Climate variability and water security for power generation

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Abstract A reliable supply of fresh water is a critical component of coal fired power generation. During periods when water supplies are reduced, power generation may be limited, with obvious impacts on power consumers. Using the reconstructed historical streamflow series contained in the IQQM water allocation model, and simple water balance modelling, the water supply security of the Bayswater Power Station in the Hunter Valley, Australia, is assessed. The study revealed that the supply of water to the Bayswater Power Station is sensitive to extended dry periods, with some historical periods experiencing water shortfalls so severe that the station would be shut down without alternative water supplies.

Key words climate variability; water supply security; water balance modelling; IQQM; Hunter Valley, Australia

INTRODUCTION

The purpose of this study is to determine the impact that climate processes such as the El Nino – Southern Oscillation have on the reliability of the water supply within the Hunter Valley, Australia. Specifically this study focuses on the water supply security necessary for power generation by Macquarie Generation at the Bayswater and Lake Liddell power stations. The generation of electricity using coal fired power stations such as Bayswater and Lake Liddell is dependent on a reliable supply of fresh water to replenish losses due to the operations of the power stations. The principle water supply dams of both of these power stations are the Glenbawn, Plashett and Liddell dams.

The influence that the ENSO cycles (among others) have on the rainfall and streamflow within eastern Australia is well documented (e.g. Franks, 2004; Verdon *et al*. 2004; Kiem & Franks, 2001, 2004; Kiem *et al*. 2003). How this process directly affects the supply of water to the end user within the Hunter Region, particularly given the large size of the Glenbawn Dam, has not been directly examined. In order to achieve such an analysis, a water balance model must be adopted that simulates the interactions between the principle water storages, inputs (i.e. rainfall and streamflow) and usages, allowing for the estimation of the system response for a much longer time period than that which is directly measured. Such a process means that the long-term interaction between climate variations and the complex water supply system can be more closely examined.

In order to achieve this, the extended data series currently employed by the Department of Natural Resources within the Integrated Quality and Quantity Model (IQQM) (DLWC, 1995) is used. This data, consisting of extended rainfall and streamflow records (generated using the SACRAMENTO soil moisture accounting model (e.g. Burnash, 1995), developed by the US National Weather Service and the Californian Department of Water Resources) is currently used by the department to assess future water allocations for the various licensed extractors, of which Macquarie Generation accounts for approximately half of the total annual volume licensed for extraction. In using this data, the analysis is based on what is currently accepted within the legislative framework, therefore giving the opportunity to first assess the adequacy of this data with respect to how well it reflects the known influence that climate variability has, and secondly to determine how this data interacts within the water supply system over a longer time scale.

It is hoped that this process will lead to a better understanding of the susceptibility that the water supply within the Hunter Valley has to the climate cycles that influence this region. In particular, it is anticipated that the findings of this report will allow for the adaptation of current management practices that more directly factor the prevailing climate conditions into future water allocations, thereby extending the availability of water during prolonged dry periods.

ENSO CYCLES

The El Nino–Southern Oscillation (ENSO) cycle is a phenomenon of alternating dry (El Nino) and wet (La Nina) periods that especially affect summer and autumn rainfall in eastern Australia. It has a typical frequency between 2 and 7 years. The driving force behind the ENSO cycle is variations within the sea surface temperatures (SSTs) across the equatorial Pacific. El Nino conditions are normally associated with warmer waters in the Eastern Pacific and cooler waters off the coast of eastern Australia, whilst La Nina conditions are the reverse.

The ENSO cycle has been shown to influence the magnitude of summer rainfalls throughout eastern Australia (e.g. Verdon *et al.*, 2004). It is therefore important when using any historical rainfall or streamflow series to bear these influences in mind.

RAINFALL AND STREAMFLOW DATA

Observed historical data

The observed rainfall data used within this study comes from rainfall gauges maintained by the Bureau of Meteorology. Numerous rainfall gauges are located in and around the Hunter, Lostock and Glenbawn catchments. These gauges have historical data sets that range in length from several years to over a century of daily data with varying degrees of completeness. A subset of the longer, more complete series are used by the New South Wales (NSW) Office of Water (NOW: formerly the NSW Department of Natural Resources) to generate the extended streamflow records discussed later.

Numerous historical streamflow gauge data series are available for the area in and around the study site from the Pinneena database, maintained by the NSW Office of Water. Like the rainfall gauges, the length of the observed series vary substantially between the gauges; however, the focus of this report will be on the four streamflow gauges along the Hunter River that the NSW Office of Water produces extended records for, specifically at the Moonan Dam, Muswellbrook Bridge, Denman and Liddell gauging stations. These catchments range in size from 103 to 13 400 km^2, and are mostly rural in nature, with pasture improved grazing lands covering a large portion of the area.

Extended historical data

The IQQM model, developed and maintained by the NOW, is a water allocation model used to determine the impact that future water allocations will have on the water supply system. As such it requires an extended period of streamflow data with which to model the past performance of the system. The daily time step, extended streamflow record used within the IQQM model is generated using the SACRAMENTO model, calibrated specifically for various catchments within the Hunter Valley. This extended the streamflow data set by inserting between 50 and 100 years of daily streamflow data. It is this extended streamflow data set that is used as the basis for the monthly water balance model developed to emulate the water supply system over the past 90 years.

HISTORICAL WATER BALANCE MODEL

A historical reconstruction of the water supply system based around the Glenbawn, Plashett and Liddell dams is constructed using a monthly spreadsheet water balance model, accounting for inputs (such as pumping from the river system and direct rainfall) and outputs (such as evaporation and use by the powerstations). The extended streamflow record supplied by the IQQM model is used as the inflow into the dam (based on the Moonan Dam streamflow record, adjusted by a catchment scaling factor of 1.42 following the recommendation in the report prepared for the former Department of Water Resources (Hydrotechology, 1995) and additional subcatchment inflows into the Hunter River upstream from the Macquarie Generation pumping station. These inflows were derived according to the method outlined in the HydroTechnology report for the outlet at Muswellbrook Bridge, the outlet at Denman and the outlet at Liddell.

The water usage and pumping capacity of both the Lake Liddell and Bayswater power stations are those specified in the report prepared for the former Department of Land and Water and Macquarie Generation (Bewsher Consulting, 1999). Additional water usage by irrigators and domestic usage are also included, based on information provided by the NSW Office of Water (personal communication). The Glenbawn dam is assumed to initially be at 50% capacity.

Figure 1 shows the monthly reconstructed water balance based on current management practices. As can be clearly seen, a substantial drop in the storage level in the Glenbawn Dam occurs after 1936, not recovering until 1950. Despite this, the levels within the Liddell Dam remain above empty, meaning that power generation is still possible, albeit restricted. The observed monthly rainfall during the modelled period is shown in Fig. 2, with a 12 month moving average included. At first glance, it would appear that the sudden drop in storage levels within the Glenbawn Dam do not correspond with a reduction in the monthly rainfall during this period, which remains at approximately 50 mm per month. Figure 3 shows the number of months within a moving 12-month period with monthly rainfall depths exceeding the 95th percentile (135mm per month). From 1935, when Glenbawn Dam storage began to rapidly decline, until 1948, just prior to the dam's recovery, there are no months that contain any high rainfall events. This suggests that the Glenbawn Dam (and similarly, lakes Plashett and Liddell) relies on larger streamflow events, such as minor flooding, to replenish water supplies. Average conditions are insufficient.

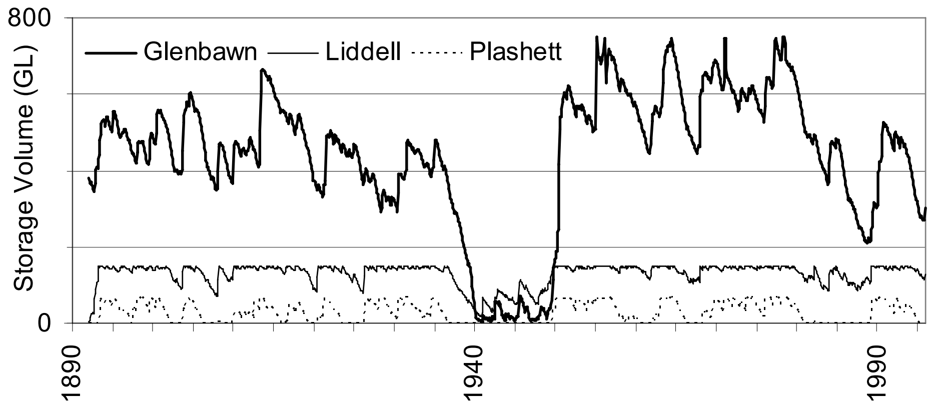

Fig. 1 Monthly reconstruction of storage volumes within the Glenbawn, Plashett and Liddell storages.

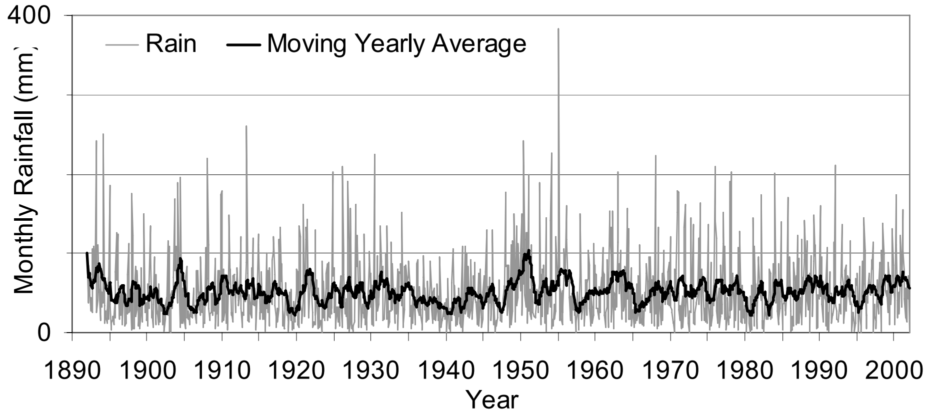

Fig. 2 Monthly rainfall (average of the four gauges in Table 1) with a continuous annual average.

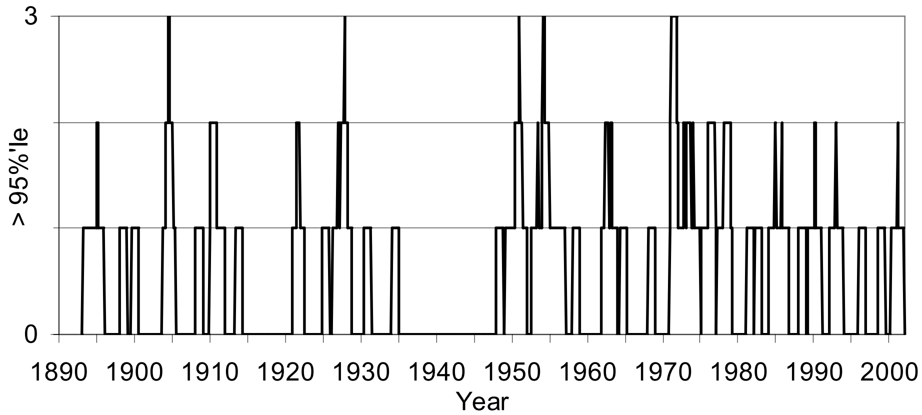

Fig. 3 Number of events within the previous 12-month period where monthly rainfall is greater than the 95th percentile level.

Climate influence on water supply

In order to further examine the influence that the different ENSO states have on the water supply within the Hunter Region, the monthly water balance model is used to simulate the water supply using synthetic rainfall series generated using the Stochastic Climate Library (SCL) (part of the eWater Toolkit, see www.toolkit.net.au for further details) under the various ENSO conditions. The SCL generates monthly rainfall data series that are statistically comparable to a given data set. By limiting the input data set to only those months under El Nino or La Nina conditions, extended rainfall series are created that numerically mimic these historic periods. This allows for the assessment of what impact that extended periods of these conditions has on the supply of water within the Hunter area.

Rainfall is translated into streamflow using a simple IHACRES model (e.g. Young, 1998) calibrated to the reconstructed streamflow series in order to maintain the similarity in catchment response between the historical reconstruction and the synthetically derived series.

ENSO influence

It has already been demonstrated that El Nino conditions result in a substantial decrease in water availability compared to La Nina conditions. Figure 4 shows how the distribution of annual rainfall totals changes in response to the prevailing ENSO conditions. For example, the 95th percentile rainfall total shows an approximately 300 mm difference between the El Nino and La Nina totals. This means that what is a 1-in-20 year event under El Nino conditions is approximately a 1-in-5 year event under La Nina conditions.

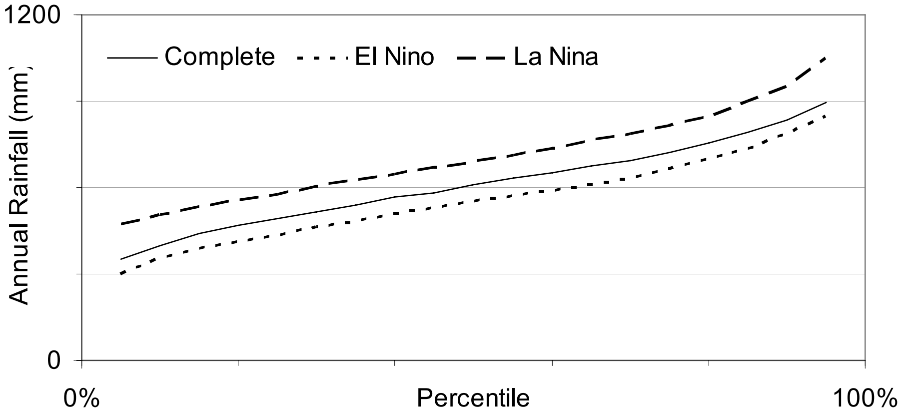

Fig. 4 Annual rainfall percentiles under El Nino and La Nina conditions.

Figures 5 and 6 show the example reconstructed water supplies generated with the water balance model under El Nino and La Nina dominated conditions. The difference between the water storages throughout the modelled periods is pretty clear, with those under El Nino conditions remaining consistently dry, with only intermittent periods of relief. In contrast the series generated using the La Nina dominated series shows storages that remain full for most of the timeline.

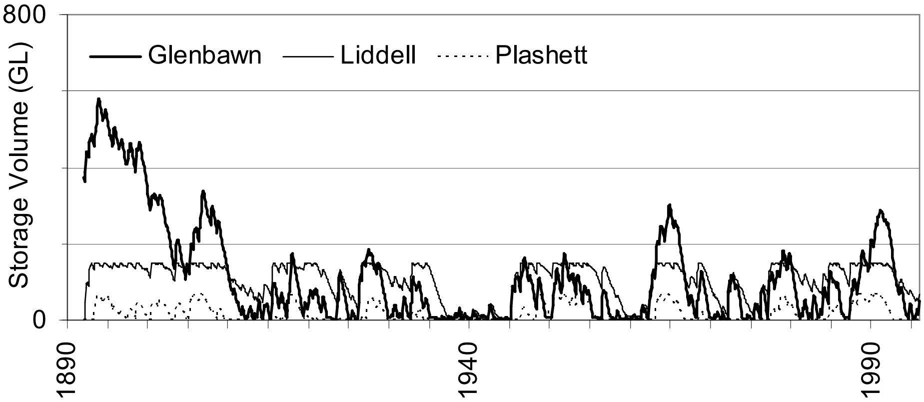

Fig. 5 Example of the reconstructed water supply under El Nino dominated conditions.

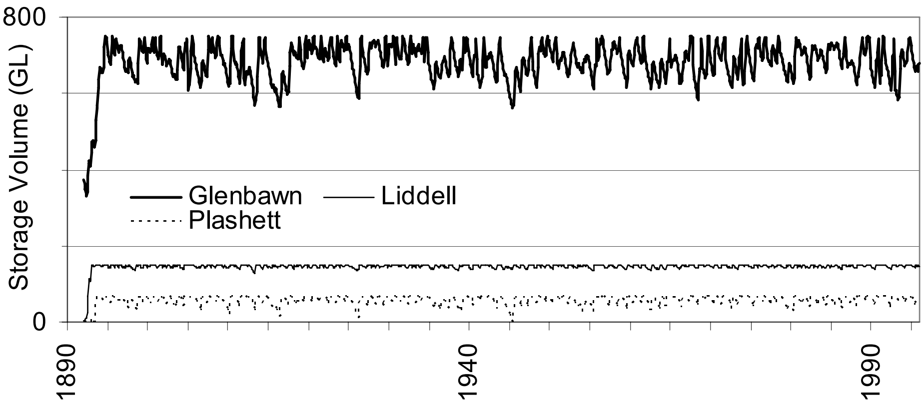

Fig. 6 Example of the reconstructed water supply under La Nina dominated conditions.

CONCLUSIONS

Climate variability has a substantial influence on the rainfall patterns across eastern Australia. The rainfall variability from year-to-year due to the ENSO cycle alone can result in a halving of expected summer rainfall (due to El Nino conditions). Other climatic cycles, such as the Interdecadal Pacific Oscillation (IPO; Power *et al.*, 1998) also have a significant influence on water supplies in the Hunter Valley; however, these have not been addressed in this paper. An understanding of such cycles is therefore critical for the long-term management of water supplies. This is of particular concern given the uncertainty regarding climatic conditions in the future.

Previously, climate cycles have been largely ignored in water management strategies. Rainfall and the subsequent streamflow are treated as being stable through time (or at least, variable about a constant mean) with metrics such as *probable maximum precipitation* and *one-in-one hundred year flood* often being cited as design criteria. This article has shown that such metrics are all but arbitrary, as they are based on the observed records which are limited in length and therefore cannot contain the full scope of climatic variation. Even longer rainfall records that date from the early 1900s will be dominated by the IPO *negative* period observed between the mid-1940s and the 1970s, resulting in an overestimation in the expected annual rainfall. The result is that whilst a 60-year rainfall record may appear to be substantial enough to estimate "normal" conditions, this series in effect splits into the flood dominated IPO *negative* period (1945–1975) and the drought dominated IPO *positive* period (1975–present). These different climate states produce distinct rainfall patterns and as such should be treated as being separate events, thereby drastically cutting down the amount of historically-observed data that is relevant to the present conditions.

In order for water management strategies to operate most effectively over the long term, the tools used to assist in decision making must adequately reproduce past behaviour of the system. By incorporating our knowledge of the ENSO cycle (as well as others such as the IPO cycle) into the decision making process, management strategies can be adjusted to allow for an increase in the security of the water supply for the longer term by employing measures that are more pro-active according to the conditions that are considered to be most likely in the medium term, rather than the current state of water supplies.

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