Toolibin Groundwater Management Program

Drilling Results

Completion report to CALM,

June 1995[1]

Explanatory notes and drill logs

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[1] Tooldril.doc RJG 2 June, 1995

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Background

Current situation.

The vegetation and fresh waters contained in Toolibin lake and its associated reserves are an important habitat for waterbirds and local fauna. Its significance prompted the listing of the Lake Toolibin under the Ramsar Convention as a Wetland of International Importance. However as a result of increased groundwater levels and saline inflows from the Toolibin catchment, Casuarina (*C. obesa*) and paperbark (*M. strobophylla*) vegetation along and near the western shoreline are dying. A considerable amount have died within the decade and the remainder of the vegetation on the lake is expected to become severely effected over the next 10-20 years.

Why Toolibin lake has remained relatively intact to date and survived as the only significant fresh water wetland in the Arthur River chain, was a question that puzzled researchers and local residents.

To reclaim the degraded areas within the lake and its associated reserves and to protect them against the continuation of salinity, CALM and associated agencies (Department of Agriculture and Water Authority of WA) developed a Recovery Plan (CALM, 1995). The Plan has been developed as both a vehicle to drive the process of lake restoration and as a means of achieving integrated catchment management. The plan recognises that the long-term survival of the Toolibin Reserves relies on both the management of the lake and their catchment.

Key components of lake protection

To manage surface and groundwater salinities within the lake, the Recovery Plan recommended that a borefield be established to maintain watertables below the floor of the lake (Martin, 1990; CALM, 1995; section 3.2) and to manage the inflow of saline and fresher waters from the Toolibin catchment (CALM, 1995, section 3.3).

While revegetation within the catchment and earthworks surrounding the lake are key components of the catchments recovery plan, this study only reports on the groundwater management systems being developed within the Lake environment.

Previous groundwater studies

Previous groundwater investigations conducted at Toolibin Lake focused on a small area near the western shoreline (Martin, 1986, 1990). Only six deep bores (one multiport bore) have been constructed within the lake environment. Two of the bores are currently equipped with submersible pumps. These bores yield less than 20 kL/day. The remainder did not yield sufficient water to

[2] Tooldril.doc RJG 2 June, 1995

warrant development as production wells and were used to monitor the aquifers during testing programs (Martin, 1990).

Groundwaters beneath the floor of Toolibin lake were noted to be within 1-1.5m of the soil surface and have salinities in excess of 30,000 mg/L. Martin (1986, 1990) considered that the lake had developed on a thin bed of fine textured sediments (<2-3m) which overlay 40-50 m of deeply weathered Archaean rocks. Groundwaters were noted to be contained within a moderately permeability saprolite aquifer (near the basement) and confined by the low permeability 'pallid' clays of the deeply weathered rocks. Martin (1986, 1990) also noted the existence of dolerite dykes within the weathered zone. Drill holes located in these materials produced little or no groundwater (pumping yield) as a result of their low hydraulic conductivity.

No long-term monitoring of waterlevel patterns exists within the lake, however piezometers monitored over the past 15 years reveal a rising trend in the vicinity of the northern Reserves. What data exists within the lake suggests that there are no clearly identifiable long-term trends. Recent, 'on site' observations indicate that saline pools (>2000 mS/m) occur on the lake floor for a considerable length of time after the lake empties and that the death of vegetation has accelerated over the past few years. The pools on the floor of the lake and decaying vegetation, are the result of both groundwater discharge and evaporation of the lakes waters.

The hydrologic significance of the lake was summarised by Martin (1986, 1990). He considered that the lake acts as a discharge area in summer (evaporation from shallow aquifers) and recharge area in winter (surface water infiltrates through the floor). Martin (1986, 1990) reasoned that hydraulic conditions within the deeper aquifers beneath the lake must allow lateral flow to occur towards Taarblin Lake throughout the year.

General objectives of this program

The first objective of the current groundwater research and development program was to locate bores within aquifers beneath the floor of the lake which were able to be pumped. The second objective was then to lower the saline watertables beneath the western edge of the lake, to at least 1.5m (up to 3.0m) below the soils surface in spring, summer and autumn, within 3 years of turning on the pumps (1996-1999).

Aim:

To lower saline watertables to allow a freshwater 'buffer' to develop beneath the floor of lake Toolibin. The buffer zone should be thick enough to provide fresh water in the root-zone of the vegetation in winter and comprise waters with a low salinity (to be set by CALM) at the end of summer.

Description:

Stage 1 of the groundwater management plan comprises seven distinct phases.

Phase 1: Airborne magnetics survey of lake and immediate reserves,
Phase 2: Site selection and placement of drill targets on lake floor,
Phase 3: Complete up to 10 test wells and construct production bores at suitable sites,
Phase 4: Develop bores and conduct pumping tests to determine likely yields and salinities,
Phase 5: Analyse data and determine effectiveness of the bores by groundwater modelling.

Phase 6: Consider the effect of the Proposal on lake Taarblin and downstream catchments and develop a salt and water management plan (evaporation basins?).

Phase 7: Finally, when the consultation with farmers and between Agencies is complete, the bore field, equipped with an appropriate pumping system(s) and necessary tanks, pumps and pipelines will be established to discharge the waters.

Results

Phase 1: Airborne magnetics survey of Lake Toolibin and Reserves

In January 1994 tenders were called for an airborne magnetics survey of the lake and its associated reserves. The survey was designed to allow drill sites to be targeted in areas where of higher permeability (pumping rates). An earlier proposal for a ground based survey was abandoned as the lake floor was inundated and access within the vegetation would have been very difficult. Tesla 10 was awarded the contract to fly an area of approximately 25km^2 at an elevation of 40m and at a line spacing of 50m.

The survey revealed the existence of a complex pattern of large east-west dolerite dykes, northwest southeast and northeast-southwest faults and other smaller structures. Two large (wide and highly magnetic) dolerite dykes occur to the north of the lake and appear, from the distribution of salinity, to be impounding or restricting southward flowing groundwaters. These dykes appear to be creating a large groundwater discharge area to the north-west of the CALM Reserves (Tesla 10, 1994) and are believed to be responsible for the delay in the development of salinity at Toolibin.

The grey scale Total Magnetic Intensity map (Figure 1) displays the major dykes and faults. The main fault is difficult to see, however its existence is apparent by the northward displacement of dolerite dykes in the north-east and south-west quadrants of the map. The exact location of the dykes is difficult to display on this image, however they typically occurs on the 'sunlit' (light color) margin of the images.

While the dykes were not expected to be totally impermeable barriers to the southward flow of groundwater, its was expected that the majority of groundwater flow may be within the large faults. One fault detected on the lake floor (orientated NE-SW) has broken the east-west sets of dykes and may provide a conduit between lakes Toolibin and Taarblin.

Phase 2: Site selection and placement of drill targets on Lake floor

The hypothesis used to select drill-sites was that the dykes were likely to be low permeability structures and should be avoided if possible. Martin (1988) had already drilled one hole into weathered dolerite and reported little or no yield. The preferred targets were to be the centre of dyke and fault bounded blocks and major faults, either at intersections with other faults or near intersections with dykes. The hypothesis was that the faults should have higher permeability's (found to be the case further west) as a result of alteration of the bedrock.

The budget allowed drilling of 10 exploration holes (100mm). Holes that yielded water (in excess of 10 kL/day by airlifting) would be reamed to 200mm, cased with 125mm PVC and screened adjacent to all of the permeable sections (aquifers).

LAKE TOOLIBIN

(C.A.L.M.)

WESTERN AUSTRALIA

AIRBORNE GEOPHYSICAL SURVEY

TOTAL MAGNETIC INTENSITY

ILLUMINATION FROM NORTH

REVISIONS			

Map Projection: TMAMG50

Geodetic Datum: AGD66

Location Code:

Scale: 1:25000

Date: MAY 1995

Compiled:

Printed:

Traced:

Checked:

Plate No.

processing by: TESLA-10

acquisition by: TESLA AIRBORNE GEOSCIENCE

Sites selected as targets were located on a 1:5000 aerial photograph after inspection and interpretation of the magnetics data (contour and image maps). Coordinates were selected and located on the ground using both photo-points and a hand held GPS.

Table 1. Preliminary bore site locations (with options at sites 95/01 and 95/04)

Bore	Priority	Easting	Northing	Easting	Northing
95/01	1	556750	6358010	556800	6357080
95/02	2	556530	6357795		
95/03	3	556360	6357510		
95/04	4	556240	6357300	556070	6357385
95/05	5	556120	6357085		
95/06	6	555945	6356760		
95/07	7	556065	6356520		
95/08	9	555770	6356480		
95/09	8	556000	6357440		
95/10	10	556400	6357030		

The accuracy of the available CALM GPS was assessed using the photo and known benchmarks (WAWA multi-port bore, GSWA pumping bores, depth gauges and NE road exit from the east side of Toolibin. The errors for these sites were (Easting then Northing): 15/45m, 0/40m, 0/15m, 36/10m, 40,40m. We concluded that the GPS is accurate to within 45m.

Bores eg, 95/01 are coded by year (1995) and site location. Suffixes are used to indicate the type of bore at each site: deep production wells (P), intermediate depth pumping wells (I) and shallow (S) and deep (D) piezometers.

Phase 3: Drilling test wells and production wells

Seven deep and two intermediate depth production wells (125mm class 9 PVC) were drilled into the floor of Toolibin Lake. In addition, four piezometers were installed at sites where insufficient flows were obtained (Figure 1).

Most bore site locations were modified after drilling was completed at sites 95/01 and 95/02. Results from drilling at these sites suggested that the GPS positions (Table 1) were likely to out by about 45m and that the target structure (main fault) was further east of the initial positions selected.

The first site chosen (95/01) was selected from the combined magnetics and photo overlay and position using the GPS. However drilling encountered weathered dolerite, no flow and basement at 34m (now 95/01S). To correctly position the bore in the centre of the fault, a small grid (100m x 100m) magnetics survey was conducted. The new bore site was chosen about 40m east of the original position. Drilling at 95/01P proceeded to 54m (into faulted bedrock), encountered 16m of permeable saprolite and was test-pumped at 50.7 kL/day (see below).

Aquifers

In brief, a small yield (<5 kL/day) was often obtained from alluvial sediments within the upper 10m of the profile. Yields were variable depending on the thickness of the clayey sands and the thickness of indurated sand lenses. The larger yields occurred within the weathered granites near the basement, in saprolite aquifers (95/01P, 9503P, 95/04P, 95/07P and 95/08P). However some 'moderate' yields (20-70 kL/day) occurred within quartz veins (95/02P and 95/02P) encountered along the fault.

Groundwater flow

Martin (1986, 1990) notes that groundwater level patterns indicate that flow occurs towards the lake in summer from all directions. However in winter (and in the deep aquifer in summer) the increase in water levels and hydraulic gradients allows water from aquifers beneath the lake to flow south-west.

Recent monitoring suggests that bores in the southern part of the lake (95/06-07 and 08) tend to have upward pressure gradients greater than those to the north (Table 2). This may either reflect the impact of pumping (reducing heads upslope) or the enhanced discharge that is able to take place from the soil surface. Alternatively, it may not indicate effects of pumping and be the results of variable recharge and discharge rates associated with the existence of poorly connected groundwaters within cells created by the dykes and faults.

Surveyed water levels (Table 2; mAHD), taken soon after drilling, indicated that the groundwaters had a tendency to flow north-west, towards the pumping wells.

Final analysis of these levels will be made after the bore casings and pump mountings have been established and several water-level records have been collected.

Old Watertables

Drilling regularly encountered an iron rich, variably oxidised and often silicified, sequence of indurated materials well below the current watertable. These materials typically occurred at a depth of about 10-15 m. Another series of indurated materials was located in Bores 95/02 and 95/05 nearer the soil surface (6-9 m). Whether the deeper or shallower zones reflect the position of the watertable prior to clearing is unclear. However it is likely that the watertable has risen of the order of ~10 m since the turn of the century. It is also likely that *both* clearing in the catchment (increase in groundwater inflow) and increased inundation of the lake (frequency of inundation and increased infiltration) has been responsible for the observed increase in levels.

Results of the drilling are summarised in Table 2 and details given in Appendix A (attached)

Phase 4: Develop bores and conduct pumping tests to determine likely yields and salinities,

Air-lifting systems were used to develop all of the production wells and piezometers. Air was pumped into the casing and screens at varying rates for periods of between 1 and 2 hours (drilling-rig compressor). An 'Air-Well' pump was used to test-pump each of the wells. Pumping tests were conducted for periods of between 2 and 4 hours. Final flow rates were noted when the pump yields had reached a new 'steady state'. This was judged by the drillers to when the pump was cycling at a consistent time interval, however it is unlikely that this yield will be the same as the long-term pumping rate.

Water samples were taken for analysis after the development of each of the bores (Table 3).

Lake Toolibin Drilling Program Details: Completed March 15 1995

Bore	Location		Levels		Details			Quality			Flow	Materials	Levels 01/06/95		Levels 23/03/95	
	Northing	Easting	Elevation Soil mAHD	TOC	Bedrock m	Casing m bTOC	Screen (s) m BGL	Salinity mg/L	Salinity mS/m	pH	Yield kL/day	Aquifer type	SWL[1] m AHD	SWL[1] m bTOC	SWL[2] m BGL	SWL[2] m bTOC
95/01S	556714	6357986	297	299.8	34	9.4	4.6-6.6	54675	8250	7.2	2	sediments	296.85	2.95	0.92	3.72
95/01P	556768	6357951	296.79	299.55	54	53.6	39.2-51.2	52851	8190	6.9	50.7	weathered granite	296.32	3.23	0.62	1.16
95/02I	556594	6357775	296.58	296.82	47	12.1	6.1-12.1	54638	8210	7.6	11.1	sediments	nd	nd	1.19	1.46
95/02P	556624	6357703	296.53	299.59	48	31.6	26.7-28.7	50701	7970	6.4	30.3	quartz vein	296.42	3.17	0.12	0.54
95/03P	556327	6357523	296.88	299.57	44	46.5	6-12; 31.9-43.9	48500	7420	6.6	68.6	weathered granite	296.17	3.4	0.91	1.37
95/04P	556037	6357308	296.83	299.53	35	36.7	6-9; 22.4-34.4	44733	7430	6.4	59.8	weathered granite	296.33	3.2	0.75	1.51
95/05D	556083	6357121	296.71	299.07	28	32.3	29.9-31.9	59750	9430	6.9	5	weathered dolerite	296.49	2.58	0.85	3.1
95/05S	556049	6357078	296.7	299.06	na	13.6	11.2-13.2	44688*	7130	7.4	1	sediments	296.26	2.8	0.95	3.2
95/05h	556090	6357072	296.61	296.61	na	3	0-3	44688*	7130	7.4	1	sediments	nd	nd	0.13	1.15
95/06S	555998	6356728	297.02	299.2	42	7.6	5.6-7.6	54380	8500	7.0	5	sediments	296.44	2.76	0.98	3.09
95/06I	555950	6356733	296.92	297.19	45	28.2	26.2-28.2	44378	7370	6.9	10	quartz vein	nd	nd	0.3	0.6
95/07P	556082	6356469	297	299.39	40	41.6	9-15; 27.7-39.7	47190	7490	6.2	72.9	weathered granite	296.8	2.59	0.01	0.68
95/08P	556285	6356787	296.67	299.3	41.5	43.3	29.2-41.2	53151	8230	6.2	61.4	weathered granite	296.6	2.7	-0.1	0.45
95/11I	555919	6357235	296.81	297.21	na	12.1	5.5-11.5	46525	7380	8.1	15.4	sediments	nd	nd	0.91	1.12
								43677	7866							

Key

m AHD = meters above Australian Height Datum

m b TOC = metres below Top of Casing (platform)

m BGL = meters Below Ground Level

SWL = Static Water Level in casing (mBTOC changed between March and June)

mg/L = milli grams per litre (* estimated)

mS/m = milli Siemens per metre

kL/day = kilo litres per day (1000 L/d)

Table 3. Bore yields and salinity details

Bore	Depth (m)	Salinity (mS/m)	Calculated salinity TSS (mg/L)	Estimated yield (kL/day)
95/01S	34	8250	52,252	#
95/01P	**54**	**8190**	**52,851**	**50.7***
95/02I	47	8210	54,638	11.1
95/02P	**48**	**7970**	**50,701**	**30.3***
95/03P	**43**	**7420**	**48,500**	**68.6***
95/04P	**33**	**8430**	**44,733**	**59.8***
95/05D	28	9420	59,720	#
95/06S	42	8500	54,380	#
95/06I	45	7370	44,378	< 5**
95/07P	**39**	**7490**	**47,190**	**72.9***
95/08P	**41**	**8230**	**53,151**	**61.4***
95/11I	12	7380	46,525	15.3
LTP1A	37	na	53,640 {42,000}	<20
GS1/88	35	na	37,368 {47,000}	<16
Summary	466 m	Ave 8055	Ave 43,677 mg/L	375 kL/day
Estimates*		**Ave 7955**	**Ave 49,521 mg/L**	**344*kL/day**

KEY:
= piezometer (S, D) or ** = insufficient yield
* = sum of all bores with yields above 20 kL/day
CCWA= Chemistry Centre of WA (TSS calculated June 1995 {1988}).

Six of the wells (Table 3 marked shown in bold) developed sufficient yield to warrant including them in the bore-field. Combined yields were estimated to be of the order of 344 kL/day. Bores 95/02I, 95/06I and 95/11I had estimated yields of less than 20 kL/day and were not considered to suitable (economics) to be included in the bore-field.

The six high yielding wells have an average conductivity (salinity) of 7955 mS/m or 49,521 mg/L.

In the future, the conversion between EC (mS/m) to Total Soluble Salt (TSS) levels can be carried using equation 1. The equation was derived from analyses of 12 samples submitted for chemical analysis to the CCWA (March 1995).

(1) $TSS = 7.30\,EC - 7361$ $\quad r^2 = 0.90 \quad n = 12\ (P<0.001)$

Using the predicted bore yields (Table 3) and Equation 1, it can be estimated that the TSS of pumping bores within Toolibin lake will have a an average salinity of approximately 50,000 mg/L and a saltload of 50 kg per kL.

The total estimated salt yield (6 pumping bores) is likely to be of the order of 16 tonnes per day (60.8 kg/kL x 320 kL/day) or about 5,800 tonnes per year.

These figures are currently only 'best bet' estimates. We believe that longer-term pumping tests or operational pumping conditions will result in lower yields (perhaps 50% of initial rates). In addition, when the bore-field is operating, each of the salinities within the wells may fall in the same way as bore GS1/88. At this site the groundwater salinity has been reduced by 10,000 mg/L (~20%) as a result of 'fresher' lake recharge since pumping commenced (Table 3)

It is likely that the long-term pump discharge will be of the order of 200 kL/day and the annual saltload may be of the order of 2000 to 3000 tonnes.

Phase 5: Analysing data and determine effectiveness of the bores by groundwater modelling.

A groundwater modelling consultant should be employed to conduct a short study into the effectiveness of the groundwater pumping project as detailed above. The consultant should be able to indicate the likelihood of success by modelling the pumping at various rates and taking account of regional inflows and local interactions between individual bores and geologic structures.

I suggest that a contract be tendered to;

(i) model the effect of pumping at estimated rates on watertables within the lake,
(ii) determine the effect of lower than expected yields (reduce by 50%),
(iii) determine the impact of pumping after 3, 10 and 30 years on watertables beneath Toolibin.
(iv) advise whether it is necessary to drill more production bores on the eastern area of the lake and,
(v) assist in the selection of monitoring wells for future assessments.

Phase 6: Prepare a Report on the effect of the Proposal on Taarblin and downstream catchments

Salt and water balance

At present, using the estimates of flow noted above, the estimated maximum load of the total pumping system (6 new bores = 16 t/day plus existing 2 bores = 1.6 t/day) will be of the order of 18 tonnes per day or 6570 t/yr. This is an increase of about 1000 t/yr on the previous estimate presented in the 'Water and Salinity Management: Toolibin Lake', submitted to the Commissioner of Soil and Land Conservation and the Department of Environmental Protection (CALM, 1995). However it should be noted that these estimates are likely to reduce when pumping rates stabilise (maybe by up to 50%).

In addition to the predicted impacts outlined in CALM (1995), recent analysis of the Toolibin catchment saltloads have become available (WAWA unpublished data, June 1995) which may change the significance of the previous estimates.

Inflows to Toolibin since 1978 have been gauged by the WAWA. Lake Toolibin streamflows have an average salinity of between 1700 and 1900 mg/L (depending on data used) and account for only 4.4 mm (~1%) of annual rainfall. The Toolibin catchment has an annual average water yield of almost 2 million cubic meters. In 11 years of reliable data, the average saltload to Toolibin has been approximately 2000 t/yr {mean 1679 t/yr (13 yrs) to 1984 t/yr (11 yrs); range 2 to 9166 t/yr}. On a catchment area basis, this load is equivalent to an annual average yield of only 0.0046 kg/m^2 (or 46 kg/ha).

By contrast, it is apparent from the WAWA Blackwood data (WAWA 1983-1985, unpublished) that the Toolibin Catchment has a considerably lower salinity than that of the Arthur River catchment monitored at the Albany Highway downstream. At this point the rivers mean annual streamflow salinity is over 5400 mg/L and represents 4.0% of the annual rainfall within its catchment. The annual salt yield is of the order of 650 kg/m^2 (650 kg/ha) At this load, and if 10% of the Northern Arthur River Catchment area was saline, the average yield of the saline land would be 6.5 t/ha/yr.

The Toolibin catchment is believed to have about 5% (based in Wickepin Shire Statistics, or 2150 ha) of its catchment area affected by salinity (ABS 1993). By contrast, the Toolibin Catchment Group have only mapped 600 ha which they considered to be severely effected. If it is assumed that 5% of the land is saline, that the saline land produces most of the salt (min. 1679 t/yr), and that all of this salt is mobilised, then the Catchment is likely to have an annual yield of about 0.8 t/ha/yr (10,570 t/yr).

The salt yield based on the Catchment groups estimates (600 ha) is similar to the Arthur River yields (~3 t/ha/yr, ie about 1800t/yr) and suggests that the Toolibin Catchment is not as saline as the ABS results, based on the Wickepin Shire, suggest. This is very different to many other cases investigated by the Catchment Hydrology Group (Unpublished State Salinity Estimates, 1995).

However the discrepancy could be in part due to the fact that the farmers underestimate the area of moderate salinity and in part due to other factors involved in the distribution and movement of salt within the catchment. In the case of the Toolibin catchment either;

(i) only 600 ha of the catchment is producing saltloads (ie is severely saline) at the expected rates for saline land in the region (~3 t/ha/yr) or,
(ii) more land is salt-affected than estimated and that this load is not being measured at the weir, or
(iii) the previous 'regionally derived' (CALM, 1995) estimates are too high, or
(iv) significant amounts of salt, mobilised from saline areas, are being lost in transit to the lake.

Maximum transmission losses in this case could account for up to (10,750 t- 1679 t) ~9000 tonnes of salt per year. This estimate is based on saltloads of 5 t/ha/yr for the 5% of the Toolibin Catchment. Some of this salt may be able to be mobilised in wetter years, while much of it may be going into storage (temporary) beneath the drainage lines. Valley recharge, measured within the Toolibin catchment (45 mm/yr, McFarlane *et al,* 1989) could provide the mechanism to account for some of this increase in storage. Storage may be occurring within the farmland (beneath drainage lines) and within CALM reserves (beneath areas of water accumulation and creeklines).

However in the future, as watertables rise and salts are re-deposited within the drainage line, large loads are likely to develop as a result of re-mobilisation of creekline storages and additions from the aquifers. If 20% of the catchment becomes saline (likely within ~20 years) and the saltload reaches 5 t/ha/yr, the annual loss of salt could be as high as 43,000 tonnes per year. Alternatively, if the mean annual salinity of the stream reached 5000 mg/L, at the current water yield rate of 4.42 mm/yr (WAWA, 1995) the saltload of the Toolibin catchment would exceed 9,000 tonnes per year.

In the future, it could be argued that the saltloads generated from the pumping system (6570 t/yr) will be small in comparison with the predicted loads (9000-43,000 t/yr). However at the moment, the increase in load attributed to pumping (6570 t/yr = maximum rates) is significant. Although it must be stressed that this load is less than predicted (9000 t/yr, Martin 1990) and is likely to be reduced by lower pumping rates (50%, 3200 t/yr) and reducing groundwater salinities (20% reduction within 5-10 years). This would reduce the load to somewhere around 2600 tonnes per year and by 2001-2005 would be equivalent to the catchment load. In the future, the load will only represent a small percentage of the estimated salt yield if catchment water management is not successful.

Effect of saltload on Taarblin and beyond

It is likely that in the initial years, the annual load of the groundwater pumping systems will exceed that current mean annual load of the Toolibin catchment. The current load may initially exceed the catchments load by a factor of 3 to 4, however as noted above, it is likely that the loads will reduce to the point where the pumping and catchment loads will be similar in the 'medium-term' planning horizon.

In the interim, it may be appropriate to install a salt management system within the floor of lake Taarblin to prevent the 'uncontrolled' loss of salts to downstream catchments. Evaporation basins could be constructed on the floor of Taarblin (or elsewhere) and be managed in such a way so as the salts are harvested or only released ahead of large floods. Design criteria should be considered in 1995 in preparation for construction in 1996.

The effect on downstream properties needs to be considered in both the short and longer terms. In the short term, small evaporation basins on Lake Taarblin will be able to accommodate the saltloads delivered from Toolibin. Taarblin will only release these salts under flood conditions and even then the volume of salts produced by the basins will not equal the sum of all of the salts pumped into them. The reason for this reduction lies in our understanding of how salt-lakes operate.

It is likely that lakes such as Taarblin, as a result of clearing and rising watertables, has become a regional groundwater discharge area for the removal of groundwaters generated from the surrounding catchments. However these types of lakes were probably active groundwater discharge areas in geologic times (over the past few 100,000 years). They fulfilled the role as evaporation basins for water loss and basins for salt loss (to streams and underground storage). Lakes often accumulated huge volumes of salt which become buried in saline floor sediments or locked in saline 'pools' in the sediments and weathered rocks below. For example, lake Toolibin contains groundwater with salinities at least double that of many of the upstream, valley bores.

In eastern wheatbelt areas, McFarlane and George (Australian Journal of Soil Research, 30, 1992) found that storages of over 10,000 t/ha (in the sediments and weathered rocks above the basement) were common beneath saline lake systems (eg North Baandee). This is likely to be the case below Taarblin, as it lies at the base of the Toolibin catchment groundwater flow system.

Today, saline groundwaters either enter the lake through specific structures (eg faults) or alluvial sediments, or well up along saline wedges of brines which commonly develop below these types of lakes (eg Lake Tyrrell, Macumber, PhD Thesis, University of Melbourne, 1983). These brine pools, which are more saline and dense that the inflowing waters, act as ramps for inflowing waters. In these types of lakes, inflows typically only occur along the perimeters of the lake. In the case of Taarblin it is likely that inflow occurs along the faults, along edges of dolerite dykes and along the lakes perimeter. The remainder of the lake acts as a temporary reservoir for salts, redirecting them downwards (called reflux brines) or into drainage lines at times of high streamflow.

Evaporation basins at Taarblin should avoid these 'necessary' discharge areas (ie required by the surrounding catchments) and be located on areas where maximum vertical salt loss is possible.

The effects of the pumping systems on the saltload of the Arthur-Blackwood Rivers has been discussed in adequate detail elsewhere (CALM, 1995), however it worth emphasising;

(i) that the initial pumping loads will be higher than the medium-term pumping loads,
(ii) that the eventual Toolibin Catchment loads will be much higher than the initial pumping loads,
(iii) that the loads which arrive at the Albany Highway are dependent on losses along the way, and
(iv) that the aim of the project is to save a locally and Internationally recognised wetland from death.

Summary

Pumping bores were located in permeable saprolite and should be commissioned in early summer (1996) after completion of community consultation and setup steps such as the connection of the wellfield, pipeline and pumping station.

The airborne magnetics survey, which was extremely useful and defined the location of major faults and dykes, maybe appropriate within Taarblin to help define the location of the evaporation ponds.

A series of small, connected evaporation basins should be setup in Taarblin in an area away from major structures and the lakes edge. The basins should be designed to stores salts under normal lake water conditions but be able to be scoured in major floods.

Monitoring of all of the new bores, the WAWA multiport bore and existing monitoring bores should be undertaken on a monthly basis. Flow and salinity testing on pumping wells should continue and flow metering systems setup on the lakes edge, as described in the Airwell pumping system, should also be monitored.

Appendix A. Drill Profile Descriptions

Drilling at Toolibin Lake was undertaken during the three week period between February 20 and March 10. Bore development commenced on March 7 and continued through until March 15. Drill logs were described from samples laid out the ground by the drillers (Flockart Drilling, Bruce Rock). Samples were logged during drilling (or within 2-24 hours).

Piezometer 95/1D - piezometer

Hole 1a depth (m)	Comments on materials	Lithology	Other
0-1	grey organic clayey sands (casuarina, paperbarks - dry)	organic	
1-2	beige fine sandy clay	alluvial	
2-3	beige fine sandy clay to medium clay	alluvial-lacustrine	
3-4	pale fine clays	lacustrine	
4-5	iron strained clayey sand, minor ironstone gravel, angular		
5-7	beige-orange gritty clayey sand, coarse quartz		
7-8	as above (finer qtz)		
8-9	brown gritty clayey sand, coarse quartz		small flow
9-10	red-brown, fine sandy clay	weathered	small flow
10-15	red brown sandy clay, some dark minerals, fine quartz	dolerite	
15-16	orange sandy clay, fine quartz		
16-19	orange fine sandy clay, pale colored matrix inside chips		
19-24	as above, (dark minerals in matrix)		
24-29	fine beige sandy clay, fine quartz sand, matrix cements	less weathered	sample dry
29-31	light brown (orange tone) sandy clay to clayey sand,		sample dry
31-32	grey fine clayey sand, fine quartz, dark minerals		
32-33	as above grey brown colour		dry sample
33-34	Bedrock, fine to medium grained dolerite	Fresh dolerite	
34-35	vvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvv		
	SWL = 0.92 , salinity 8250 mS/m, pH = 72; screened 5-7m,		
	No flow from saprolite, < 5kL/day from sediments at 9m		

Production Bore 95/01P

Hole 1b depth (m)	Comments on materials	Lithology	Other
0-1	grey, fine sandy clay, organic, orange mottles	sediments	
1-2	grey green, fine silty clay, highly dispersive		
2-3	orange, fine silty clay, some fine quartz, highly dispersive		
3-4	coarse gritty clayey sand, quartz <3mm, orange brown, white cemented clay and feldspars, highly dispersive,		small flow <2 kL/day
4-5	grey, fine sandy clay (minor sands present as layers)		
5-6	iron stained mottles in pallid sandy clay	highly weathered	
6-7	a/a less iron, little qtz	granite	
7-9	occasional iron, pallid fine sandy to medium clay		
9-11	mottled fine sandy clay, qtz opaque <1mm		
11-15	fine, light brown-pink sandy clay, fine qtz (<1mm), coarse concretions from cemented matrix (white chips)		old watertable?
15-19	pale, very fine qtz in pale clay to medium clay, red-brown matrix with grey blue veins or mottles by 19m		
19-21	grey to white fine sandy clay, red-brown coated clods		
21-22	purple colour coated pallid 'stones' of clay (40-50mm)		hardpan
23-29	pallid, white clay, orange mottles in fine matrix, no qtz?		
29-38	fine textured pallid clay, little or no quartz, yellow 'spiders web' pattern in clods		
38-39	abrupt change to gritty clayey sands by 39m	saprolite grits	
by 40	quartz mean size of 3mm (max 7mm) minor K-spar <10%, pale colour still gritty, small biotite minerals <1mm		
by 45m	Qtz size increase to 5-7mm (max 15mm), iron stained K-spar		
by 50m	Qtz size increase to 6-8mm (max 20mm), biotite stuck to K-spar, both minor (10%) of matrix		
by 54m	Qtz to 30mm (mean as above), milky and opaque qtz, highly fractured qtz, iron stained qtz, grey green colours in K-spar, some of the larger qtz pieces appear like honey comb.		
	+++		
Bedrock	Basement at 54m	Granite	
	SWL at 0.62m, EC=8190 mS/m, pH 6.9, Estimated yield <50.7 kL/d		
	Screened from 36-48m. Hole lost back to 48m		

Bore 95/02I (Site at Intermediate Pumping bore 95/02I)

Hole 2a depth (m)	Comments on materials	Lithology	Other
0-1	orange/beige to grey organic clays		
1-2	fine, cemented grey fine sandy clay (occ larger qtz)	sediments	
2-3	ironstone bands, increased quarts in sandy clayey matrix		
3-4	coarse sand, clayey sand (red colour)		
4-5	red/beige clayey sand		
5-6	as above (lighter colours)		
6-7	coarse qtz, sticky clayey sand		small flow <5
7-8	beige, fine white clay, minor iron, small quartz	weathered basement	
8-9	ironstone gravels, 10-20mm, angular and sharp quartz		old watertable?
9-10	clayey sand, fine to med grained, sticky s. clay		
10-13	brown to beige, fine clayey sand, iron and fine qtz		
13-14	increased clay, med. clay sand, fine qtz, iron stained		
14-15	gritty clay sand, red-brown, qtz <1mm (some to 3mm)		
15-16	as/above (some larger gravels)		
16-18	Heavy textured, fine white sandy clay		
18-19	pale, fine qtz, sandy clay		
19-20	change, cemented kaolin 2-10mm, qtz 1-5mm, iron		
20-21	orange fine sandy clay, occ chunks of qtz. to 15mm	quartz vein?	
21-24	pallid sandy clay, fine quartz, minor iron.		
24-29	mustard-beige, weathered granite, coarse quartz, s. clay		
29-30	sticky, less qtz, pastel yellow sandy clay		
30-31	weathered dark minerals (biotite), in pale sandy clay		
31-33	mustard-beige sandy clay cont.		
(34)	gritty sandy clay, fine to medium qtz (increase with depth)		
36-37	coarse qtz, medium clayey sand (no dark minerals)		
42-47	fine grained, medium clayey sand, green colored, weathered feldspars, qtz 1-4mm	poor saprolite	
47	coarse angular quartz (5-7mm), 80% fine sands, minor feldspars, poorly weathered, minor biotite	Granite bedrock	
	+++		
	SWL at 1.19m, EC= 8210 mS/m, pH 7.6, Yield est (2I), <0.2 L/sec		
	Intermediate bore screened from 6-12m. No piezometer to basement		

Pumping Bore 95/02P

Hole 2b depth (m)	Comments on materials	Lithology	Other
0-1	orange, grey to black fine clay, little quartz	sediments	
1-2	grey brown fine clay (lacustrine)		
2-3	clayey sand, fine to medium qtz		small flow <5
3-7	grey fine lacustrine clays (minor iron staining)		
7-8	Clayey sand, Qtz 1-2mm, iron concretions, dry	weathered - basement?	
8-10	sandy clay, fine qtz, white colour		
10-12	grey clay matrix, clayey grit, qtz to 3mm		
12-13	fine grey clay, minor qtz, iron stones -2mm qtz		
13-14	coarse sand, as above white cemented concretions		old watertable?
14-15	heavier textured a/a		
15-16	a/a		
16-17	tight grey sandy clay, dense, some clayey sand from above		
17-18	gritty clay sand, cemented kaolin, qtz to 4mm, small rounded iron pebbles		
18-24	white to pallid sandy clay (sticky)		
24-25	coarse grit, v angular, weathered qtz - pitted, 3-5mm (max. 10mm)	quartz	moderate flow to 30kL
25-26	finer clayey sand (some grit from above)		
26-29	as above (matrix sticky sandy clay)		
29-30	coarse grit, qtz to 10mm, mean 3-5mm (clayey grit)	quartz	flow to 40kL
31-48	fine sandy clays, grit present, alternating gritty then clayey, beige colored sandy clay		
48m	Basement - ?fine to medium grained granite	Bedrock	
	++		
	SWL at 0.12m, EC= 7970 mS/m, pH = 6.4, Estimated yield <30.3 kL/d		
	Deep bore screened from 32-44m. No piezometer to basement		

Pumping Bore 95/03P

Hole depth (m)	Comments on materials	Lithology	Other
0-1	grey fine sandy clay, minor qtz		
1-2	brown gritty sandy clay, coarse quartz		
3-4	red-brown gritty sandy clay		
4-5	dry, beige, pink sandy clay		
5-8	beige pink clayey sand, coarse qtz, iron stained		
8-10	as above, less clay, sandy texture mainly at 9m		small flow <5, 7200 mS/m
10-15	red-brown clayey sand to sandy clay		
15-16	heavier textured sandy clay (inc clay cont) as above		
16-18	colour change, red-brown gritty clay sand		
18-19	grey sandy clay (iron, goethite colours), in beige-mustard gritty sandy clay, qtz to 3mm, mean <2mm		
25-26	increase in qtz, clayey sand, Qtz 5-20mm, in mustard sandy clay	quartz vein?	no flow
26-31	white to mustard sandy clay		
31-40	clayey grit, qtz to 20mm mean size less than 2mm, clayey sand matrix, qtz inc with depth, minor k-spars and biotite		major flow
40-43	granite sands, coarse qtz (max 20mm), k-spar and qtz chunks, minor biotite		major flow
43	granite basement	Bedrock	
	+++		
	SWL at 0.91m, EC= 7420mS/m, pH=6.6, Estimated yield < 68.6 kL/d		
	Pumping bore screened from 6-12, 30-42m.		

Pumping Bore 95/04P

Hole 4 depth (m)	Comments on materials	Lithology	Other
0-1	grey fine clay, clayey sand, organic	sediments	
1-2	gritty clayey sand, red-brown, ironstone chips, coarse qtz, light grey clay in chips		
2-3	red-brown gritty clay sand		
3-4	red-pink gritty clay sand		
4-9	gritty, ironstone, coarse qtz to 1-5mm, angular in clayey sand		small flow <5
9-10	pale, white-beige-pink sandy clay, minor qtz <<1mm	weathered	
10-11	silicified, pale grey chunks to 5mm, coarser qtz (<2mm)	granite	old watertable?
11-17	iron stained, pale to beige sandy clay		
17-26	beige mustard sandy clay, gritty, qtz to 2mm, increase to 5mm by 26m	mod. weathered	
26-32	iron stained qtz, clayey sand, gritty sand	saprolite	flow from saprolite
32.5	Basement	Granite bedrock	
	++		
	SWL at 0.75m, EC= 8430mS/m, pH=6.6, Estimated yield < 59.8 kL/d		
	Pumping bore screened from 6-9, 21-35m.		

Piezometer 95/05D

Hole 5c depth (m)	Comments on materials	Lithology	Other
0-1	grey, mottled sandy clay (qtz fine to med. angular)	sediments	
1-2	grey mottled s. clay		
2-3	orange-red, med to coarse clayey sand, qtz to 5mm (2mm)		
3-4	pallid, less mottled - pale fine sandy clay		
4-6	fine white sandy clay		
6-7	red-brown mottled sandy clay, ironstone pebbles in pallid-brown matrix (up to 5mm).	(weathered. dolerite?)	small flow, old watertables?
9-14	weathered dolerite, grey-green fine clay, orange-green mottles, fine cob-web structures in clods	intensely weathered dolerite	
14-15	crumbly, orange - whole colored, green-purple-white mottling, fine grained dark minerals, clayey sand		
19-28	less-weathered dolerite, minor pale fine clay, dolerite chips by 27m, poorly weathered k-spar and ferromag minerals.	less weathered	
29m	basement	dolerite	
	vvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvv		
	SWL at 0.85m, EC= 9430 mS/m, pH= 6.9, Yield est <0.1 L/sec		
	5s = SWL at 0.95m, EC= 7133 mS/m, pH= 7.4, Yield est <0.1 L/sec		
	Sites 5a and 5b encountered similar materials to 9-12m. Impenetrable ironstone at 12m at 5a, b (broke rods off).		

Piezometer 95/06D

Hole 6b depth (m)	Comments on materials	Lithology	Other
0-1	grey brown coarse sand, clayey sand, qtz to 5mm	sediments	
1-2	orange brown coarse sand, clayey sand, qtz to 5mm		
2-3	minor bands of fine clay in orange coarse medium to coarse sands to clayey sands		small flow
3-4	white clayey sand, some qtz, gritty		
4-5	dominant grey colour, fine to v fine qtz		
5-6	pallid-white sandy clay	weathered bedrock	
6-7	pallid sandy clay, fine qtz and kaolin - dry		
25-30	mustard yellow, fine sandy clay, increasing qtz content with depth	less weathered	
30-43	beige-mustard sandy clay, slurry, coarser with depth, minor k-spar near basement, qtz to 5mm, sloppy ooze?		
43	Basement	Granite bedrock	
	++		
	Piezometer installed to 6m ish		
	SWL at 0.98m, EC= 8500 mS/m, pH= 7.0, Estimated yield < 5 kL/d		

Pumping Bore 95/06P

Hole 6a depth (m)	Comments on materials	Lithology	Other
0-1	grey clay, fine sandy, mottled orange gritty	sediments	
1-2	orange brown clayey sand (lenses)		
2-5	fine grained clays (lacustrine) dry and firm		
5-8	pallid-grey fine sandy clay	?	
8-9	ochre colours, ironstone chips in white fine sandy clay		old watertable?
9-10	moist gritty (fine) sandy clay	weathered granite	
21-22	grey, fine clay, minor qtz, sticky-firm sandy clay		
22.8-23.5	quartz, sharp-angular, 3-15mm, crystalline grit, mean grain size about 5mm	quartz	flow < 0.3 l/s
23.5-27	as above, however quartz is finer and in clay matrix, coarser zone at 27m (sample contamination possible)		minor flow
28-31	mustard, fine textured sandy clay		
31-40	pallid clays inside mustard sloppy to gritty clays, some angular coarse qtz		
40	sloppy ooze, sticky sandy clay, minor k-spar and qtz in mustard sandy clay to basement.		no flow
45	Basement	granite bedrock	
	++		
	SWL at 0.30m, EC= 7370 mS/m, pH 6.9, Estimated yield, < 5 kL/d		
	Intermediate bore screened from 18-30m. No piezometer to basement		

Production Bore 95/07P

Hole 7 depth (m)	Comments on materials	Lithology	Other
0-1	grey-orange, fine qtz sand	sediments	
1-2	red-brown fine sandy clay (lacustrine by 1.5m)		
2-7	white, fine grained lacustrine clay, very little qtz (if any)		
7-10	orange, fine to med. sand, sub-rounded		small flow
10-13	white-beige fine sandy clay		
(1-13)	(all samples above slake-disperse)		
13-14	white-fine to med. qtz, silicified; 'sandstone'	weathered granite	old watertable?
21-26	pink, pallid sandy clay, medium qtz (3mm), orange grey fine pallid chunks in fine pink clayey sand - fine clays too		
26-39	poorly developed saprolite, clayey sand, iron stained by 32m, quarts opaque (greenish colours) 1-3mm, max to 5mm, little k-spar and still weathered		moderate flow
39.2	Basement	Bedrock	
	++		
	SWL at 0.01m, EC= 7490 mS/m, pH 6.2, Estimated yield, < 72.9 kL/d		
	Pumping bore screened from 7-15, 27-39m. No piezometer to basement		

Production bore 95/08P

Hole 8 depth (m)	Comments on materials	Lithology	Other
0-1	fine grey lacustrine clays	sediments	
1-2	fine lacustrine clays		
2-3	as above grading into orange brown coarse clayey sands		
3-4	orange brown clayey sands		
4-8	return to lacustrine sediments		
8-13	fine quartz, white sandy clay	weathered granite	
13-25	orange-beige fine to medium textures sandy clay, qtz to 3mm max, silicified at 13m		old watertable?
25-33	coarse qtz, clayey sands		
33-40	grey-green micaceous fine clayey sand, quartz (1-5mm)	poorly weathered	
40-41	stones containing qtz and feldspars, others containing a schistose biotite (weathered grey-green)		minor flow
41.5	basement	Bedrock	
	++++++++++++++++++++++++>>>>>>>>>>>>>>>>>>		
	SWL at -0.1m, EC= 8230 mS/m, pH 6.2, Estimated yield, < 61.4 kL/d		
	Pumping bore screened from 27-39m.		

Production Bore 95/11I

Hole 11I depth (m)	Comments on materials	Lithology	Other
0-1	grey, fine to medium clay	sediments	
1-2	orange, red-brown clayey sand		
2-3	orange-beige sandy clay to clayey sands (iron stained)	weathered granite?	small flow
3-9	beige-white, indurated (at 4m) sandy clay	or here	small flow
9-12	white-beige sandy clay		
	SWL at 0.91m, EC= 7380 mS/m, pH 8.1, Estimated yield 15.4 kL/d		
	Intermediate bore screened from 6-12m.		