# Aligning water security policy with increasing drought persistence.

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Abstract:
Both historical and stochastic modelling techniques have been used in Australia to simulate the performance of urban water supply storages. Traditional storage yield estimation is now being questioned as new norms are being established necessitating increased understanding of how climate is changing. By considering drought trends, a better understanding of future water supply requirements may be gained. This paper investigates trends in drought persistence variability and associated meteorological drivers and also describes how changes in climate drivers resulting from northern hemisphere warming may potentially impact equatorial winds and consequently rainfall patterns and water supply planning in Australia and Mexico.

## Introduction

Regional water supply strategies in Queensland, Australia were first created in 2007. Since that time large areas up to 350,000 square kilometres have had regional water strategies developed. These strategies provided a long term strategy for utilising the regions' water resources to best meet mining, agricultural and urban needs. Additionally, these strategies outlined broad water supply risks and provided recommendations to address the risks and catered for growth and when drought occurred.

Subsequent to the development of the broad, all-encompassing, regional strategies, assessment of water supply security for urban centres commenced in 2014 to develop an understanding of the existing reliability of urban water supply systems and their capacity to support current demands and future growth. Reliable water supplies are an essential asset, not only providing for community needs, but also enabling economic development.

Water supply security assessments for larger growth centres have been undertaken (Department of Energy and Water Supply, 2017a) and provide fundamental information on water availability and demand to the community and water service providers. Traditionally in planning for the provision of water supplies, planning engineers simply considered rainfall, runoff, evaporation, water storage capacities, historical annual yield to storages and water use data. The assessments undertaken have attempted to identify the timing and magnitude of potential water supply risks and required augmentations. These assessments were carried out using historical and stochastic modelling to simulate the performance of water supply storages. Historical modelling was undertaken to identify how well storages would have provided for a range of water demand requirements. Stochastic modelling was undertaken to show how water supply storages would behave under a range of climatic scenarios. The stochastic modelling included consideration of drought frequency and severity but could potentially be improved should consideration be given to the trends now being reflected in the form of increasing drought persistence.

The severity of a drought is measured by its duration and magnitude of rainfall deficit. By considering not only the frequency and severity of historical droughts, but by also including consideration of increasing duration and magnitude trends, a clearer understanding of future water supply storage behaviour and required operations is potentially possible.

Water supply planning requires not only an understanding of potential changes in water demand due to growth but also an understanding of how climate is changing. Australia's climate can vary greatly from one year to another. Climate direct drivers and a potential indirect driver and their interactions have been considered. These studies have identified potential interactions by an indirect climate driver on direct climate drivers which may provide for longer range forecasting of the El Niño Southern Oscillation thereby enabling improved climate preparedness by water service providers as they endeavour to increase their resilience to water scarcity.

Investigations into trends in drought persistence variability and potentially associated meteorological drivers, including not only sea surface temperatures, have been undertaken to develop an improved understanding of how climate is changing from a practical viewpoint so as water supplies can be managed and augmentations correctly timed.

Many of the key drivers for the world appear early between Australia and Mexico in the Pacific Ocean. These include the El Niño Southern Oscillation, a key direct driver for both Mexico's and Australia's climates. Although changes in the Interdecadal Pacific Oscillation change the strength of El Niño Southern Oscillation it also appears to be driven in part by the Siberian High. Changes in the strength of the Siberian High resulting from warming or cooling in the northern hemisphere may potentially impact equatorial winds, in particular the strength of the northeast trade winds and consequently the commencement and duration of El Niño and La Nina phases impacting Australia and Mexico.

## Queensland's water supply assessment program

Under the water supply assessment program for urban centres (Department of Energy and Water Supply, 2017a), water storages for different centres were reviewed and catchment area, storage capacity, minimum operating volume, useable storage volume, storage ownership and operation identified. Water licences and their volumetric limits for extracting water were evaluated.

## Water demand

The volume of water sourced for urban use, including any reticulation losses, and the size of communities serviced enabled the average water demands per capita (litres per capita per day (L/c/d)) for each urban centre considered to be determined. Water use data was used to determine the range of annual water demands and the average volume required from each of the assessed storages.

In projecting future urban water demand, the average and maximum daily water demand over the past few years were determined. By using the average daily water demand different future demand projections were able to be compared to determine if available supply would meet demand. Figure 1 shows the projected average water demand for a small urban centre (Department of Energy and Water Supply, 2017b:p7). A higher demand reflecting a possibly drier period is also depicted to assist in the determination of timely augmentations.

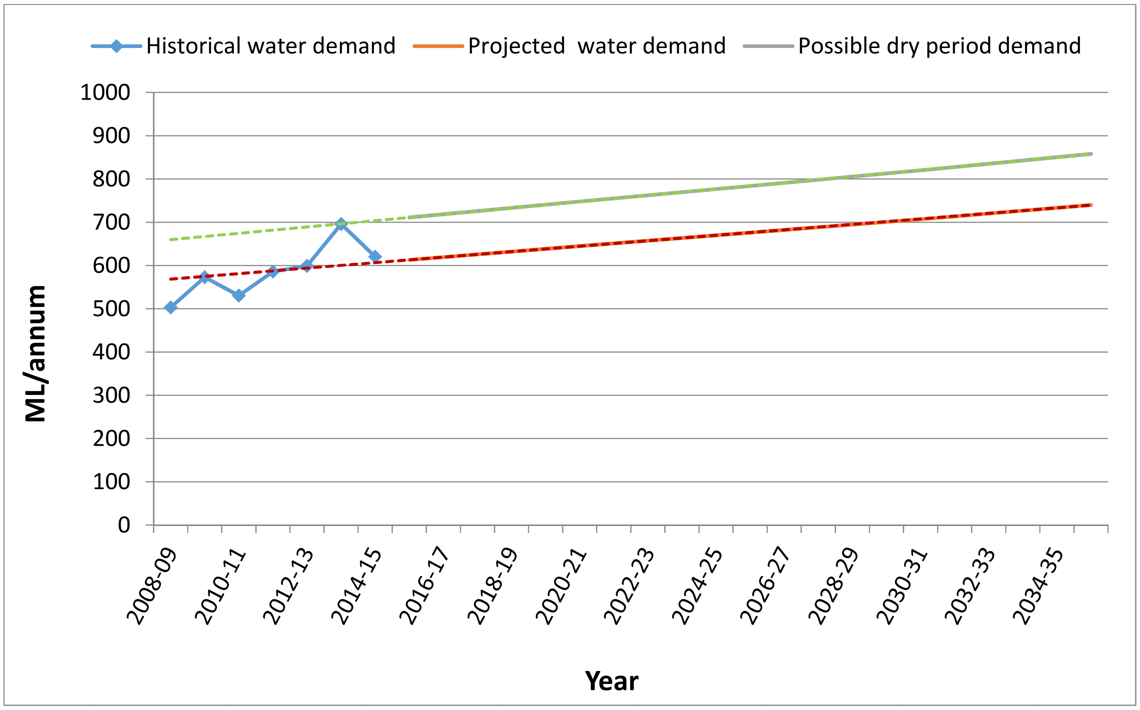


Figure 1: Projected average water demand on a small storage by a small urban centre (Department of Energy and Water Supply, 2017b:p.7). © State of Queensland, 2016.

Recycled water

A significant proportion of the water supplied through urban reticulation systems is ultimately returned to wastewater treatment plants where it can be recycled. Up to 57% of water sourced annually is recycled. All recycled water produced is used by industry or recreation areas. This reduces the potential demand on the associated storages.

Impacts resulting from annual variations in rainfall

Urban water demand differs from year to year and throughout each year depending largely on season and rainfall. Figure 2 shows the relationship between annual rainfall and the volume of water sourced for the associated reticulation network in a small urban centre (Department of Energy and Water Supply, 2017b:p5). An inverse relationship between rainfall and water demand is observed due largely to residential external use.

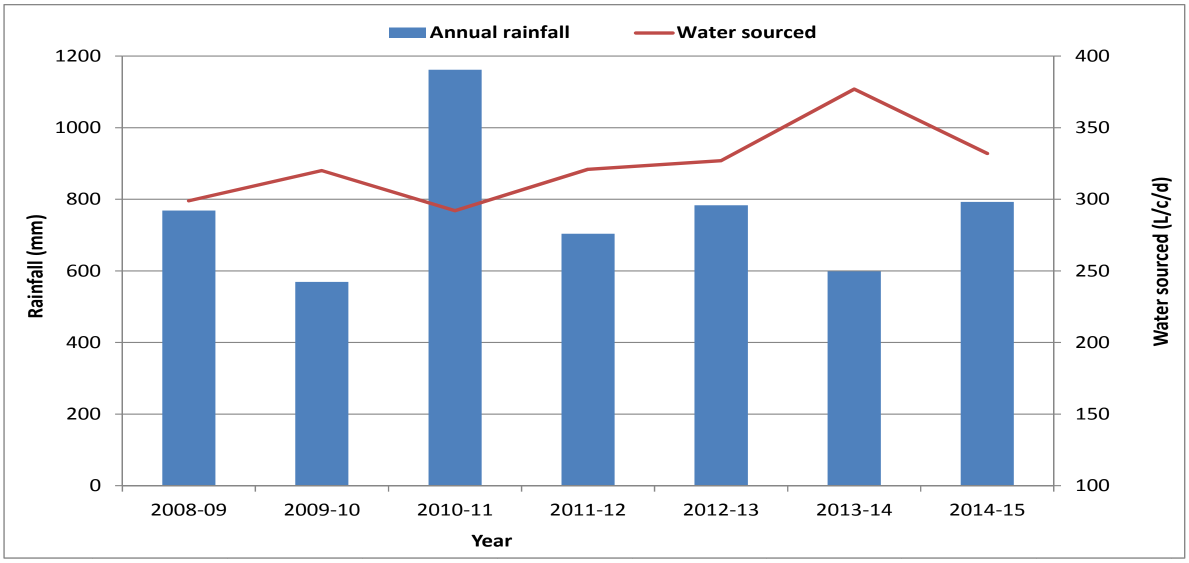


Figure 2: Total annual rainfall vs total water sourced (Department of Energy and Water Supply, 2017b:p.5). © State of Queensland, 2016.

Other users of storages

Both agricultural and mining industries close to an urban centre are often a significant part of the local economy. Depending on their size these industries can place minor or major demands on the water storage used by the urban centre. Additionally, with these industry demands there is potential for the scale of their associated production to increase which may impact the supply of water to the urban area.

Historical water supply storage performance

In Australia droughts appear to be growing in persistence. Figure 3 shows the storage behaviour of a small urban centre’s storage with negligible change in demand (Department of Energy and Water Supply, 2017b:p.6). The storage did not fail during the period however it did fall to low levels with increasing frequency and severity. As a result, there was a need for extended water restrictions at times to ensure water service provision. Subsequent to years of below average rainfall, water levels in the storage fell to very low levels in 2007 with water restrictions remaining for three years. The storage recovered following above average rainfall in late 2007.

Small capacity storages are particularly vulnerable to droughts and seemingly historical performance is not as reflective of how a storage may behave in the future. Trends as reflected in the figure below are now indicating an expansion of the duration and magnitude of droughts.

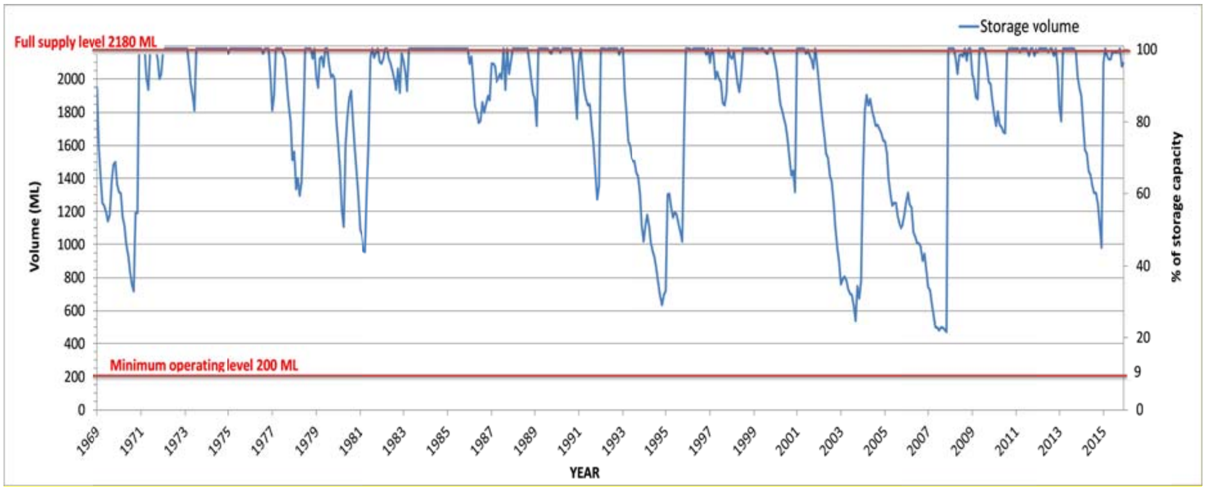


Figure 3: Recorded storage behaviour from 1969 to 2015 (Department of Energy and Water Supply, 2017b:p.6). © State of Queensland, 2016.

Hydrologic assessment of water supplies' capability

Hydrologic assessments have been performed for a number of both large and small urban centres in Queensland to determine the capability of the respective water supply system to meet both the present and future water demands of the various coastal and inland communities.

These assessments were carried out using historical and stochastic modelling of rainfall, evaporation and runoff to simulate the performance of water supply storages. Historical modelling was undertaken to identify how well various associated storages would have provided for a range of water demand requirements by different communities. Stochastic modelling was undertaken to show how water supply storages would behave under a range of climatic scenarios with some harsher sequences utilised than would have been experienced in the historical record. The stochastic modelling included consideration of drought frequency and severity but could potentially be improved should consideration be given to the trends now being reflected in the form of increasing drought persistence which is one of the characteristics of climate change.

Data sequences were generated with stochastic modelling that included both extended wet and dry periods from the historical record. One hundred replicates of stochastic rainfall, evaporation and streamflow data were produced for the associated storages' catchment areas, and hydrologic modelling using the replicates was undertaken to provide outputs from this modelling to enable the development of a number of regional water supply security assessments (Department of Energy and Water Supply, 2017a).

The hydrologic assessments were undertaken assuming that all water entitlements aligned with the associated storage or watercourse sources that support the system are fully used except for the water entitlements aligned with the urban reticulation network. Various water demands for urban centres linked to growth rates were then considered to show a range of impacts on the supply sources.

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Water service providers have designed water restrictions around storage volumes to prolong the availability of water supply. Table 1 shows how water restriction levels can be aligned with storage volume (Department of Energy and Water Supply, 2017b:p.10).

Table 1: Water restriction levels for a small urban centre (Department of Energy and Water Supply, 2017b:p.10). © State of Queensland, 2016.

| **Restriction level** | **Supply trigger levels (% of full supply volume)** | **Targeted maximum daily residential consumption (L/p/day)** |
|---|---|---|
| Permanent | 75% and above | 230 |
| Medium | 70% (or below). Relaxed when volume increases to 75% | 200 |
| High | 50% (or below). Relaxed when volume increases to 55% | 170 |
| Extreme | 30% (or below). Relaxed when volume increases to 35% | 140 |

Historical modelling assessments

Historical modelling for the period 1890 to 2015 indicated that some storages would have been consistently capable of meeting average demand. However, without restrictions being applied storages would have dropped to very low levels frequently during the modelled period. The historical modelling also showed that should the required water demands grow by 20% as a result of an increase in population, storages would fall below their minimum operating level at times during the historical period.

Stochastic modelling assessment

As stochastic modelling provides for a wider collection of climatic scenarios than the historical modelling, it is helpful for interpreting water supply systems' future capabilities. Figure 4 depicts the frequency of water restrictions versus total annual water demand for a small urban centre's reticulation network under water restrictions (Department of Energy and Water Supply, 2017b:p.11).

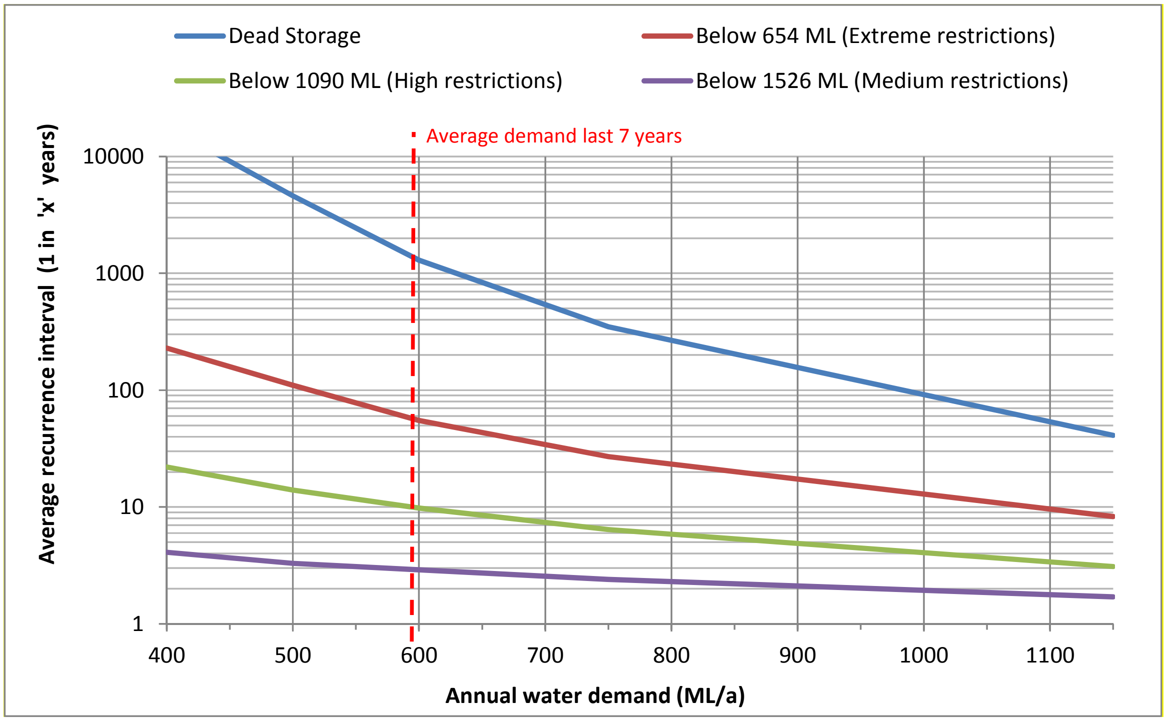


Figure 4: Frequency of water restrictions versus total annual demand (Department of Energy and Water Supply, 2017b:p.11). © State of Queensland, 2016.

As water demand increases, the frequency of any trigger level being reached increases. For example, should an increase of 20 per cent in the required water demand occur, the high level restrictions could be expected to be triggered every 6.4 years rather than every 10 years as shown by the dotted red line in the above figure. Determination of acceptable frequencies of restricted demand are an important consideration for water service providers and communities alike as there are cost implications associated with improving the resilience of water supply.

Duration and magnitude of water restrictions

Although the frequency of water restrictions is an important consideration, the duration and magnitude of each restriction period may be more important for many water users. For example, it may be more acceptable to experience less severe and shorter periods of water restrictions more frequently, than to experience more severe and longer periods of water restrictions less frequently.

Figure 5 shows the number and duration of high level water restriction events occurring at various annual water demands. The occurrence of restrictions lasting for longer than one month, three months and six months is shown to double should water demand increase by approximately 50 per cent up to 1150 ML/annum (Department of Energy and Water Supply, 2017b:p12).

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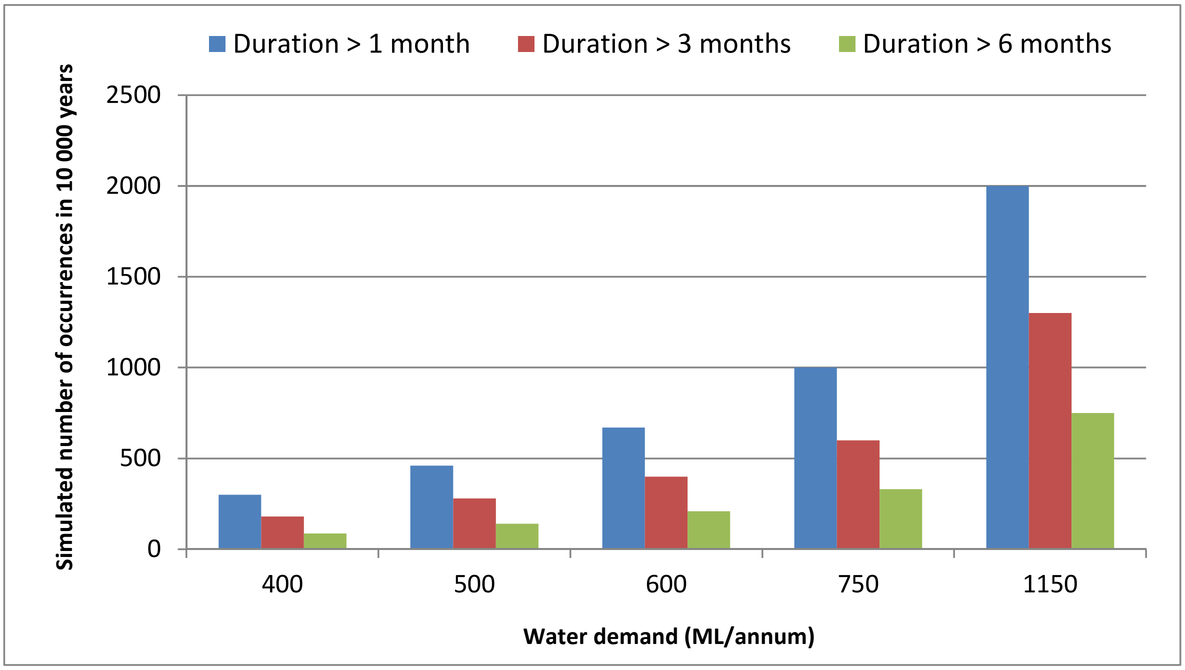


Figure 5: Number and duration of high level water restriction events occurring at various annual water demands (Department of Energy and Water Supply, 2017b:p12).

Together, the frequency, duration and magnitude of water restrictions, along with the ability to maintain a minimum supply during drought, are fundamental parts of water supply planning and are referred to as ‘level of service’. The level of service has been a matter for the respective water service provider to determine, in discussion with the associated community.

Future planning and policy considerations

The approach and assessments outlined above has served planners well to date, however trends are now developing which may benefit water supply planning should they be included. As earlier indicated, trends in increasing drought severity have been experienced in Australia over the last 40 years. Although the stochastic modelling used in the assessments undertaken to date, and other studies (Cox, Smythe & Koutsoyiannis, 2006) has involved generating data sequences that incorporate key statistical indicators from the historical record which include persistence of individual drought events, limited inclusion of trends relating to increases in duration and magnitude of droughts have been considered or their causes identified or proposed. Some reports suggest that it is winds or ocean currents that are responsible for climate variations, which in part is directly true but when their cause is investigated it stems back to variations in pressure being responsible for the patterns of atmospheric circulation that determine wind directions which in turn are subsequently are largely responsible for sea currents’ magnitude and duration, and impact sea surface and sub-surface temperatures.

Although sea surface temperatures, currents and winds can enable short to medium range climate forecasting it is potentially possible through looking at large pressure systems, for which significant data is held, that longer range forecasts are potentially possible.

Direct climate drivers of the Pacific

The highest, simultaneous correlation of the various El Niño Southern Oscillation indices with Australian rainfall is obtained using the Southern Oscillation Index. This index is a measure of the pressure difference between Tahiti and Darwin in northern Australia and is provided by the Australian Bureau of Meteorology (Risbey et al, 2009). Although a sea surface temperature index, for example Niño-3.4, may enable a longer range forecast of Australian rainfall than the Southern Oscillation Index (Lo et al, 2007) historical data is limited. However, the amassing of warm waters towards the western or eastern Pacific Ocean is potentially determined by winds supported by large persistent land based pressure systems for which significant data is available.

Although the El Niño Southern Oscillation is the main Pacific based direct driver there are additional direct drivers of climate located within the Pacific region that give indication of future weather. These include the Interdecadal Pacific Oscillation, the Intertropical Convergence Zone and the Southern Pacific Convergence Zone. The location of the Southern Pacific Convergence Zone can reflect support of an El Niño or La Niña phase. This zone moves between being close to Australia during a La Niña event and being positioned to the northeast during an El Niño event and impacting the Cook Islands and Tahiti (Ngari, 2016. Ravenel, 2016). Additional impacts of a supported El Niño include intensification of winter storms along the USA's west coast, gulf and southeast states and dampening of Atlantic hurricane formation (Human, Deluisi & Joy, 2010).

An indirect potential climate driver

The Siberian High shows direct and significant influences on the East Asian cold and dry winter monsoon, particularly on sea level pressure and winds along the East Asian Coast. The East Asian winter monsoon system is one of the most active components of the global climate system. Climate variability in East Asia has widespread effects. One of the most prominent surface features of the East Asia winter monsoon is the prevailing north easterlies over the South China Sea. Sea level pressure indices were developed for the Siberian High and the East Asia winter monsoon for which the correlation coefficient was found to be 0.8. (Wu & Wang, 2002).

The Siberian High showed pronounced weakening during approximately 20 years to 2000 (Gong & Ho, 2002). Data for this study was attained from the Climatic Research Centre at the University of East Anglia in the United Kingdom and from the National Centre for Atmospheric Research in Boulder, Colorado. Subsequent to the 20 years of reduction in the Siberian High central intensity centered over northern Siberia and the area around Lake Baykal in southern Russia, the millennium drought (1995 to 2009) in Australia occurred. Should the winds around the Siberian High, that strengthens the north east trade winds over the South China Sea, prevail for an extended period of years, there would could potentially be a strengthening of the westward equatorial circulation which in turn would encourage a La Nina event to develop. The onset and duration of such would likely have a direct relationship with the strength and duration of the Siberian High over the preceding years. The variability of the El Niño Southern Oscillation therefore may partly lie in the Siberian

High being an influencing source which could through the availability of significant land based data improve the longer term prediction of El Niño Southern Oscillation and hence drought onset and severity in Australia and Mexico.

## Implications for water supply planning

Should droughts continue to become more severe it will become increasingly important for water supply planners to understand the potential extent of increases in duration and magnitude and how such may best be included in modelling techniques. To understand the future likelihood of when water supply storages will be replenished is very valuable to a water planning engineer, water service providers and associated communities, as such information strongly impacts final investment decisions in the timely augmentation of infrastructure.

## Conclusions

Well-founded and secure water supply planning necessitates an understanding of the likely changes in water demand into the future and an understanding of how climate is changing. Through consideration of meteorological drivers and their interactions it is hoped to be able to provide accurate long range forecasts. Water service providers are keen to receive input from meteorologists, climate change scientists, water planning engineers and their respective communities to ensure the necessary planning is in place to bring about appropriately secure water supplies.

Water supply sources' capabilities have been assessed for many urban centres across Queensland and the timing of required augmentations identified. Improvement to the timeliness of augmentations through longer range forecasting is considered possible through further evaluation of the mechanisms that drive the El Niño Southern Oscillation which may include the Siberian High.

## Acknowledgements

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