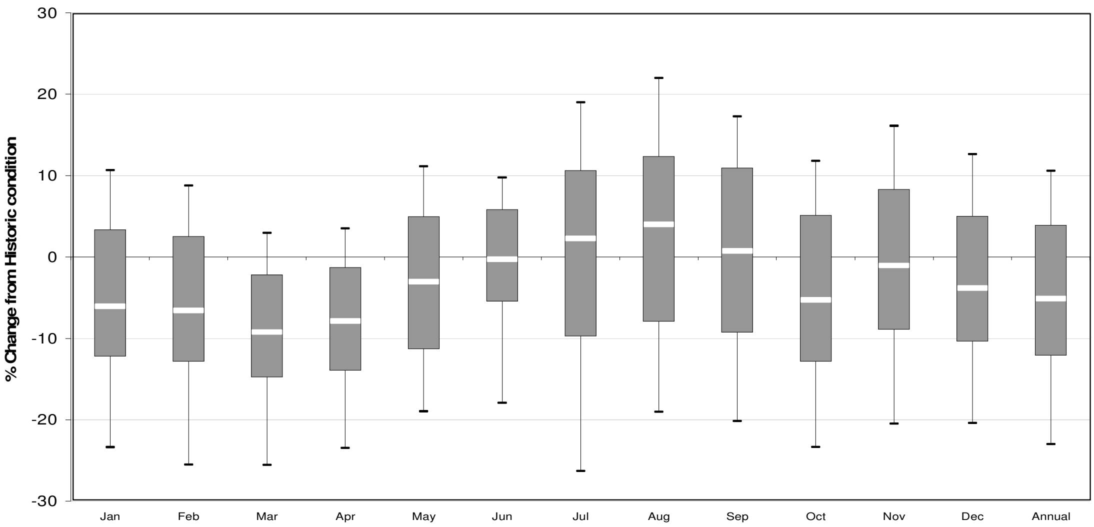
6.4 Projected Changes in General Security Regulated Diversions

The projected changes in total general security diversion are shown in Figure 6. The median projected change in total general security diversion was -5.12% under ~2030 climate. This was different from over 10% reduction in the total inflows and flows at main gauging sites.

The range of change in total general security diversion was similar to those of inflows and flows. The 5th, 25th, 75th, and 95th percentile values of change were -23.00%,-12.8%, 3.98%, and 10.66%, respectively. It appears that climate change impact on total diversions is smaller than those of total water resources.

Figure 7 also illustrates that potential diversions at July, August and September will be higher than the historical condition while other months, especially summer months are lower. It is not clear if this was the result of higher evapotranspiration under ~2030 climate.

Figure 7 Projected changes in total general security diversions under ~2030 climate condition.



6.5 Projected Changes in Allocations on 1st October

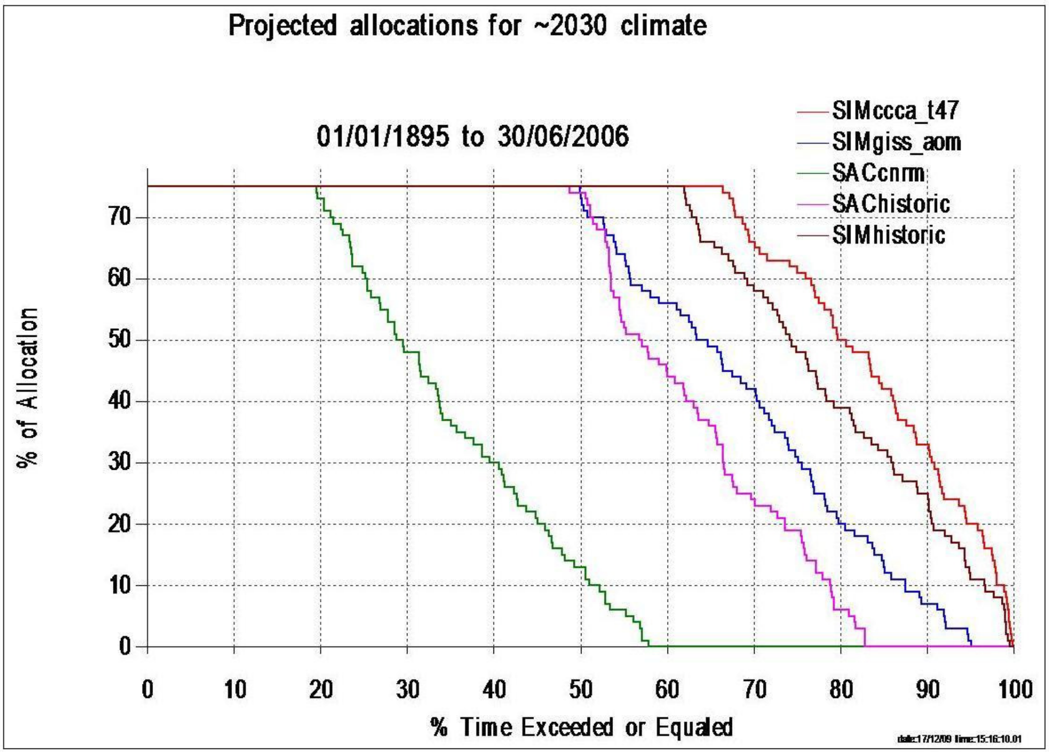
Changes to the water allocation anouncement on 1st of October may lead to changes in areas of irrigated crops for the coming cropping season, and hence land use patterns. Although updates on allocation are progressively announced throughout the year as resources becomes more certain, the allocation announcement on 1st of October is an important indicator for irrigation and cropping plans for the coming crop season.

The projected average allocation on 1st of October under ~2030 climate is 9.31% lower than the historic conditions. This is consistent with the total inflows. Figure 8 showed the high, median and low projections for general security allocation reliability on 1st October among the 15 GCMs modelled by SIMHYD and Sacramento. The high projection was obtained from the SIMHYD runoff inflow series for the Canadian Climate Centre's CCCMA T47 model. It projected a 6.7% increase to the historical allocation reliability on 1st October, and a 67% probability to reach the full allocation limit. The low projection was obtained from Sacramento runoff inflows for Meteo-France's CNRM model. The projected allocation reliability on 1st October was 43.7% lower than the historical average, and less than 20% of probability to reach the full allocation limit.

The median projection was obtained from the SIMHYD runoff inflows for the GISS-AOM model of NASA/Goddard Institute for Space Studies. The projected average allocation reliability on 1st October was 13.5% lower than the historical average, and about 50% of probability to reach the full allocation limit.

The allocations simulated using runoff estimated by both SIMHYD and Sacramento were also included in Figure 8 to provide a reference for the projected high, median and low allocations under projected ~2030 climate. Changes of the high and median allocations may be compared with the SIMhistoric curve in Figure 8. Changes of projected low allocations are comparable with the SAChistoric curve in Figure 8.

Figure 8 High, median and low projections of allocation reliability on 1st October under ~2030 climate.



In summary, the case study demonstrated that the data is useful in projecting future water availability and can be used to make management changes. The Murray-Darling Basin Sustainable Yields Project (CSIRO, 2008) used only three GCM to represent the dry, median and wet projections. This data made it possible to use all 15 GCMs to use a probablity approach to project the climate change impact on water availability and management. In this study the 25^{th}, 50^{th}, and 75^{th} percentiles were calculated from 30 projected runoff series (15 GCMs by 2 rainfall-runoff models) to represent the dry, median and wet projections. In addition, the 5^{th} and 95^{th} percentiles as indicators for the extreme dry and wet projections.

7. CONCLUSION

The potential impact of climate change is a significant consideration for decision making on large scale infrastructure projects. With the current dry conditions covering most of NSW, the issue of water security will become even more important to the community who will demand the best possible management of this precious resource. Vaze *et al* (2008) has provided the NSW Government with the best and most comprehensive climate and runoff projections dataset that is currently available, *The Climate Projection 2030 Portal*, a community based knowledge management framework, has been created to maximise the value that can be obtained from this important dataset. The framework contains a number of access, export and analysis tools that can not only help stakeholders to make the decision but also to communicate the outcomes of their analysis with the general public that may be affected by the decision.

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