Submission to:

The Institution of Engineers, Australia National Salinity Prize

Salinity Management at Toolibin Lake, Western Australia
Innovative and Practical Engineering Systems

Submitted by: **K J Wallace, Chair**[1]

On behalf of: **Toolibin Lake Recovery Team and Toolibin Lake Technical Advisory Group**

[1]Department of Conservation and Land Management
P O Box 100
NARROGIN WA 6312
Tel: 08 9881 9222 Fax: 08 9881 9327
Email: kenw@calm.wa.gov.au

SUMMARY

Dryland salinity has already claimed 8% of the Toolibin Lake Catchment and severely threatens a wetland recognised internationally for its conservation importance. The entire lake complex and much of the associated nature reserves are at risk. Approximately 24% of the lake's catchment – mostly agricultural land – is also at risk. Severe degradation has already overcome some 1.8 million hectares of farmland and all similar lakes in the Western Australian wheatbelt.

An integrated system of recharge and discharge control is essential to protect assets threatened by salinity in the longer term. At Toolibin and within its catchment a range of activities including:

1. Actions in the catchment to reduce recharge – including remnant vegetation protection and revegetation. These programs include using commercially prospective species and trialing alley designs;
2. Changes in agronomic practice, such as contour farming and increasing use of perennial grasses for grazing;
3. Surface water management in the catchment to reduce waterlogging of agricultural lands;
4. Surface water management to decrease the salinity of water entering the lake (diversion), and to decrease salt loading of the lake (outlet control); and
5. Groundwater pumping to lower the water table beneath the lake.

Progress to date has relied on collaborative work between agencies, landholders and other private enterprise groups and non-government organisations. Future work, and the future of Toolibin Lake, will continue to depend on the effective collaborative efforts of these groups and individuals.

In this application, we focus on the engineering systems covered under items (4) and (5). While integrated recharge and discharge systems are essential for the long term recovery of Toolibin Lake and many other important community assets, groundwater and surface water management systems are often vital to protect high value areas from salinity in the short term.

Innovative surface water management and groundwater pumping systems have been installed at Toolibin Lake and modeling forecasts undertaken to predict the likely impacts. Results to date suggest that the surface water management system has been successful in diverting over 4000 tonnes of salt and that the groundwater pumping system will be able to lower watertables under the lake floor. There are already some positive effects on conservation values from both engineering actions.

The fate of the lake is dependent on the groundwater pumping system working to plan and the continued, improved management of surface flows from the catchment.

An additional, important aspect of the research and development work at Toolibin is that it is providing important information for the management of salinity elsewhere in agricultural lands facing similar problems with salinity.

TOOLIBIN LAKE – AN OVERVIEW

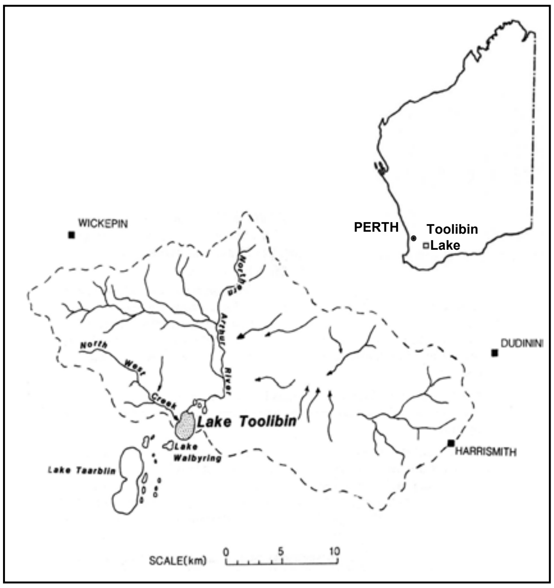


Figure 1. Location of Toolibin Lake.

Toolibin Lake (300 ha, Figure 1), located at the headwaters of the Blackwood River, is a seasonal wetland and lies east of Narrogin in the Western Australian wheatbelt. It is a Ramsar listed Wetland of International Importance under the control of the Conservation Commission of Western Australia and managed by the Department of Conservation and Land Management. Annual rainfall in the catchment is 400 mm, with Class-A pan evaporation of 1900 mm. Approximately 95% of the Toolibin catchment (47,000 ha) has been cleared of deep-rooted perennial native vegetation within the last 100 years.

The conservation values of the lake relate to its comparatively good water quality and the persistence of sheoaks (*Casuarina obesa*) and paperbarks (mainly *Melaleuca strobophylla*) across parts of the lake floor. When flooded, this habitat supports a high diversity of waterbirds, many of which breed on the lake. Toolibin is now the largest remaining area representing a habitat that has now almost completely disappeared due to salinity and other changes resulting from clearing of bushland for agriculture.

Secondary salinity - from both increasingly saline surface water inflows and rising hypersaline groundwater - poses a serious threat to the biodiversity values of the lake and catchment, and to the agricultural values of the catchment. Dryland salinity has already claimed 8% of the Toolibin Lake Catchment. About 24% of the catchment is at risk in the longer term. While significant parts of the vegetation on the lake floor are degraded, current water quality together with surviving areas of living vegetation allow the lake to retain much of its nature conservation values.

In 1996 the State government affirmed Toolibin Lake's importance for nature conservation by including it among the first three natural diversity recovery catchments where protection of natural values is a key community goal. These catchments are also an important vehicle for testing and developing generic technologies for tackling salinity.

Toolibin Lake has the longest history of management intervention among the existing natural diversity recovery catchments. The five principal goals of management listed in the Toolibin Lake recovery plan (Toolibin Lake Recovery Team and Toolibin Lake Technical Advisory Group, 1994) are:

- To conserve Toolibin Lake and its associated wildlife as a freshwater habitat.
- To improve land use decision making and practice within the Toolibin Catchment so that land management:
  - is sustainable, productive and profitable in the long term (over 100 years);
  - reduces the current area of degraded land;
  - favours conservation of local wildlife.
- To demonstrate that, within a large catchment, it is possible to stabilise hydrological trends which if unchecked threaten land, water and biodiversity resources.
- To demonstrate to other land managers in Australia methods of protecting their biodiversity, land, and water resources.
- To develop mechanisms which lead to community ownership of Western Australia's natural resources including management problems and their solution.

Actions to recover the values of the lake and catchment include:

6. Actions in the catchment to reduce recharge – including remnant vegetation protection and revegetation;
7. Changes in agronomic practice, such as contour farming and increasing use of perennial grasses for grazing;
8. Surface water management in the catchment to reduce waterlogging of agricultural lands;
9. Surface water management to decrease the salinity of water entering the lake (diversion), and to decrease salt loading of the lake (outlet control);
10. Groundwater pumping to lower the water table beneath the lake.

Work at the lake and in its catchment has been undertaken through the combined efforts of many organisations including local landholders. Several State agencies have collaborated for more than 25 years to develop an understanding of the lake, and to develop and implement actions to recover the lake in partnerships with local landholders and other private enterprise groups.

Work in the lake's catchment is largely planned through the Lake Toolibin Catchment Group which is led by local landholders. Work to recover the lake is focused through the Toolibin Lake Recovery Team which is advised by the Toolibin Lake Technical Advisory Group. The Catchment Group and Recovery Team have inter-locking memberships, a structure that has been effective.

This application addresses the engineering of items (4) and (5).

ENGINEERING TO MANAGE SURFACE INFLOWS

Salinity Problem and Action Taken

The Toolibin catchment, gauged from 1978 to the present, has a highly variable flow and salt load (Figure 2). Two major runoff events (1983 and 1990) skew the data. In June/July 1983 and January 1990, the maximum monthly flow exceeded 2000 ML. The average monthly flow is 121ML. The average catchment salt load measured at the gauging station immediately above the lake is estimated to be 111 tonnes/month, with a flow weighted mean concentration of 3200 mg/L.

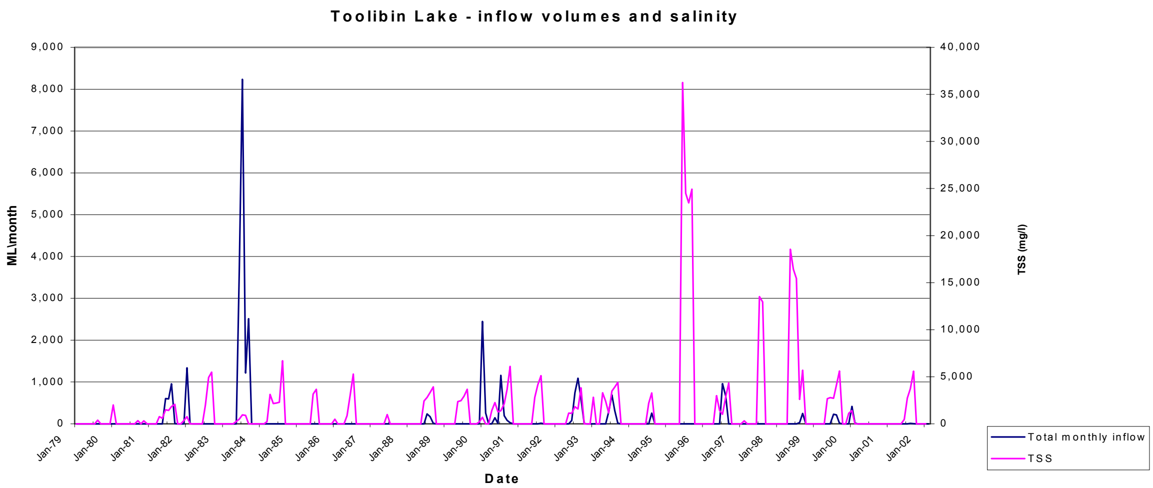


Figure 2: Monthly total inflow and salinity, the relatively lower inflow corresponds to high salinity; inflow data highlights the variability of monthly surface water inflow in to the Toolibin Lake.

The flow and salt load data suggest that low volume inflows - that is, those <1000ML/month - have relatively higher salinity (> 1000 mg/L). The results also highlight the significant contribution of low volume, saline water inflow to the salt balance of the lake, a problem that will continue to worsen before the catchment salt outputs stabilise. This increasing salt load is contributing to the degradation of Toolibin Lake and its environmental values.

A priority under the Toolibin Lake Recovery Plan, therefore, was to divert low volume, highly saline inflows around the lake. To achieve this, a separator gate was constructed (photographs 1 and 2) over the inflow to the lake so that low volume, high salinity flows can be diverted around the lake and an associated wetland (Walbyring Lake) to a highly salt affected lake downstream. Since the installation of the separator and diversion channel in 1995 about 4000 tonnes of salt have been prevented from entering the lake and contributing to its salt load. Due to difficulties associated with design and cost, the diversion channel was constructed within the lake along its western boundary (photograph 1). This design allowed saline and freshwater flows to be captured and manipulated to improve management of lake water. The total length of the diversion channel is some seven kilometres.

Photograph 1: separator gate

Photograph 2: the inverted "V" shaped separator sits over the lake inflow entering from the bottom right side of the picture

An outflow regulation system has also been installed to allow lake water to be periodically discharged into the separator channel. This allows some control when the period of inundation is too long or additional lakebed leaching is required. Recent surface water modelling results (J. Davies, pers. comm.) suggest that the diversion channel and single outlet pipe will result in an 80% reduction in the increase of salt load in the lake. About 60% of this reduction is due to the diversion channel and 20% due to the outlet pipe. The 80% reduction in salt load would equate to a minimum 8000 tonne reduction over the 19-year modeling period (1979-1997) if both structures had been in operation.

Assessment Against the Criteria

While there has not been sufficient inflow to the lake to test the more recently constructed outflow control, the separator and diversion channel have proved very effective in allowing the diversion of low volume, high salinity flows on a number of occasions since construction. Since the construction of these structures there has been widespread seedling regeneration on the floor of the lake (for example, photograph 3), and this is undoubtedly at least partially related to the significantly decreased salt loads entering the lake.

Thus the engineering solution has made an important contribution to protecting an environmental value – the lake – that is of International significance.

A similar structure is under consideration for at least two other wetlands (Lake Mears and Lake Bryde), demonstrating that the concept is more broadly applicable.

Photograph 3: seedlings of Melaleuca strobophylla on the lake floor.

ENGINEERING TO MANAGE HYPERSALINE GROUNDWATER

Salinity Problem and Action Taken

The separator and diversion channel has made an important contribution to slowing the decline of vegetation and water quality within Toolibin Lake. In the longer term, however, the impact of the groundwater level rise is at least as important as the influx of saline surface water in degrading the lake's ecological system. Groundwater levels are rising due to increased recharge that was brought about by landuse change. To maintain or lower current groundwater levels, recharge rates must be reduced or groundwater discharge rates increased, or both must occur. In areas where salinity threatens public assets such as water resources, infrastructure or important ecological systems such as wetlands, the management of recharge by alternative farming systems or revegetation, while essential in the longer term as part of the total salinity package, may take too long to protect valley floor assets in the short term. Therefore, a short-term solution in such areas is to enhance groundwater discharge (for example, installation of production bores).

Investigations of salinity at Toolibin Lake began with the establishment of the Northern Arthur River Wetlands Rehabilitation Committee in 1977. The scope of this study was to highlight the adverse impact of the increasing salinity on the lake ecosystem. A hydrogeological investigation was initiated to better understand aquifer hydraulics, properties, and the groundwater dynamics under the lake (Martin, 1982, 1987, 1990). However, these investigations focused only on a small area on the western shoreline and the conceptual model developed was unable to describe the multi-aquifer system occurring under Toolibin Lake.

The groundwater beneath Toolibin Lake is within 1-1.5m of the soil surface and has salinities in excess of 30,000 mg/L (Martin 1987, 1990). Martin considered that the lake had developed on a thin bed of fine textured sediments (<2-3m) overlaying 40-50 m of deeply weathered Archaean bedrock. Groundwaters were noted within a moderately permeable saprolite aquifer (near the basement) and confined by the low permeability 'pallid' clays of the deeply weathered rocks. The study also revealed the existence of dolerite dykes within the weathered zone that produce little or no groundwater (Martin, 1987, 1990). More recent hydrological studies within the Toolibin catchment (George and Bennett, 1995; De Silva, 1999; Dogramaci, 1999), and within the nearby Yilgarn Craton (Waterhouse et al, 1994; Salama, 1997), have provided regional and catchment-based data upon which to revise the initial model (Martin, 1990). Airborne magnetic, electromagnetic and radiometric analyses of the catchment (George, 1998; Fugro, 2000) have also made important contributions to understanding the hydrogeology of the catchment and lake.

In March 1997 eight production bores (Photograph 4) were established along a major lineament that runs approximately north-south through the lake bed near and parallel to the western boundary of the lake. This production field produces up to 230 kilolitres per day and has resulted in draw down of groundwater close to all pumps. In at least one case draw down appears to be having an impact over 180 metres lateral distance from the production bore (see attachment).

Photograph 4. *An air displacement pump on the floor of Toolibin Lake.*

The data acquired from the recent investigations form the basis for a new hydrogeological model for the Toolibin Lake (Figure 3). East of the palaeochannel and within Toolibin Lake, the upper 8-10 m comprises lacustrine sediments overlain by 6-8 m high lunettes on the lake's rim. The lunettes overlie ~20 m of intensely weathered basement rocks and below that, ~10 m of saprock. The aquifer is confined in this area, although a perched system exists within the lunettes. Shallow sediments comprising alluvio-lacustrine materials of approximately 10 m thickness covers the western half of the lake. These materials produce small volumes < 10 kL/d of groundwater from ferricretes and minor sands and appear to be distributed in the northwest segment of the lake. Below these sediments lie the weathered and saprock profiles. Recorded depths of weathering exceed 56 m, except near mafic dykes where weathering is shallower (34 m). The aquifer in this area is unconfined.

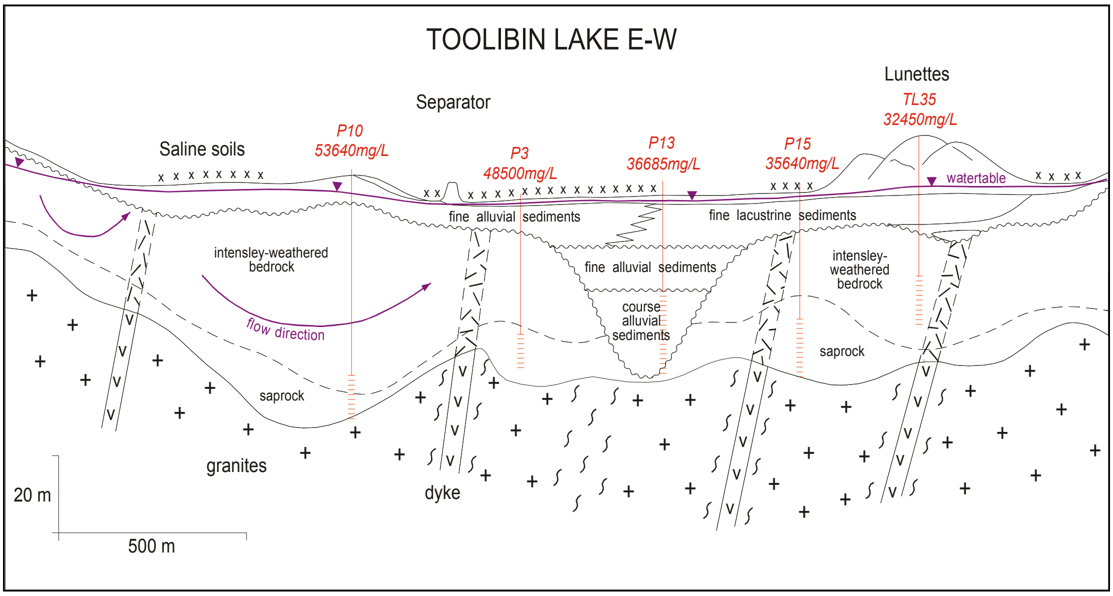


Figure 3: East west Toolibin Lake cross section showing the hydrogeology of the palaeochannel within the lake.

The palaeochannel is overlain by relatively low permeability, swelling lacustrine clay. It has a thickness of ~ 10 m. Below this material lies a further 5-10 m of alluvial and interbedded finer-grained sediments. These in turn overly 10-20 m of fine sands that define the basal palaeochannel, containing lignitic materials. No large gravels were recorded. The palaeochannel bores have a maximum thickness of 34 m (+/- 3 m). The bedrock underlying the palaeochannel is elevated by comparison with basement beneath the surrounding weathered zones. The palaeochannel is considered to be semi-confined to locally confined. Piezometric heads in the palaeochannel (eg P11 40 m deep) remain near ground surface, while in shallow observation bores (6 m deep) water levels are 1-2 m below lake level. The palaeochannel is likely to be recharged by lateral flow, perhaps directly in eastern and northern areas, and after inundation.

Twenty-four to seventy-two hour pumping tests were undertaken on 5 pumping bores to determine aquifer parameters for hydraulic conductivity, transmissivity and storage coefficient. The transmissivity ranged from 19.6 m^2/d for the palaeochannel aquifer to 1.2 m^2/d for the weathered granite aquifer. The hydraulic conductivities range from 1.03 m/d for the palaeochannel to 0.02 for the intensely weathered aquifer encountered in bore P14. A MODFLOW groundwater model was developed using the hydraulic properties from the pumping tests to evaluate various pumping scenarios, and their impact on groundwater level beneath the lake (SKM, 2000). The model was calibrated against seven years of monitoring records.

Eight scenarios, presented in terms of percentage of the Lake area with a watertable < 2 m (the depth below which groundwater impacts on plants are generally significantly reduced), were used to test the sensitivity of the model. As expected the results suggest that the model is sensitive to variations in hydraulic conductivity. Increasing the hydraulic conductivity (Kx, Ky) reduces the impact to 40% of the lake, while reducing it increases the protected area to 90%. Changing the vertical hydraulic conductivity results in the protected area changing from 67 to 88%. Increasing and decreasing hydraulic conductivities to the east of the lake (lunettes) does not significantly change the predicted zone of impact (82-83%). Neither does reducing the connectivity of the palaeochannel and saprolite aquifers (83%) or reducing the hydraulic conductivity (Kx, Ky) of the dykes that exist in the weathered zones (83%).

The results of the modelling of various pumping scenarios are as follows:

- *No pumping*: Lake groundwaters remain within 2 m of the surface and lake discharges saline groundwater.
- *Continuous pumping from original bore field plus from the palaeochannel*: Pumping at rates of approximately 1000 kL/d for 4000 days results in drawdown ~ 2 m across 82% of the lake floor. At these rates, watertables are lowered by 1m over the entire lake– within three years (Figure 4).
- *Non-Continuous pumping from original bore field plus from the palaeochannel* (pumps off when lake full): Results are similar to Case 2, except that there is a lagged recovery.
- *Water level recession*: This scenario looked at the frequency of filling and found that a drawdown of greater than 2 m would be sustained over 82% of the lake with the current filling regime.

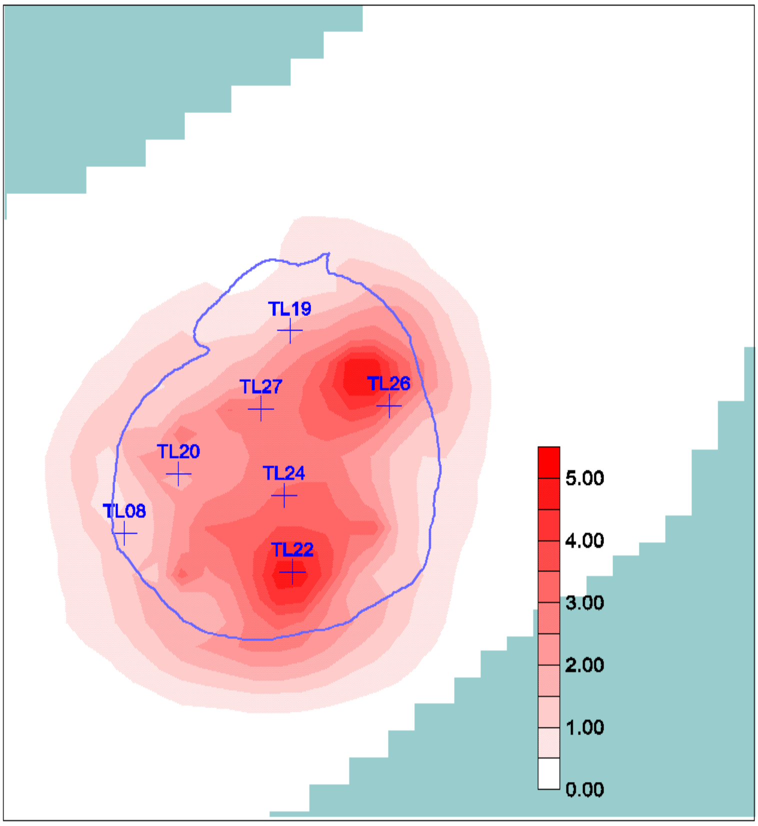


Figure 4. The predicted impact of groundwater pumping across Toolibin Lake. TL represents deep and shallow observation bores. The scale shows depth of groundwater beneath the Lake bed in metres. The lake width is approximately 2 km east to west (from SKM, 2000). Two production bores have been established on the palaeochannel in the centre of the red zones.

Thus it was determined that three production bores extracting water from the palaeochannel would significantly improve protection of the lake floor vegetation and other conservation values. In July 2001 a production borefield began operation based on the palaeochannel.

Assessment Against the Criteria

The groundwater pumping is directed at managing a current salinity problem that will, if unmanaged, effectively destroy many of the conservation values of Toolibin Lake.

From the Attachment it can be seen that, for the pump shown, the initial borefield is having a significant impact on groundwaters within their sphere of influence. This impact has been expressed near two of the bores (pumps 9 and 10) in regeneration of older trees that were significantly in decline. Also, an electromagnetic survey of the lake floor in May 1998 showed a circular pattern around the site of an experimental production bore (replaced with a full production bore in March 1997). This circular pattern, not present elsewhere on the lake floor, showed reduced salinity around the experimental production bore, consistent with pumping positively affecting groundwater.

Groundwater pumping is being widely considered, and in some cases applied, to protect assets threatened by salinity. This is particularly so in the case of the protection of infrastructure in wheatbelt towns, many of which are situated on poorly transmissive soils such as those at Toolibin. Thus the research and development, including survey, interpretation, modeling and results from application, are all of relevance to many other situations where conservation and infrastructure assets are at risk. Information is also made available to farmers and others interested in pursuing similar actions.

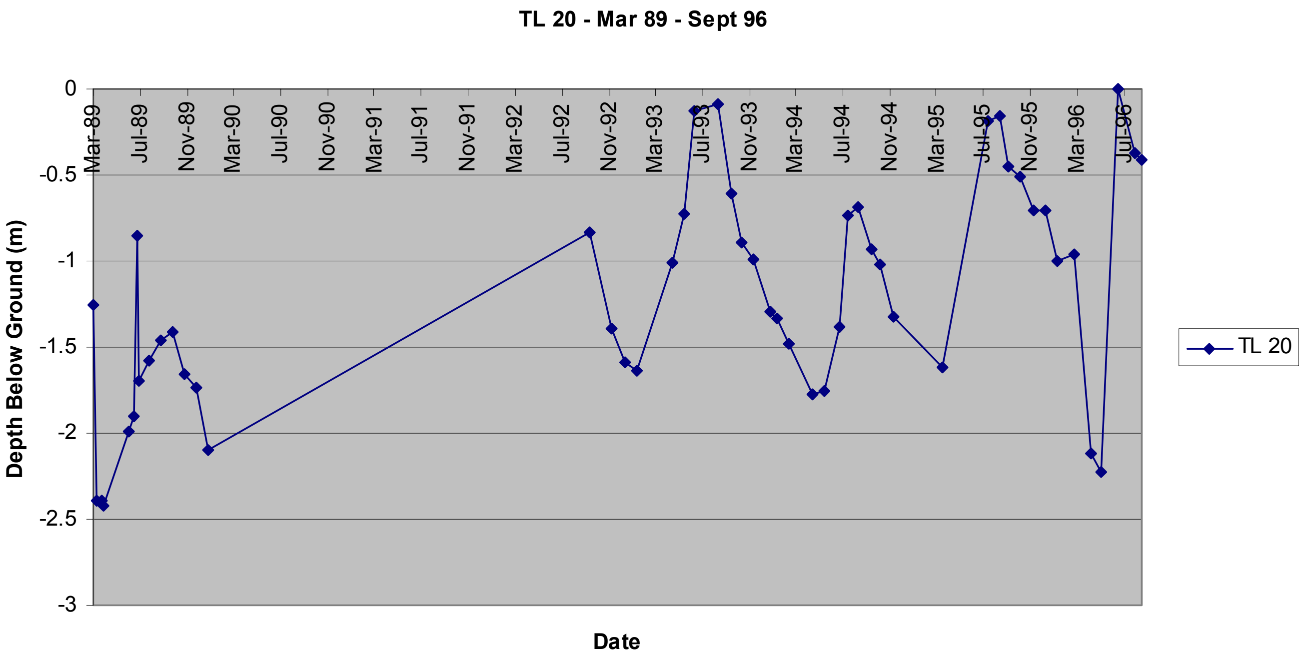
It should be noted that the above work has also been assessed in terms of environmental impacts downstream (Actis Environmental Services 2001), and these procedures are also more widely applicable in the wheatbelt.

REFERENCES

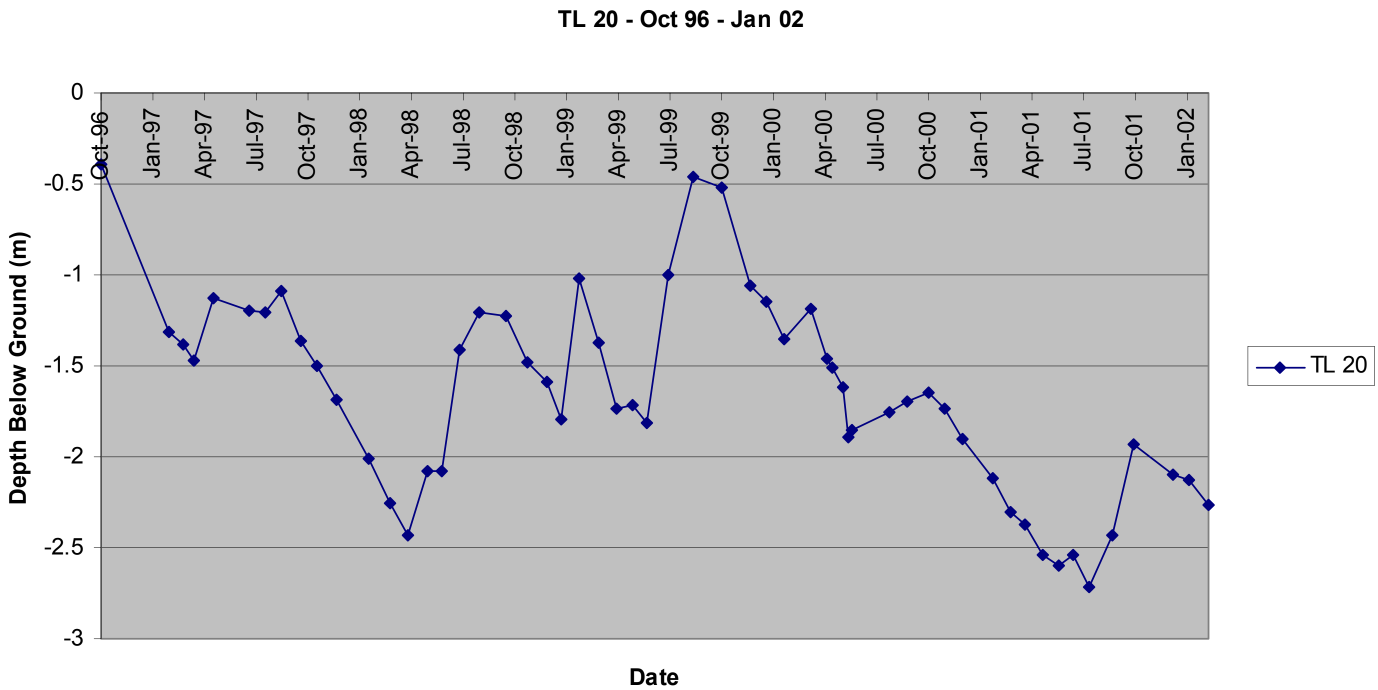
ACTIS ENVIRONMENTAL SERVICES. (2001). Evaluation of Saline Discharge to Taarblin Lake within the Context of Toolibin Lake Recovery Plan: Groundwater pumping and drainage proposals. Consultancy report prepared for the Department of Conservation and Land Management.
DE SILVA, J. (1999). Toolibin Catchment Airborne Geophysics Bore Completion Report. Water and Rivers Commission, Hydrogeological Report No. 126.
DOGRAMACI, S. (1999). Lake Toolibin Drilling Program- Bore Completion Report and Pumping Test Data. Water and Rivers Commission, Hydrogeological Report No. 139
GEORGE, G. AND BENNETT, D. (1995). Toolibin Groundwater Management Program, Drilling Results, Explanatory Notes and Drill logs, Catchment Hydrology Group, South-Western Rivers Region.
GEORGE, R. J. (1998). Evaluation of Airborne Geophysics for Catchment Management. (at www.ndsp.gov.au)
FUGRO AIRBORNE SURVEYS (2000). Toolibin Lake – Upgrading Catchment Interpretation. Department of Conservation and Land Management, Western Australia
MARTIN, M. W. (1987). Hydrogeology of Lake Toolibin, Western Australia Geological Survey, Hydrogeology Report 2797.
MARTIN, M. W. (1990). Salinity Control by Groundwater Pumping at Lake Toolibin, Western Australia, Geological Survey of Western Australia, Hydrogeology Report No. 1990/30.
MARTIN, M. W. (1982). Lake Toolibin: Control of Secondary Salinisation by Groundwater Dewatering, Geological Survey of Western Australia, Hydrogeology Report No 2427.
MCFARLANE, D.J., ENGEL, R., AND RYDER, A.T. (1987) The Location of Recharge Areas Responsible for Valley Salinity in the Toolibin Lake Catchment, Western Australia, In Groundwater Recharge Ed. (Sharma, M.L.), Proceedings of the Symposium on Groundwater Recharge, Mandurah, Western Australia, p. 255-267.
SINCLAIR KNIGHT MERZ PTY. LTD (2000). Groundwater Model of the Effects of Groundwater Pumping on Lake Toolibin, Conservation and Land Management, Western Australia.
GEORGE, R. J., CLARKE, C. J., HATTON, T., REGIANNI, P., HERBERT, A., RUPRECHT, J., BOWMAN, S., AND KEIGHERY, G. (1999). The Effect of Recharge Management on the Extent of Dryland Salinity, Flood Risk and Biodiversity, Western Australia: Preliminary Computer Modelling, Assessment and Financial, Analysis. Contract for the Sate Salinity Council. (Confidential: 22 pp).
SALAMA, R. B., FARRINGTON, P., BARTLE, G. A., AND WATSON, G. D. (1993). The Role of Geological Structure and Relict Channels in the Development of Dryland Salinity in the Wheatbelt of Western Australia. Australian Journal of Earth Science, 40, 45-56.
TOOLIBIN LAKE RECOVERY TEAM AND TOOLIBIN LAKE ADVISORY GROUP. (1994). Toolibin Lake Recovery Plan. Department of Conservation and Land Management, Western Australia.
WATERHOUSE, J. D., COMMANDER, D. P., PRANGLEY, C., AND BACKHOUSE, J. (1994). Geological Survey of Western Australia, Annual Review 1993/1994, p 82-85.

ATTACHMENT

PIEZOMETER READINGS OVER TWO PERIODS FROM ONE POINT 180 METRES FROM PUMP 9



Peizometer readings for the period 1989 to 1996.



Piezometer readings for the period 1996-2002. Note the declining trend compared with the previous rising trend. **<u>However</u>**, note that this data is not corrected for rainfall. The pumping system was switched on permanently in March 1997, coinciding with a relatively dry period.