RELATIONSHIP OF RECENT CLIMATE VARIATION AND WATER TABLES TO STREAM SALINITY TRENDS IN NORTHERN AUSTRALIA.

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Abstract: Assessment of large databases of stream and groundwater measurements show that regional patterns have been observed in water tables over wide areas of Queensland, despite widely differing rainfall and landuse practices. Typically, groundwater levels were falling in the mid to late 1960s, but then rose sharply until the late 1970s. Levels then declined until the mid 1980s, when a brief recovery was followed by a further decline that continued until the late 1990s. This pattern of groundwater level trend is particularly pronounced in central to northern areas of the state, but similar patterns are observed in other parts of Australia, including the Northern Territory.

The impact of climate on groundwater levels was investigated through a representative time series. This was constructed from the annual averages of monthly medians, in a historical data collection containing about 500,000 individual water level records from over 30,000 bores. Similar time series were produced to represent median streamflow and salinity. These time series were then compared with climatic indices, using multiple regression.

The water table time series proved to have a strong correlation with the rate of change of the Interdecadal Pacific Oscillation (IPO). Streamflows were more affected by the SOI, with stream salinity being affected by both. The observed patterns in all three time series can be explained through decadal scale balances between surface flow and baseflow.

Specific studies were then carried out on hydrographic and salinity records of bores and streams in northern Queensland, based on the same climatic indicators. These studies indicated that there is a strong and measurable climatic signal in the water tables. This can be differentiated from other effects, of which landuse is probably the greatest. The implications for stream salinity are also discussed.

Key Words: climatic effects, groundwater monitoring, groundwater recharge/water budget, groundwater statistics, groundwater/surface-water relations, hydrochemistry, salinization, solute transport, statistical modelling, Australia.

INTRODUCTION

Salinisation of streams, as well as of the wider landscape, is seen as a major water quality issue in Australia. It is recognised that all forms of such salinisation are affected by rises in groundwater levels, and that these are strongly influenced by landuse such as tree clearing and irrigation. However, the range of natural variation due to decadal scale climatic fluctuations is not clearly understood. If this is significant, then the effects of landuse, or attempts at remediation, could be difficult to define. Although it is widely apparent that unconfined groundwater levels are influenced by medium term climatic fluctuations, little work has been done on measuring these effects, and extracting the signal to better define the landuse trends. This is an exploratory study, to establish whether there is a generalised climatic component discernible in Queensland groundwater levels. If this is the case, then it should be possible to develop a regional relationship between water levels and a suitable climatic indicator, which in turn, could be used to extract the true landuse component.

Broadscale Climatic Indicators

The relationship between precipitation and climate is well established in Queensland, and a number of authors including McBride and Nicholls (1983), Ropelewski and Halpert (1987, 1989), and Chiew et al (1998) have emphasised the importance of the El Nino/Southern Oscillation phenomenon (ENSO), particularly in the north eastern part of the state. ENSO can be characterised by indices based on variations in either sea-surface temperatures (SST) or differences in barometric pressures such as the SOI. The Wright SST anomaly (Wright 1984, 1989) is defined as the SST over the equatorial Pacific Ocean west of Central America. ENSO is the strongest naturally occurring climatic signal (Enfield and Mestas-Nufiez 2000, Philander 1990), but there are other, longer term modes of variability on decadal time scales that are controlled by SST anomaly patterns. These have been detected by complex empirical orthogonal functions (CEOF) (Trenberth and Hurrel 1994, Rowell and Zweirs 1999, Zhang et al 1997). CEOF is a statistical technique used to detect structure revealed by very slow decay of percent variance in noisy data. The most significant climatic signals which have been identified to date by CEOF analysis of global SST data are a secular trend representing global warming (IPCC 1996) and the Inter-decadal Pacific Oscillation (IPO) (Power et al 1999, Latif and Barnett 1996).

The impact of climate on groundwater involves more factors than just precipitation. There is the added effect of evapotranspiration, as well as delayed response times in the rainfall runoff processes owing to soil and groundwater storage (Chiew et al 1998). This complexity requires either (a) the use of a suite of climatic indicators to match the groundwater signal, including selective rainfall and evapotranspiration criteria, or (b) a general indicator, applicable throughout northern Australia, with a demonstrated relationship to groundwater level behaviour.

Evidence of a Climatic Factor in Queensland Stream Salinity Trends

The influence of climate variation on Queensland stream salinity was first indicated during a previous study (QDPI 1994), in which conductivity trends were calculated for around 500 gauging stations with records covering a twenty year period. These trends were expected to follow styles of catchment management, but instead, they showed a regional pattern over extensive areas of Queensland, despite widely differing rainfall and landuse practices. It was considered that this pattern was at least partly related to hydrological regimes. A typical example of the pattern is apparent in the salinity and flow records of Baffle Creek near Bundaberg, as shown on Figure 1; the interpretation of the trends is as follows.

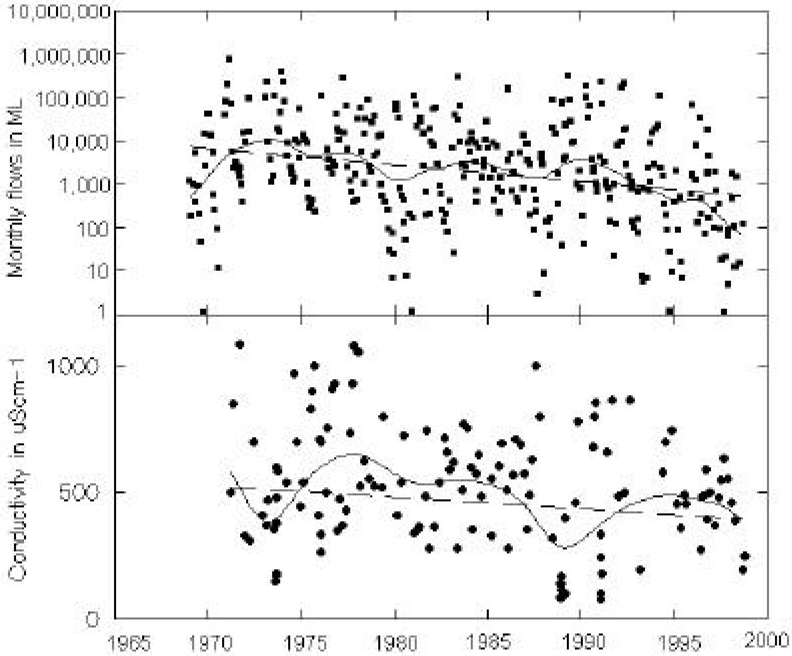

Figure 1 Monthly stream flows and randomly sampled conductivity measurements at Gauging Station 134000 on Baffle Creek on the central coast of Queensland over a 30 year period. Smoothed lines are lowess curves.

The late 1960s were generally dry, and the low levels of streamflow were dominated by concentrated surface water. This, however, was still less saline than baseflow, which has had prolonged exposure to weathering minerals and desiccated salts in the soil profile. Heavy flows in the early 1970s resulted in dilute surface runoff, causing a sharp decline in stream salinity. The prolonged wet conditions recharged the alluvial aquifers, so that when conditions became drier, prolific baseflow increasingly replaced surface runoff at low flows, causing a rise in salinity trends. However, as the dry period continued into the 1980s, baseflow was lost and surface water again prevailed at low flows, reversing the salinity trend. This pattern was repeated from the mid 1980s to late 1990s, and could be expected to continue into the mid 1990s, with rising salinity trends as the seasons become drier. Unfortunately, there do not appear to be any bores in the with substantial water level records in the immediate vicinity of this site, so the baseflow component of these cycles cannot be verified.

Nature of General Climatic Groundwater Level Trend

This theme has been further developed in another study (McNeil and Cox in prep) in which the impact of climate on stream flow, stream salinity, and groundwater levels is investigated through representative time series. The series for groundwater was constructed from the annual averages of monthly medians, in a historical data collection containing about 500,000 individual water level records from over 30,000 bores.

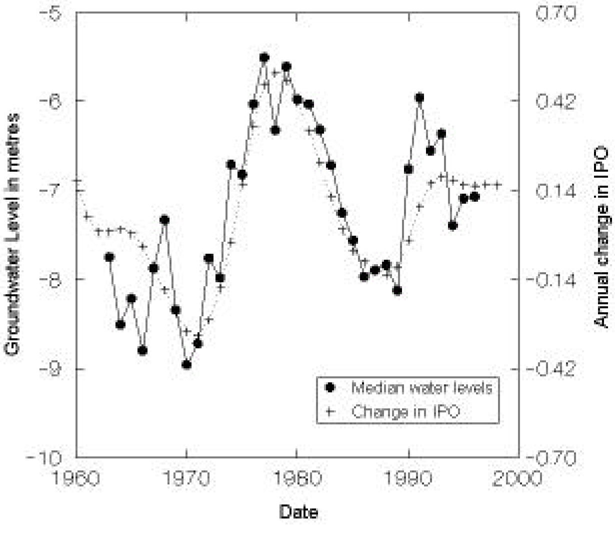

Figure 2 Time series of median water levels for Queensland, compared with the rate of change of the IPO

These time series were then compared with climatic indices, using multiple regression. The water table time series proved to have a strong correlation with the rate of change of the IPO, as shown in Figure 2. Streamflows were more affected by the SOI, with stream salinity being affected by both. Typically, groundwater levels were falling in the mid to late 1960s and the early 1970s, and rose sharply until the late 1970s. Levels then declined until the mid 1980s, with a brief, sharp recovery which was followed by a further decline that continued until the late 1990s. These groundwater level trends are particularly pronounced in central to northern areas of the state; however, similar patterns are observed in other parts of Australia, including the Northern Territory (Jolly and Chin 1991).

In this current investigation, the effect of climatic on groundwater levels is further examined, through an automated statistical process, which compares the hydrographic records of all suitable bores in the groundwater database with a simple, general climatic indicator.

DATA AND METHODS

Databases

This study was carried out using the hydrological and chemical databases held by the Queensland Department of Natural Resources and Mines (NRM). They contain records of stream flows, which have been gauged throughout the state at 777 sites, with a reasonable coverage since 1920. There are also around 60,000 analyses of surface water chemistry, collected from the same gauging station network since about 1962, usually four times a year. The groundwater database contains about 800,000 individual water level records from over 50,000 bores, most of which were only sampled once or twice, usually when first drilled. These data are accompanied by around 70,000 chemical analyses.

Methodology

Most bores are located in irrigation areas, where they are subject to several landuse-related impacts. Other records represent artesian or other deep groundwaters unlikely to be influenced by current surface conditions. It was clear that any climatic effect would be masked or diminished in most of these latter bores. The approach was therefore designed to determine whether there is a discernible association between water level and a decadal scale climatic indicator, in a significant component of Queensland groundwater. As this had to be carried out by processing a very large, irregular, historical data collection, it was essential to use an automated methodology. This methodology was compiled using computer procedures written in SYSTAT 5.1 BASIC language.

The initial step was to select all bore records with a reasonably long and regular time series of water levels. This selection was achieved by scanning the water level database, and classifying each bore in terms of length of record, beginning and end of record, total number of readings, and longest data gap. Bores which satisfied four of the following five criteria were used in the study.

- at least 20 water level observations
- first observation was made in 1970 or earlier
- last observation was no earlier than 1995
- total record covered at least 10 years
- maximum data gap was no longer than 5 years.

The above approach produced a list of 5,680 bores with reasonably long and continuous records. Multiple pipes were treated as separate bores.

The climatic indicator used was the change in the IPO between January 1st of the nominated year, and January 1st of the following year. This simple function was considered sufficient for a broad scale assessment on the basis of the previous study (McNeil and Cox in prep). The variation, as demonstrated in Figure 2, was sufficiently smooth that seasonality was not a significant factor. An automated procedure was also used to calculate the Pearson correlation coefficient between the water levels readings and the annual values of the climatic indicator for each selected bores.

The number of bores involved precluded graphical inspection of the results, so that distortion of the correlations through outliers or artifacts of the data distributions remained a possibility. This was evaluated by repeating the correlation procedure, after randomly scattering the water levels for each bore in relation to the climatic indicator, a technique adapted from those discussed by Manly (1996). The resulting distributions of correlation coefficients for actual and randomized data were then compared. The percentiles for each distribution were also calculated to indicate the proportion of bores with a demonstrable association with the climatic indicator. Individual locations were plotted on GIS, to reflect regional patterns in the influence of this climatic indicator over the period of record. A selection of records of well-correlated bores from a variety of locations was also graphically displayed.

RESULTS

The distribution of correlation coefficients for actual water levels and the climatic indicator are shown on Figure 3a, and the distribution for the randomized data are shown on Figure 3b. Table 1 lists statistics for both distributions, which are close to normal in each case. The coefficients of the actual data have a mean of 0.08, median of 0.09, and standard deviation of 0.34, which suggests a slight positive association with the climatic indicator of just under 10% in the average extensively measured bore. Additionally, 30% bores show a correlation of at least 0.3, and more than 10% are over 0.5 correlated. The spatial distribution of the most highly correlated bores are illustrated on Figure 4, and Figure 5 illustrates some examples of correlated water level records from various parts of the state.

Table 1. Statistical Ranges of Correlation between Actual and Randomised Water Levels with the Climatic Indicators

Correlations of climatic indicator with:	Mean	Median	Standard Deviation	40th Percentile	50th Percentile	75th Percentile	90th Percentile
Actual data	0.082	0.085	0.376	0.001	0.085	0.344	0.575
Randomised data	0.002	0.000	0.113	-0.025	0.000	0.070	0.170

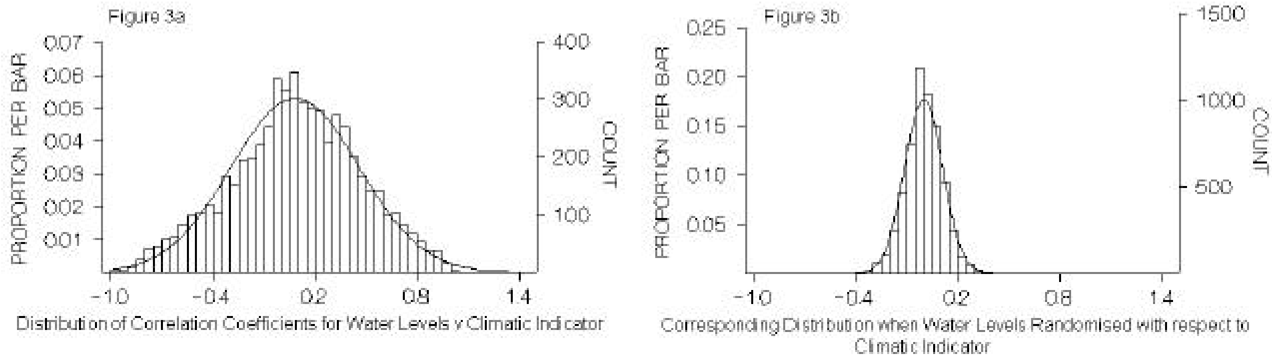

Figure 3 Distribution of correlations of climatic indicator with actual water levels (3a) and randomised water levels (3b).

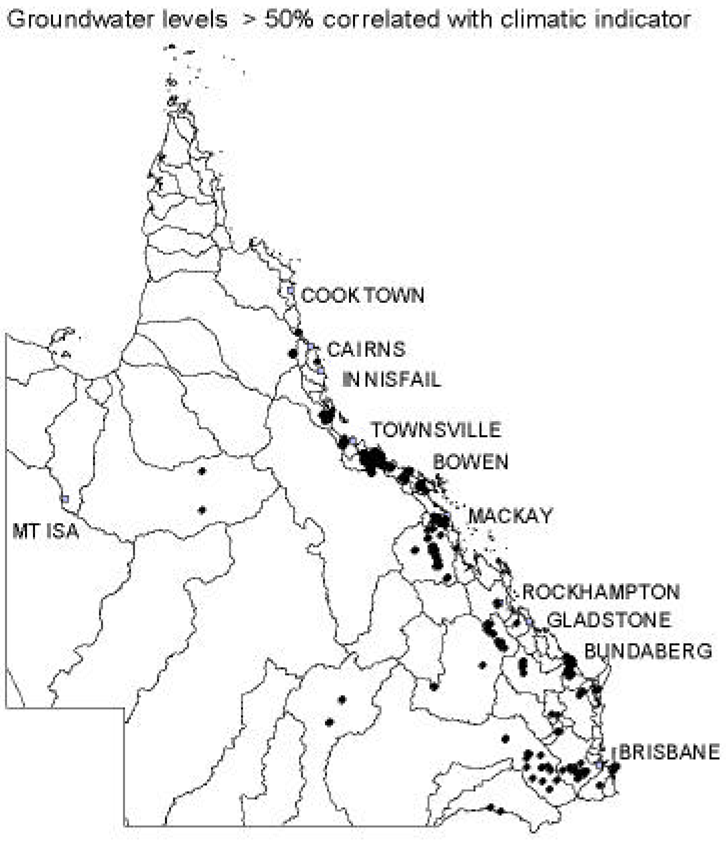

Figure 4 Locations of bores where the correlations of water level with the climatic indicator exceeds 0.5

DISCUSSION

The rate of change of the IPO is a crude and general climatic indicator, but results of the correlation procedures demonstrated here, are sufficient to indicate that there is a consistent, medium term, climatic signal evident in many bores over wide areas of Queensland (Figure 4). It is clear from Figure 3, that the distributions of correlation coefficients are very different between actual water level time series data, and randomised data. The time series distribution for the actual data is broader, with a slightly positive mean, and a much wider variability. The random distribution, on the other hand, has a virtually zero mean, and narrow variability, as one would expect from a randomised data set. This difference shows that the climatic signal in the groundwater record is significantly non-random, and that a percentage of bores show a strong relationship between the water levels and the indicator. It is strongest in the northern and central parts of the state (Figure 5), and appears to be moving out of phase in more southerly regions.

It is acknowledged that the demonstrated climatic trend in unconfined aquifers is dominated by the very intense rise that occurred in the early 1970s, and this may be overwhelming some of the time series. The inevitable autocorrelation present in such time series also creates difficulties in analysing the true values of the trends. However, the relationship between climatic fluctuations and median groundwater levels shown in Figure 2 over a period of more than 30 years, clearly indicates that it would be possible to develop a method of extracting the climate signal from other types of variability such as landuse, if these problems in interpretation were further evaluated. Several indicators would probably be required to cover the whole state, as well as elsewhere in Australia, to allow for the changes in climatic influences.

In summary, this broadscale study demonstrates that the climatic signal is detectable in water table variations, and numerical estimation should be possible, however, it does not provide sufficient information to implement this out without further investigation at a more local level. Such information will be required for current catchment management issues such as the National Action Plan for Salinity and Water Quality (NAP), as this intends that the community set targets for the improvement of stream salinity (AFFA 2001). If realistic targets are to be set, it is essential to be aware of the natural trends, over which the effects of clearing or reafforestation will be superimposed. It would also be desirable if the impacts of landuse could be assessed if they do coincide with natural climatic extremes.

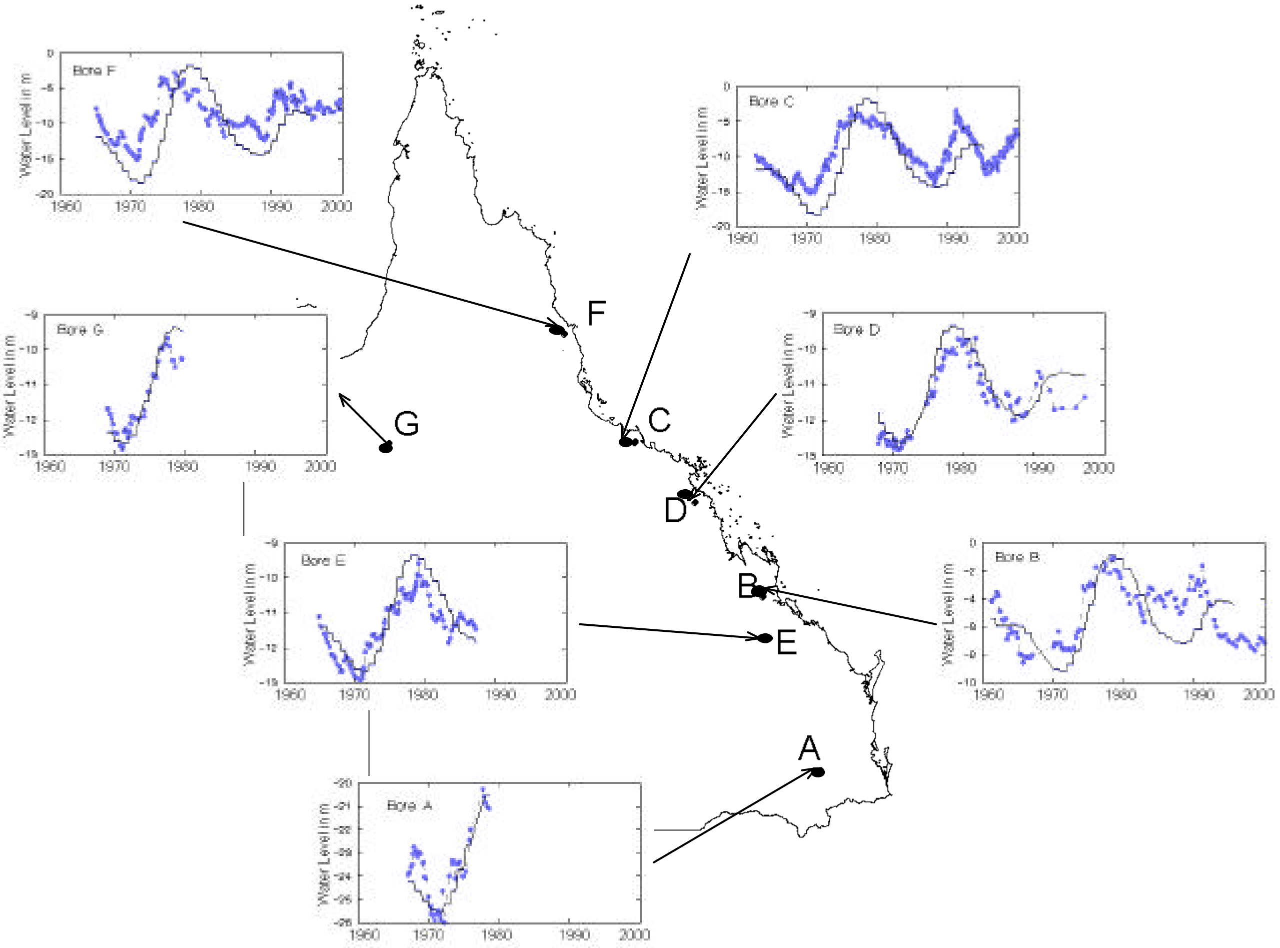

Figure 5 Some examples of Queensland bores where water levels are well correlated with the climatic indicator. The scaled indicator signal (solid line) displayed against the water level records is stepped, because only annual values are calculated.

CONCLUSION

This preliminary study indicates that there is a strong and measurable climatic signal in water table variations for many areas of unconfined aquifers in Queensland, and this can probably be extrapolated to other areas of northern Australia. The majority of bores measured are within irrigated agricultural areas, and extract from aquifers formed of unconsolidated sediments, although many bores also intersect underlying bedrock. These observations enable development of a conceptual model for the natural baseflow-related salinity trends in streams, which have been widely observed in Queensland. Further investigation of available data would enable specific models to be developed to differentiate these trends from the effects of landuse. The actual climatic indicators which would be used are likely to vary for different regions (e.g. rainfall, temperature, evapotranspiration, ENSO, or some combinations), but the observed patterns are sufficiently widespread to suggest that relatively few of the indicators would need to be modelled in detail for specific regions.

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