Salinity control by groundwater pumping at Lake Toolibin, Western Australia

by

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Abstract

Lake Toolibin is a shallow, ephemeral, freshwater lake in the wheatbelt of Western Australia. It is an important breeding area for water birds and is threatened by salinization from a rising, saline watertable.

Groundwater occurs in a heterogeneous unconfined aquifer in weathered granitic rocks. The watertable is less than 2 m below the lake floor and the groundwater salinity ranges from 30 000 to 60 000 mg/L.

Analysis of the drawdown response to the pumping of a production bore on the western side of Lake Toolibin (after 113 days at an average rate of 16 m^3/d) indicates an aquifer transmissivity of 4.92 m^2/d, hydraulic conductivity of 0.15 m/d and specific yield of 0.01. After 1 year of pumping (pseudo steady-state condition) a drawdown of 1.5 m would occur 30–40 m from the production bore with no drawdown beyond about 650 m.

These results show that control of salinization at Lake Toolibin can be achieved by locating production bores about 300 m apart to give a drawdown of at least 1.5 m by mutual interference. A total of 25 production bores would be required to lower the watertable at the sites that are threatened by salinization.

Discharge of saline water from the pumping to nearby Lake Taarblin is unlikely to result in a significant increase in the salinity of flow in the Blackwood River. However, the environmental impact of the discharge, and the feasibility of recovering both salt and freshwater from the discharge by solar distillation should be considered.

KEYWORDS: Groundwater, salinity, watertable, pumping, lake

Introduction

Lake Toolibin is a small, shallow, ephemeral lake in the Northern Arthur River drainage system about 200 km southeast of Perth (Fig. 1). It is one of a small number of relatively freshwater lakes in the region, and provides an important breeding area for a wide variety of waterbirds.

A report by the Northern Arthur River Wetlands Committee (NARWC, 1987) on the status and future of Lake Toolibin highlights both the importance of the lake to the wildlife ecosystem and the degradation, due to salinization, of lakebed vegetation. The recommendations of that report prompted the Geological Survey of Western Australia to undertake a drilling and pumping program during 1988/89 to assess the extent to which dewatering would lower groundwater levels in areas where the lakebed is salinized.

This paper describes the drilling and pumping program and the effectiveness of pumping to lower groundwater levels. The predicted distance–drawdown response is used to determine the spacing between pumping bores and to establish the measures required to lower groundwater levels in the salinized areas.

Physiography

Lake Toolibin is one of several shallow, ephemeral lakes in a palaeodrainage now occupied by the headwaters of the Arthur River, a tributary of the Blackwood River. The catchment area for Lake Toolibin covers 476 km^2 of which some 90% has been cleared of native vegetation for dryland agriculture (Stokes and Martin, 1986). Clearing has resulted in the appearance and subsequent spreading of salinized land, and about 6% of the catchment is now moderately to severely affected by high salt levels.

The climate of the area is Mediterranean with mild, wet winters and hot, dry summers. The mean annual rainfall is 420 mm and pan evaporation averages 1800 mm/year.

From historical rainfall records, it has been shown that inflow to Lake Toolibin occurs, on average, 7 years out of 10 (Stokes and Sheridan, 1985). However, because of recent below-average rainfall, significant inflow to the lake has occurred in only 3 years (1981, 1983, and 1990) since lake-level gauging began in 1977. When full, the lake covers an area of about 3 km^2 with a maximum water depth approaching three metres.

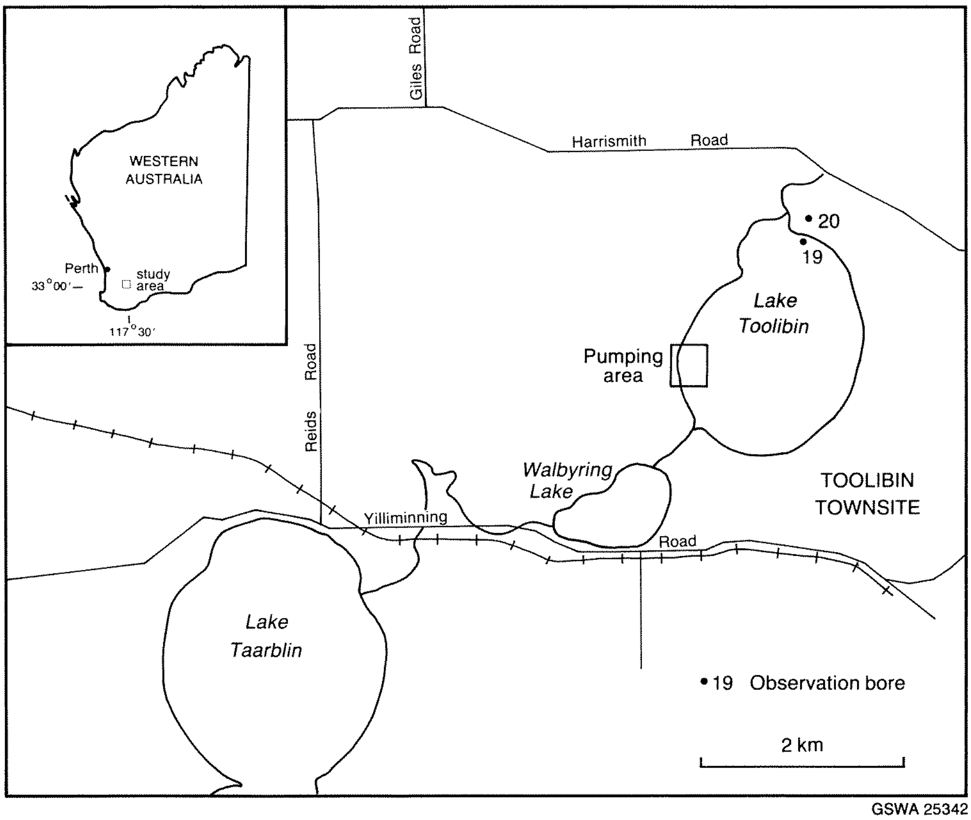

Figure 1. Lake Toolibin — location map

Previous investigations

Investigations into salinization at Lake Toolibin began in 1977, and the Northern Arthur River Wetlands Committee was established. In 1987, the committee reported on the status and future of Lake Toolibin in its final report (NARWC, 1987). The hydrogeology of Lake Toolibin has been described by Martin (1986), and the lake hydrology discussed by Stokes and Sheridan (1985). A vegetation study was carried out by Mattiske (1986), and Halse (1987) discussed the effect of increased salinity on the waterbirds of Lake Toolibin.

Methods

A production bore was drilled through the lakebed on the western side of Lake Toolibin (Fig. 1) in an area where the shallow depth to saline groundwater has resulted in severe salinization of the lakebed. The production bore and observation bores were drilled by the Mines Department Drilling Branch during 1988. Completion details for the bores are given in Table 1 and their locations are shown on Figure 2. The production bore (1/88), and the deep and intermediate observation bores (denoted by the suffix A and B respectively) were drilled using a mud-flush rotary method; the other (shallow) bores were drilled using solid augers. The annulus adjacent to the slotted intervals of the bores was packed with graded sand and the remaining annulus was sealed with cement slurry. All bores were developed by airlifting.

The casing of the production bore extends about 2.5 m above the lake floor and preformed-concrete well-liners with base and lid were placed around the casing. The concrete lid stands about 2.7 m above the lake floor and provides a platform, above the maximum lake waterlevel, for the automatic pump control. The control switches the pump off when the waterlevel in the bore is drawn down to about 28 m below ground level, and restarts the pump when the waterlevel recovers to about 25 m below ground level. The discharge from the bore is measured with an in-line flow meter, and the water is piped through about 8 km of 40 mm diameter poly-pipe to Lake Taarblin, a salinized lake downstream of Lake Toolibin.

Geology

Much of the Lake Toolibin area is mantled by thin Cainozoic deposits consisting of laterite, colluvium, and reworked alluvium. The region, which lies within the Yilgarn Craton, is underlain by Precambrian granitic rocks and occasional dolerite dykes. The rocks have been weathered and lateritized and the thickness of the weathered profile ranges from a few to about 40 metres. Thin lacustrine sediments have been deposited in the lakes.

At the pumping area, the weathered profile is about 33 m thick and consists of variably coloured brown to white sandy clay and clayey sand. The profile intersected by bores O3A and O4A is weathered dolerite, whilst at all other sites weathered granite or migmatite is

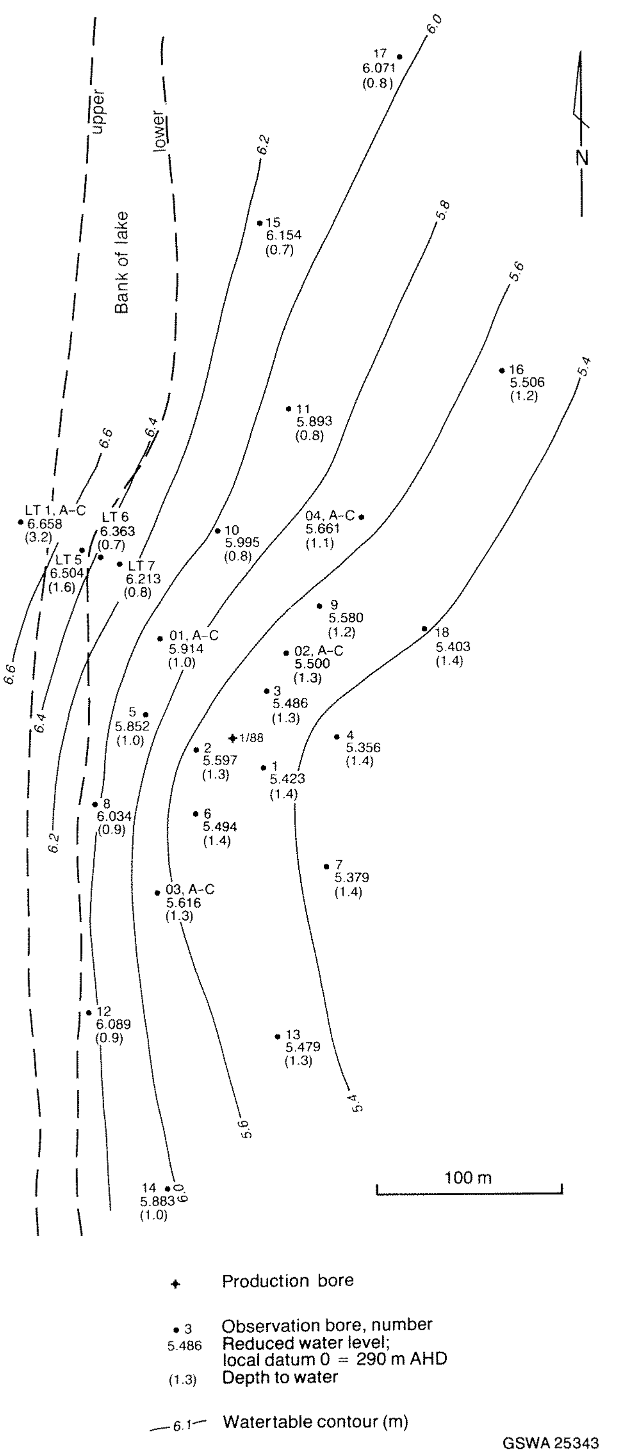

Figure 2. Watertable contours at the pumping area, March 1989

encountered. The upper 0.5–2 m of the weathered profile has been lateritized, and this is overlain by thin (<0.5 m) lacustrine deposits.

Hydrogeology

The groundwater system at Lake Toolibin is unconfined and is recharged by direct rainfall infiltration and by downward leakage from the lake when it contains water. When the lake is dry, the depth to groundwater beneath the lakebed is less than 2 m (Fig. 2) with groundwater being lost partly by evaporation and to some extent by transpiration from vegetation on the lake floor. During winter, when evaporation is low, the groundwater level rises and seepage faces develop in the salinized areas.

The direction of groundwater flow is normally towards Lake Toolibin but, when the lake contains water, there is some flow away from the lake near the southern end (Fig. 3). The March 1989 watertable contours for the pumping area (Fig. 2) imply an easterly groundwater flow towards the lake. The flattening of the watertable gradient in the direction of groundwater flow is probably due to loss of groundwater by evaporation.

The groundwater hydrographs of two bores, 19 and 20, near the northern end of Lake Toolibin are shown on Figure 4. The waterlevel in these bores is unaffected by the pumping, and the hydrographs show that the seasonal fluctuation in the watertable approached 1.7 m with minimum levels at the end of April and maximum levels between July and October. At the pumping area, the watertable rises to the floor of the lake during winter in response to reduced evaporation.

The groundwater in the region is saline and at the pumping area, the general range of salinity was 30 000–50 000 mg/L (total dissolved solids, Table 1). The salinity of the groundwater increased to about 60 000 mg/L near the centre of Lake Toolibin.

Response to pumping

Pumping from production bore 1/88 commenced on 28 June 1989 and continued until the pump failed on about 9 November 1989. Pumping recommenced on 28 November, but heavy rainfall from the remnants of tropical cyclone Tina filled the lake in January 1990.

The waterlevels in the observation bores and the cumulative discharge from the production bore were monitored fortnightly for the first month of pumping, and monthly thereafter. The discharge rate between 28 June and 19 October ranged from 14.4 to 18.6 m^3/day with an average of about 16 m^3/day.

The watertable contours for 19 October (before the pump failed) are shown on Figure 5. With the exception of the area within about 30 m of the production bore, the watertable was higher than that recorded in March 1989; a reflection of the seasonal rise in the watertable. However, the watertable contours indicate radial groundwater flow toward the production bore. The regional inflow of groundwater toward the east is largely responsible for the observed steeper hydraulic gradient west of the production bore.

The changes in waterlevels in the observation bores result from a combination of pumping, variation in evapotranspiration, and seasonal recharge. Before the response to pumping can be evaluated, the recorded waterlevel changes at the pumping site need to

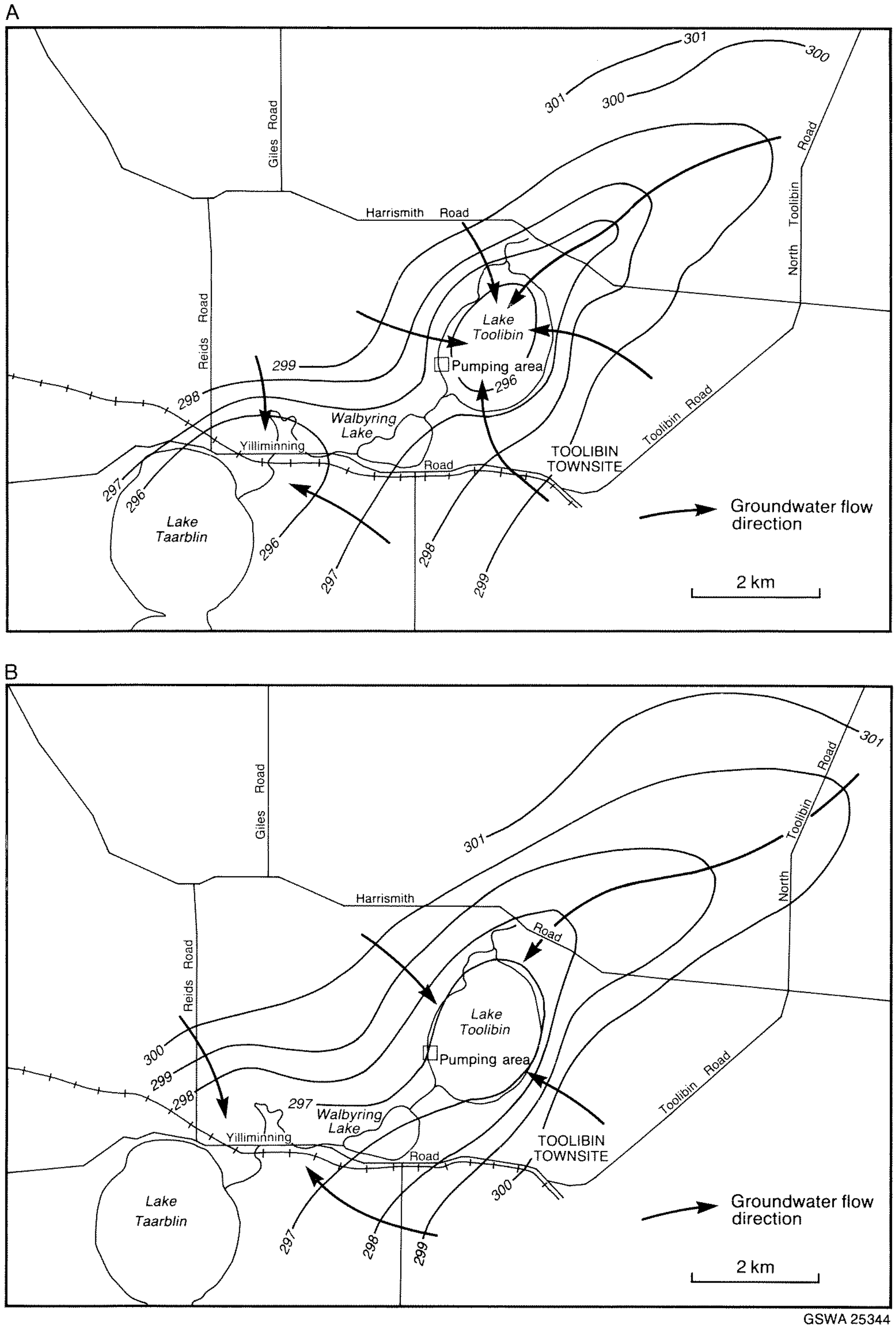

Figure 3. Watertable contours and direction of groundwater flow at Lake Toolibin
A. Lake dry
B. Lake full

Table 1. Bore completion details

Bore no.	*Distance from 1/88 (m)*	*Depth (m)*	*Reduced level TOC (m AHD)*	*Reduced level GL (m AHD)*	*Slotted interval (m BGL)*	*Salinity TDS (mg/L)*	*Salinity Date sampled*
1/88	0	35.5	299.584	296.84	1 – 32.3	47 000	7/4/88
O1A	65.0	37.0	297.488	296.88	33.3 – 36.3	23 500	"
O1B	65.5	17.0	297.533	296.85	14 – 17	36 500	"
O1C	64.8	2.7	297.094	296.86	0.2 – 2.7	41 000	"
O2A	49.8	35.0	297.374	296.80	31 – 34	29 000	"
O2B	48.6	17.0	297.363	296.78	14 – 17	35 500	"
O2C	51.6	3.1	297.178	296.82	0.1 – 3.1	50 000	"
O3A	85.1	29.5	297.342	296.88	26 – 28	44 000	"
O3B	83.7	16.0	297.340	296.89	13 – 16	28 000	"
O3C	90.6	3.4	297.150	296.88	0.2 – 3.4	40 000	"
O4A	130.5	33.0	297.173	296.74	30 – 33	47 000	"
O4B	129.0	17.0	297.209	296.73	14 – 17	32 000	"
O4C	133.4	3.3	296.906	296.71	0.3 – 3.3	46 000	"
1	21.8	4.3	297.153	296.80	0.2 – 4.3	46 000	"
2	20.3	3.0	297.185	296.87	0.2 – 3.0	41 500	"
3	30.2	3.5	297.139	296.83	0.2 – 3.4	47 000	"
4	53.1	3.3	297.118	296.79	0.3 – 3.3	46 000	"
5	47.9	2.8	297.112	296.87	0.3 – 2.8	35 500	"
6	43.7	3.4	297.106	296.88	0.2 – 3.4	43 500	"
7	82.1	3.2	297.002	296.79	0.3 – 3.2	47 500	"
8	80.4	3.5	297.229	296.94	0.3 – 3.5	31 000	"
9	83.2	3.0	297.004	296.74	0.3 – 3.0	49 000	"
10	108.8	3.3	297.010	296.81	0.3 – 3.3	43 000	"
11	173.3	3.3	297.013	296.75	0.3 – 3.3	45 000	"
12	163.2	3.3	297.134	296.98	0.3 – 3.3	31 500	"
13	158.1	3.3	297.074	296.82	0.3 – 3.3	49 000	"
14	237.7	3.3	297.133	296.87	0.3 – 3.3	45 000	"
15	266.4	2.1	297.229	296.86	0.2 – 2.1	34 000	"
16	239.5	2.9	296.986	296.75	0.3 – 2.9	44 000	"
17	362.5	3.3	297.119	296.83	0.3 – 3.3	38 500	"
18	117.9	2.8	296.993	296.76	0.3 – 2.8	50 000	"
19	-	4.7	297.438	297.21	0.4 – 4.7	44 000	"
20	-	6.5	298.879	298.44	0.2 – 6.5	34 500	"
TO1A	160.0	38.0	300.734	299.92	33 – 36	42 000	22/3/83
TO1B	160.0	17.5	300.718	299.86	14.5 – 17.5	32 800	"
TO1C	160.0	6.3	300.726	299.88	3.3 – 6.3	8 500	11/9/84
TO5	126.2	2.2	298.891	298.10	0.2 – 2.2	ns	
TO6	116.7	1.1	297.963	297.10	0.2 – 1.1	ns	
TO7	108.8	1.1	297.813	296.96	0.2 – 1.1	35 500	11/9/84

Note: AHD Australian height datum; BGL below ground level; TDS total dissolved solids; TOC top of casing; GL ground level; ns not sampled

be corrected for the influence of evapotranspiration and recharge. This has been done by noting the changes in waterlevel, since pumping commenced, in observation bores 19 and 20 (Fig. 3). Because of the difference in the response of the two bores, the average change has been used to correct the drawdown.

Analysis

The corrected drawdown versus distance from the production bore for 19 October (113 days pumping) is shown on Figure 6. Two factors contribute to the observed scatter in the data points; the heterogeneity of the aquifer, and the use of an average correction for the regional trend.

The response to pumping has been analysed applying the Jacob distance–drawdown method (Kruseman and de Ridder, 1976) to the data obtained after 113 days pumping, with:

$$T = \frac{2.30\,Q}{2\pi\delta s} \qquad (1)$$

$$S = \frac{2.25Tt}{r_0^2} \qquad (2)$$

$$k = T/b \qquad (3)$$

where T = transmissivity (m^2/d)
Q = pumping rate (16 m^3/d)
δs = slope of straight line per log cycle (1.19)
S = specific yield
t = time elapsed since pumping commenced (113 days)
r_0 = distance from pumping bore zero drawdown (360 m)
k = hydraulic conductivity (m/d)
b = aquifer thickness (33 m)

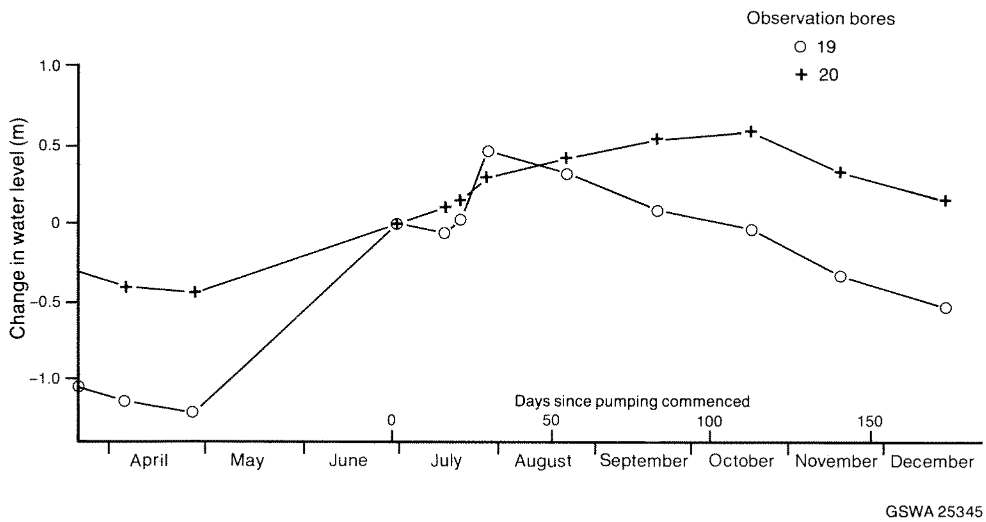

Figure 4. Groundwater hydrographs for bores 19 and 20

By substitution, the following values are obtained:

Transmissivity	=	4.92 m^2/d
Specific yield	=	0.01
Hydraulic conductivity	=	0.15 m/d

Long-term drawdown

The drawdown due to pumping for 300 and for 400 days has been evaluated by rearranging equation 2 to solve for r_0, and the resulting distance–drawdown lines are shown on Figure 6. Beyond this time, drawdown approaches steady-state conditions in response to regional groundwater inflow, local recharge, and reduced evaporation because of the greater depth to groundwater.

The results indicate that a drawdown of 1.5 m would occur 35–40 m from the production bore and that no drawdown would occur beyond about 650 metres. Additional production bores would be required to achieve the recommended Northern Arthur River Wetlands Committee (1987) minimum drawdown of 1.5 m over a larger area. The principle of superposition can be used to evaluate the drawdown resulting from the mutual interference of a number of pumping bores located some distance apart. A minimum drawdown of 1.5 m by mutual interference between two pumping bores would require a drawdown of 0.75 m midway between each bore. From the distance–drawdown data (Fig. 6), this would occur at 150 m from each bore, and a 1.5 m drawdown would require a spacing of about 300 m between the bores. The effect of mutual interference is shown schematically in Figure 7 for three pumping bores, firstly 300 m apart and in-line and, secondly, at the apices of a 300 m equilateral triangle.

Borefield dewatering design

The salinized areas at Lake Toolibin, shown on Figure 8, are predominantly on the western and southern parts of the lake. In order to lower the watertable to a level which would effectively control salinization, at least 9 pumping bores (8, in addition to 1/88) would be required along the western side of the lake and a further 16 bores would be required for the remaining areas. The suitability of a site for a production bore will depend largely on avoiding weathered dolerite dykes and other locations with high proportions of clay in the weathered profile. Geophysical techniques involving the use of magnetic, electromagnetic, and possibly resistivity methods may be suitable for locating dykes and also for defining areas where drilling is most likely to be successful. Proposed drillhole sites are indicated on Figure 8.

Discharge of groundwater

The groundwater pumped from production bore 1/88 has a salinity of 47 000 mg/L and is discharged to Lake Taarblin at a rate of 16 m^3/day. This is equivalent to a discharge of about 270 tonnes of salt per year. With 25 production bores, each discharging 20 m^3/day of 50 000 mg/L salinity water, about 9000 tonnes per year of salt would be discharged to Lake Taarblin. The accumulated salt would be flushed to the Blackwood River drainage system when the lake overflows. At present, the Blackwood system discharges about 2 x 10^6 tonnes per year of salt, and the additional salt from pumping Lake Toolibin would represent an increase of about 0.5%. Because Lake Taarblin discharges during large flow events, the effect of the additional salt on the salinity of the Blackwood river is likely to be small. If Lake

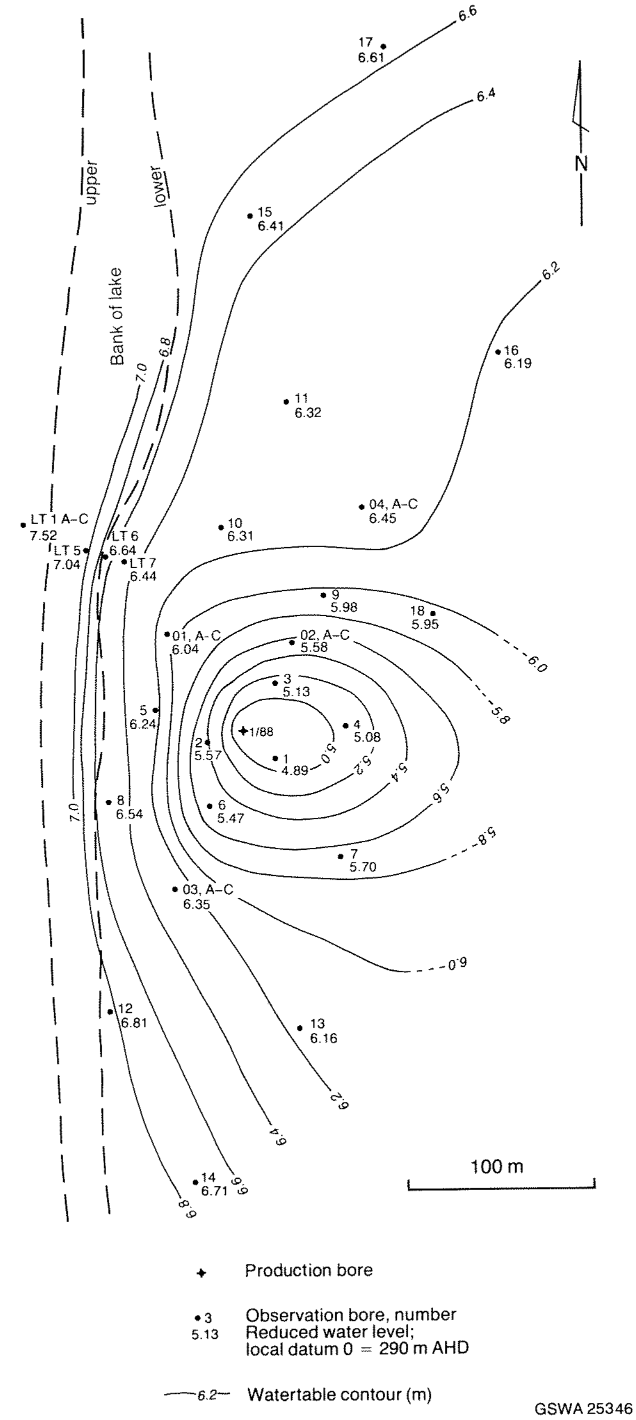

Figure 5. Watertable contours at the pumping area, October 1989

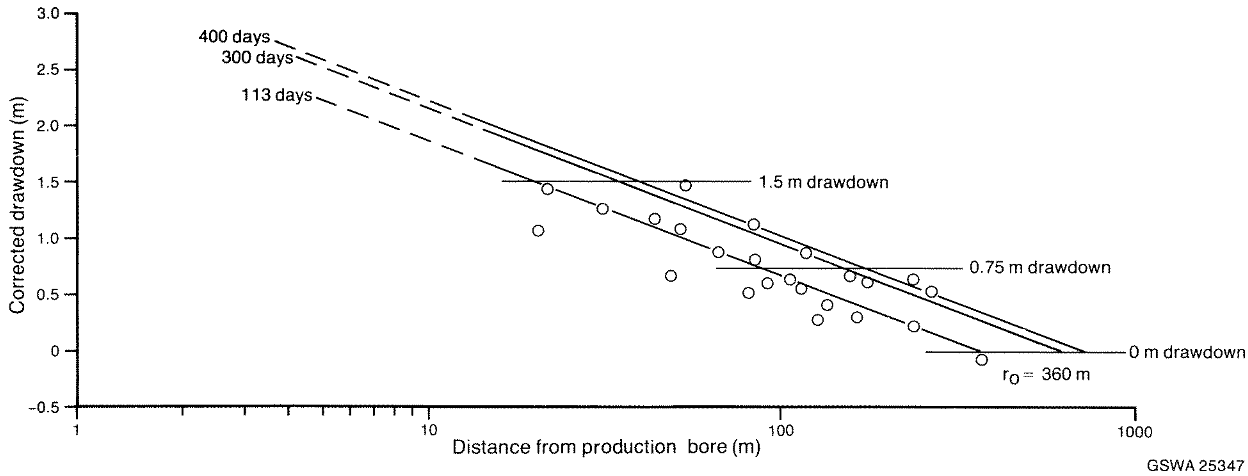

Figure 6. Distance-corrected drawdown plot (after 113 days pumping)

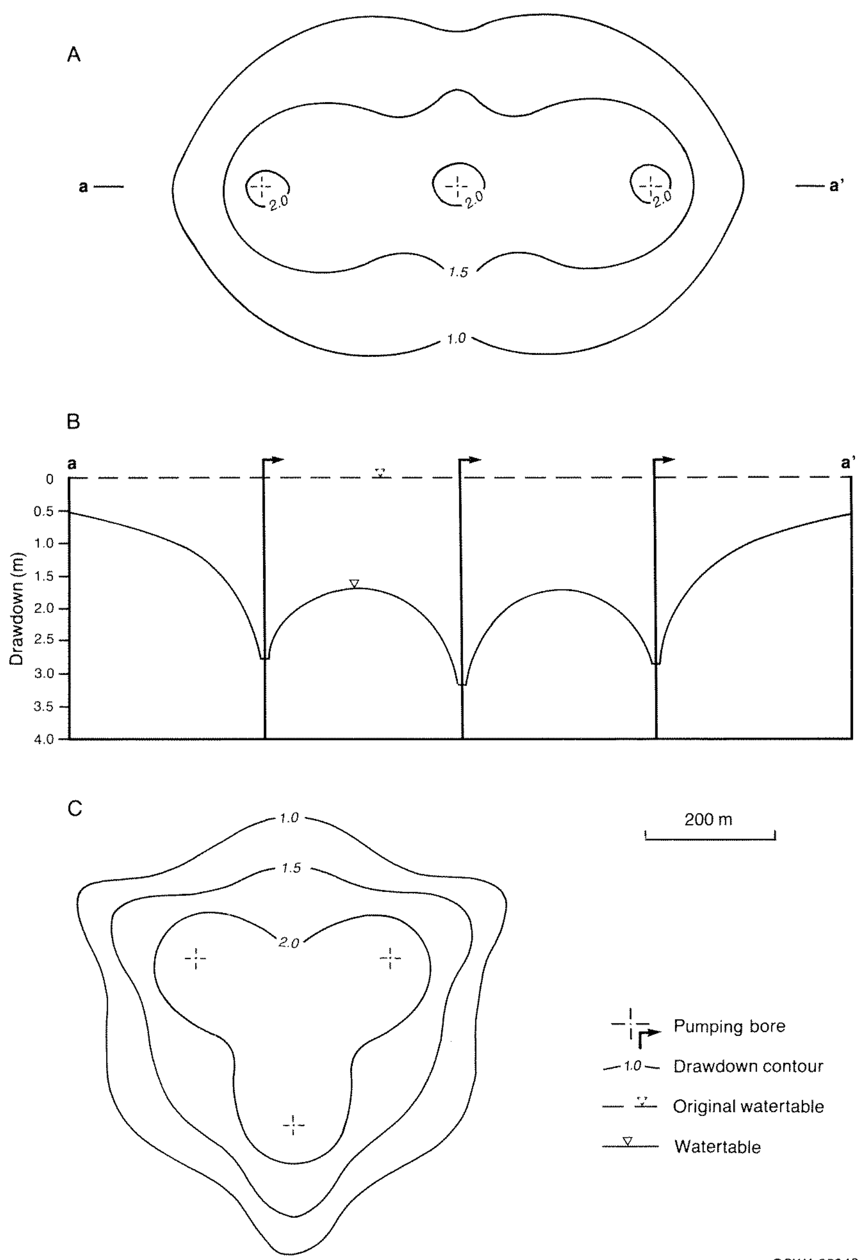

Figure 7. Drawdown resulting from mutual interference
A. Three bores in line
B. Section for Diagram A
C. Three bores at the apices of an equilateral triangle

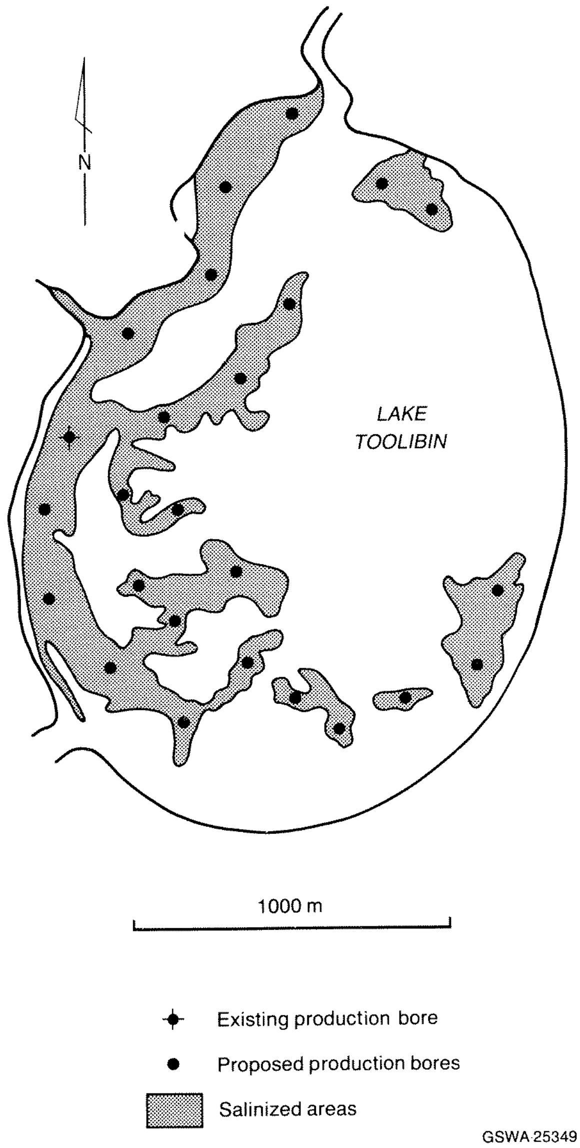

Figure 8. Proposed locations for production bores

Toolibin became completely salinized, and periodically flushed, the effect on the salinity of the Blackwood River may be greater than that resulting from pumping the groundwater to Lake Taarblin and subsequent flushing to the Blackwood River. However, the environmental impact of discharging saline groundwater into the Blackwood River system should be considered.

The potential use of solar distillation technology to recover freshwater and salt products from the groundwater pumped from Lake Toolibin should also be examined.

Conclusions

The aquifer beneath Lake Toolibin is about 33 m thick and is heterogeneous and unconfined with a watertable less than 2 m below the lake floor, and salinity at that level of 30 000–60 000 mg/L. The hydraulic parameters of the aquifer are: transmissivity 4.92 m^2/d, hydraulic conductivity 0.15 m/d, and specific yield 0.01.

Control of salinization at Lake Toolibin can be achieved by lowering the watertable by mutual interference from pumping production bores located 300 m apart. Pumping from nine production bores on the western side of the lake and sixteen at other sites would lower the watertable by at least 1.5 m in areas which are threatened by salinization. About 20 shallow (<4 m) observation bores, midway between production bores, would be required to monitor the effect of pumping.

The discharging of saline water to Lake Taarblin is unlikely to significantly affect salinity in the Blackwood River, but both the environmental impact of this discharge, and the feasibility of salt and of freshwater reclamation by solar distillation should be considered.

The results from this investigation show that pumping groundwater can lower the watertable and thereby assist in the control of land salinization resulting from the clearing of native vegetation in agricultural areas of Western Australia.

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