TECHNICAL REPORTS ON THE HYDROLOGY OF PINK LAKE

Department of Conservation and Environment
Perth, Western Australia

Technical Series 4 February 1986

TECHNICAL REPORTS ON THE

HYDROLOGY OF PINK LAKE

to the

PINK LAKE HYDROLOGICAL STUDY GROUP

by

D HURLE AND ASSOCIATES

Department of Conservation and Environment
Perth, Western Australia

Technical Series 4 February 1986

ISSN 0817-8372
ISBN 0 7309 0667 1

CONTENTS

PART 1

HYDROLOGICAL STUDIES

AT

PINK LAKE ESPERANCE

CONTENTS

FIGURES

TABLES

1. INTRODUCTION

The increasing demands on the uses of Pink Lake and adjacent areas at Esperance has led to the need to have a more detailed understanding of the area's hydrology. Land use impacts on the lake can then be defined and appropriate planning and management procedures can be employed.

The major uses of the lake are:

- tourism, due to its natural pink colour;
- extraction of high grade salt; and
- algal cultivation and harvesting.

In addition, the catchment area of the lake is also used for:

- agricultural development, mostly to the north and west;
- groundwater pumping for Esperance township supply from the coastal dune aquifers; and
- general industrial development such as roads, railway line, etc.

There is concern that these uses may have some effects on the regional hydrology, which may change the water, salt and nutrient balance of the lake and, in turn, affect the biological status which causes its pink colour.

Following briefing by Mr Trevor Bestow of the State Geological Survey and Mr Ian Loh of the State Public Works Department, a two-day site visit to Esperance was undertaken with Mr David Galloway, the Project Manager from the Department of Conservation and Environment.

During this visit, discussions were held with personnel from Esperance Shire Council, Western Salt Refineries Pty Ltd and representatives of Vitamins Australia Ltd in order to:

- define the hydrological study programme;
- assess the resources available for the programme; and
- obtain existing data relevant to the study.

Following a preliminary assessment of the hydrology of Pink Lake (Hurle and Associates, 1984), a detailed field survey was undertaken to:

- quantify the total water and salt storage within the lake system and in the sedimentary soils beneath the lake surface;
- estimate the salt and water balance components in terms of inflows from surface and groundwater, and losses by evaporation and salt harvesting; and
- determine any significant nutrient inflows to the lake by drainage from agricultural lands.

This was achieved by undertaking an extensive core drilling programme on, and adjacent to the lake. Core samples were analysed for salt and water storage. The core holes were lined with slotted casing and used as observation wells which were monitored over the 1984-1985 summer.

Additionally, the Public Works Department's Water Resources Branch undertook a hydrographic survey of the lake at the end of winter 1984, to determine total water and salt storages.

To estimate surface water and salt inflow, surface water flow-rates and water salinity were measured on some small streams feeding the lake during August 1984.

2. ENVIRONMENT OF THE STUDY AREA

2.1 GEOGRAPHY AND CLIMATE

Pink Lake (Lake Spencer) is situated approximately 4 km to the west of the Esperance township in the south of Western Australia (Figure 1). The land is generally very flat, within the area. Typical surface elevations range from about 2 to 30 m above sea level. The coast is indented with numerous rocky headlands. The lake is separated from the coast in the south and south-east by low sand dunes. To the north and north-west of the lake, surface gradients are smaller and surface-water drainage is poorly defined. Pink Lake is less than 1 km south-west of Lake Warden, which is considerably less saline. Surface drainage between the lakes would be negligible due to the construction of the railway embankments.

Annual rainfall varies from about 700 mm near the coast and decreases northwards to less than 400 mm/yr some 70 km inland. The average annual pan evaporation exceeds average rainfall by more than 1 m/yr. Rainfall is strongly seasonal and falls in winter. It often exceeds measured evaporation from May to August. Table 1 lists the long-term average climatic data for Esperance township.

Table 1. Esperance Climatic Data.

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
Rainfall (mm)	15	31	23	51	75	85	93	83	57	52	40	18	623
Pan Evap (mm)	245	202	180	123	96	69	78	96	117	164	192	236	1798
Mean Monthly Temp (^oC)	20.1	20.5	19.6	17.4	14.9	12.8	12.1	12.6	13.9	15.2	17.3	18.9	16.3

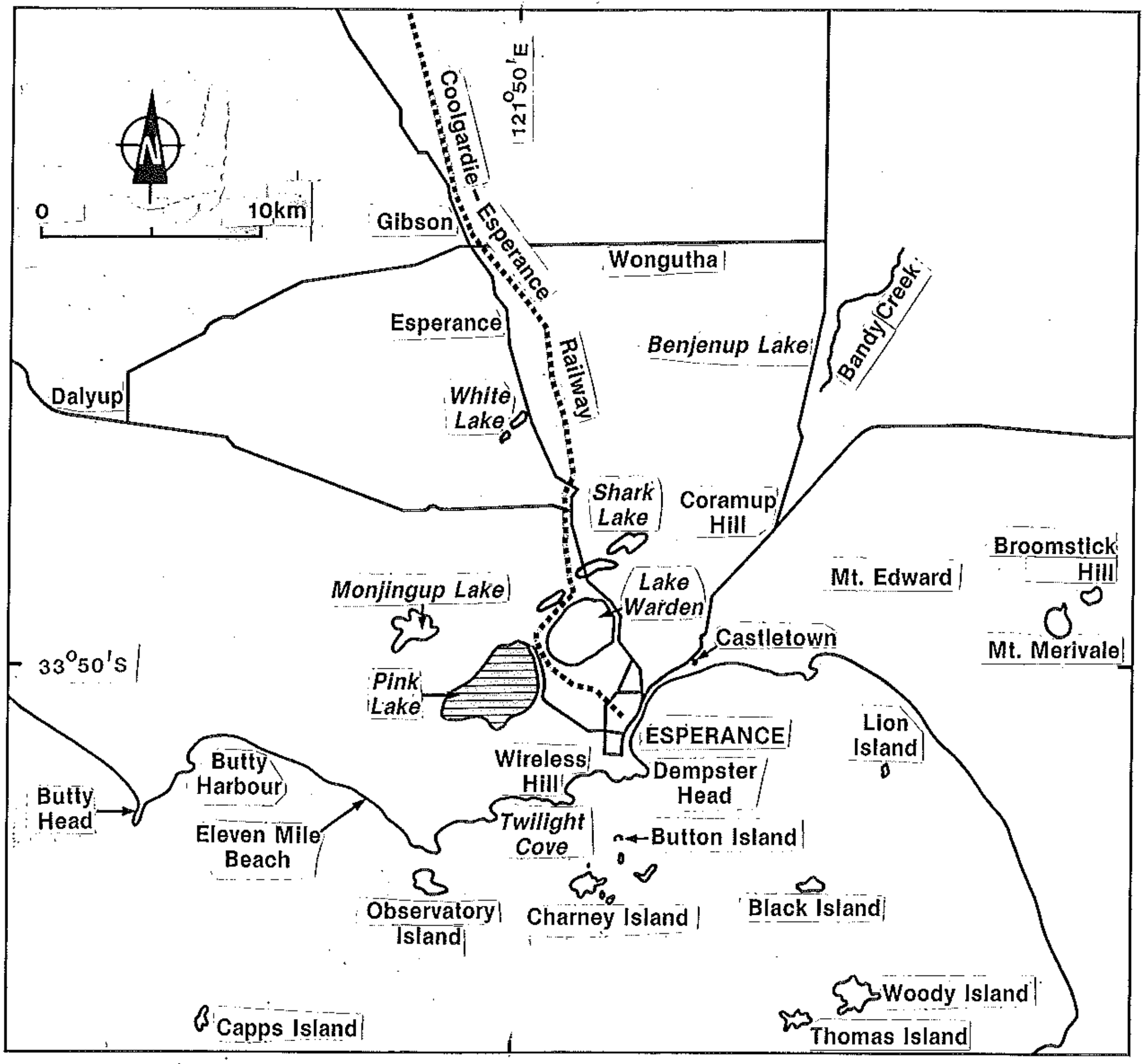

Figure 1. General Location Plan.

2.2 GEOLOGY

Regional geological mapping has been undertaken by the Mines Department (Sheet SI/5-6,10 International Index, Morgan and Peers, 1973). Within the area of the Pink Lake, the Precambrian basement of genisses and granites is exposed locally on the north-western edge. The lake-bed is covered by silt and clay alluvial material. These materials are locally underlain by the siltstones, claystones and sandstones of the Tertiary Pallinup and Werrilup Formations, which overlie the Precambrian basement; but it is unknown whether the lake-bed is sufficiently incised to intersect these formations.

The soils surrounding the lake to the south and south-west are Quaternary coastal dune sands which overlie the Pallinup Formation. Groundwaters encountered in these sands are generally of higher quality (potable) and of higher yield than in the underlying materials, and provide the water supply for the town of Esperance.

To the north and north-west of the lake, less is known about the geohydrology due to the fact that groundwaters are generally more saline (>5 000 mg/l) and of little use for farm or stock water supplies.

Bore drilling records held by the State Geological Survey were examined to define the geological conditions experienced near Pink Lake. The records of four bores (Nos 29, 45, 51 and 74) are listed in Part 2.

2.3 HYDROLOGY OF THE STUDY AREA

The general hydrogeological setting of the Pink Lake area is relatively well known, due to the extensive drilling that has been undertaken to provide township and farm water supplies. The relationship between these groundwaters and salt and water balances of Pink Lake, however, is not well known.

Few clearly defined stream channels discharge into Pink Lake. Surface flow from the northern catchments appear to terminate in Lake Warden approximately 1 km to the east. During flood years, lakes to the east and north of Pink Lake fill and interconnect to Lake Warden (PWD, Personal Communication). However, this system is separated (by surface flow) from Pink Lake by the high ground of the railway construction. It is very likely, however, that groundwaters may flow from the Lake Warden area to Pink Lake. Figure 2 shows a general plan of the study area.

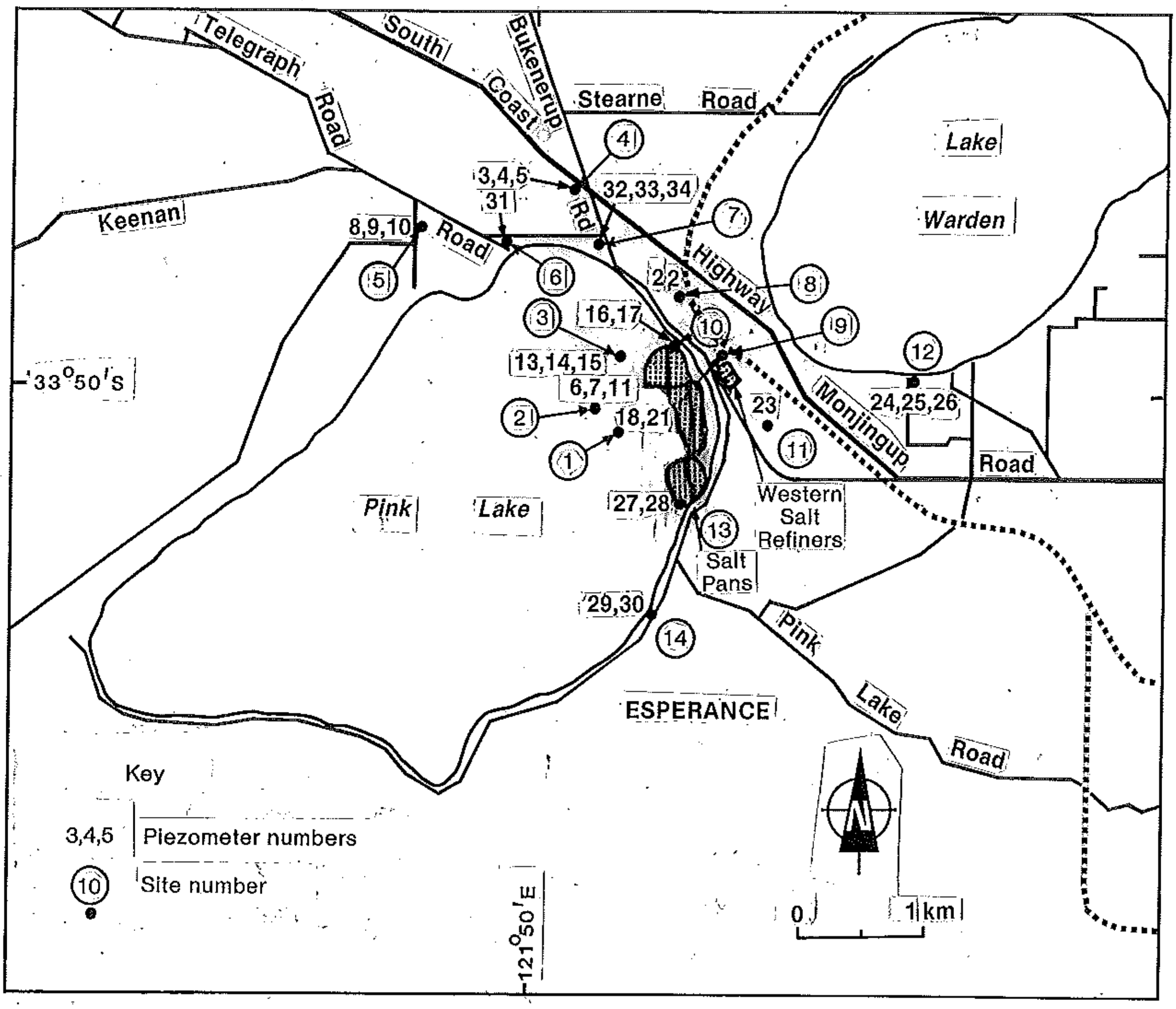

Figure 2. Plan of Study Area.

The quaternal coastal sands, west of Esperance and south of Pink Lake, contain a large quantity of potable water (less than 1000 mg/l salts), which is currently used for Esperance township supply.

To the north of the lake, water is generally of poorer quality and fewer exploration bores have been drilled.

Within Pink Lake, average maximum depths of brine are related to seasonal and annual rainfall, but are generally less than 1 m following winter. Similarly, lake-water salt concentration varies throughout the year. Measurements of percent saturation taken by Western Salt Refiners Pty Ltd (Mr F Lister, personal communication) from 1975, have shown that (in 1975) the salt concentration of the water rose from about 40% of saturation (146 000 mg/l) in late June to saturation in the following February (365 000 mg/l). In later years, saturation occurred earlier, and this is thought to be due to the lower winter rainfall than in 1975.

2.4 BIOLOGICAL STATUS

The chemistry and biota of saline lakes in Western Australia, including Lake Warden and Pink Lake, have been studied in some detail. For a more complete review, the reader is referred to (Geddes, De Deckker, Williams, Morton & Topping, 1981).

The presence of the alga *Dunaliella salina* in Pink Lake is important as a tourist resource. In high salt concentrations, this alga accumulates carotenoids and appears red. This causes the lake's natural pink colour.

This accumulation of carotenoids (mostly β-carotene) is attributed to high salt concentration, high light intensity and high temperatures. *D salina* grown in 25 g/l salt concentration are red; whereas it has been reported that when grown in brine having salt concentrations of 12.5 g/litre, the algae has no obvious accumulation of the carotenoids and are green due to their natural chlorophyll colour.

In lakes which have salt concentrations above 20 g/l, it is possible for both the eukaryotic (blue-green *Dunaliella)* and the procariotic algae *(Cyanobacteria)*, as well as for halophilic bacteria *(Halobacterium* and *Halococcus)* to grow. A review of conditions (including salinity, temperature, light intensity, nutrients) conducive to growth of these organisms in salt-lakes is given by Borowitzka, 1981. The biotechnology of some Australian salt-fields has been described by Jones Ewing & Melvin, 1981. Salt production, although mostly determined by climate, may also be controlled by biological interactions. For example:

- the degree of solar absorption and its consequent effect on evaporation is related to brine colour. Red halophyllic bacteria and algae in brine will reduce the reflection of light from white salt lake floors and increase evaporation;

- an increase in viscosity of brines containing in particular, *Coccohloris*, can result in reduced salt crystallisation; and

- brine clarity can be increased by the presence of the brine shrimp *Artemia salina*.

Consequently, it is apparent that any alteration of the parameters which have led to dominance of *D salina* at Pink Lake may introduce conditions for species changes.

3. THE STUDY PROGRAMME

3.1 HYDROGRAPHIC SURVEY OF PINK LAKE

Water storage in Pink Lake was estimated by measuring water depths along four equally spaced traverses.

These measurements were taken by Years 11 and 12 Science Students from Esperance High School under the supervision of personnel from the Department of Conservation and Environment.

A contour of the lake-bed surface was interpolated from the depth measurements and a depth versus water storage capacity relationship was developed by the Survey Branch, Water Resources Section, Public Works Department.

Figure 3 shows the contour map of water depths interpolated from measurements made in late September 1984.

The derived capacity/depth relationship (Figure 4) was used to estimate the volume storage at this time of about 5 200 000 m^3 of brine. The water was also routinely sampled for salt concentration (by density), and was seen to vary only by about 2% both within the area over the lake, and its depth. Lake-water salt concentration was on average about 214 000 mg/l, which yields an estimate of total surface salt-storage of about 1.1 million tonnes. At the time of sampling, it was reported that there was no salt crystallisation apparent on the lake-bed. This estimate is approximately double that determined in 1981 (Walker, unpublished report).

3.2 SOIL AND WATER SALT STORAGE

The existence of deep relatively saline groundwaters in areas adjacent to the lake indicated that considerable quantities of salt were stored in the sedimentary soils beneath the lake surface.

In September 1984, a drilling programme was undertaken to sample the soils profiles at sites on and adjacent to Pink Lake.

Coring was attempted using the CSIRO's 'LINKEN' drilling rig, which was equipped with hollow-stemmed augers and wire-line core recovery equipment. It was impossible to obtain satisfactory core recovery due to the generally loose nature of the sands and silts, so soil samples had to be obtained from the drill cuttings.

Samples were sealed in tins and later analysed for gravimetric water content and soil salt storage.

Thirty-four holes were drilled at 14 sites on and adjacent to the lake (Figure 2). Generally, three holes were drilled at each site. One hole was drilled and sampled to maximum drilling depth (defined by encountering bedrock or by drilling conditions). The PVC casing was slotted over the bottom two metres, and the hole back-filled with drilling spoil. A second hole was drilled, sampled and screened over an intermediate section of the profile, but within the sedimentary clays and silts. A third hole was drilled into the surfical materials (generally less than 5 m). Part 3 lists the drilling depths and level data at each drilling site.

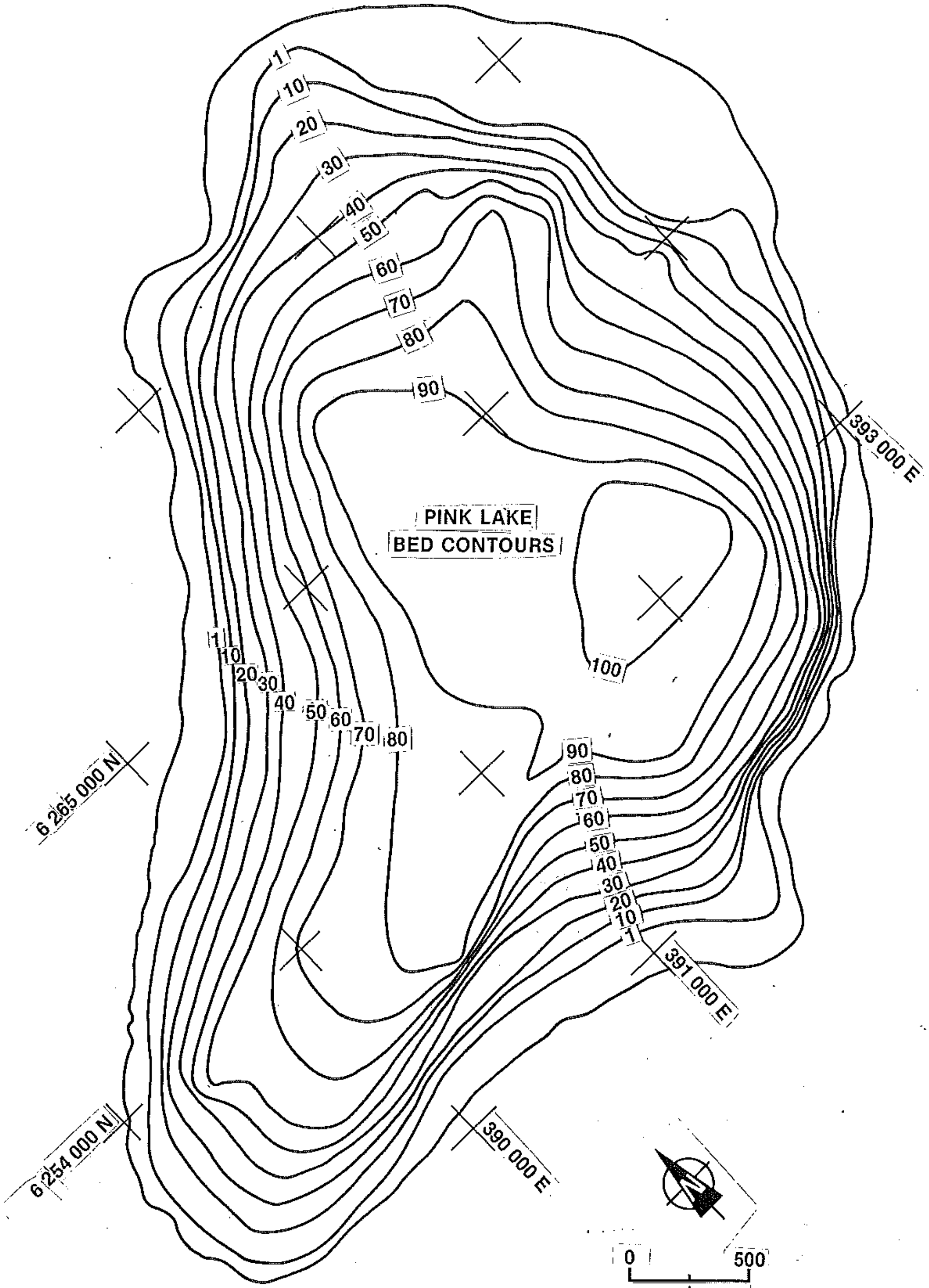

Figure 3. Contour Map of Lake Depths (depth contours in centimetres).

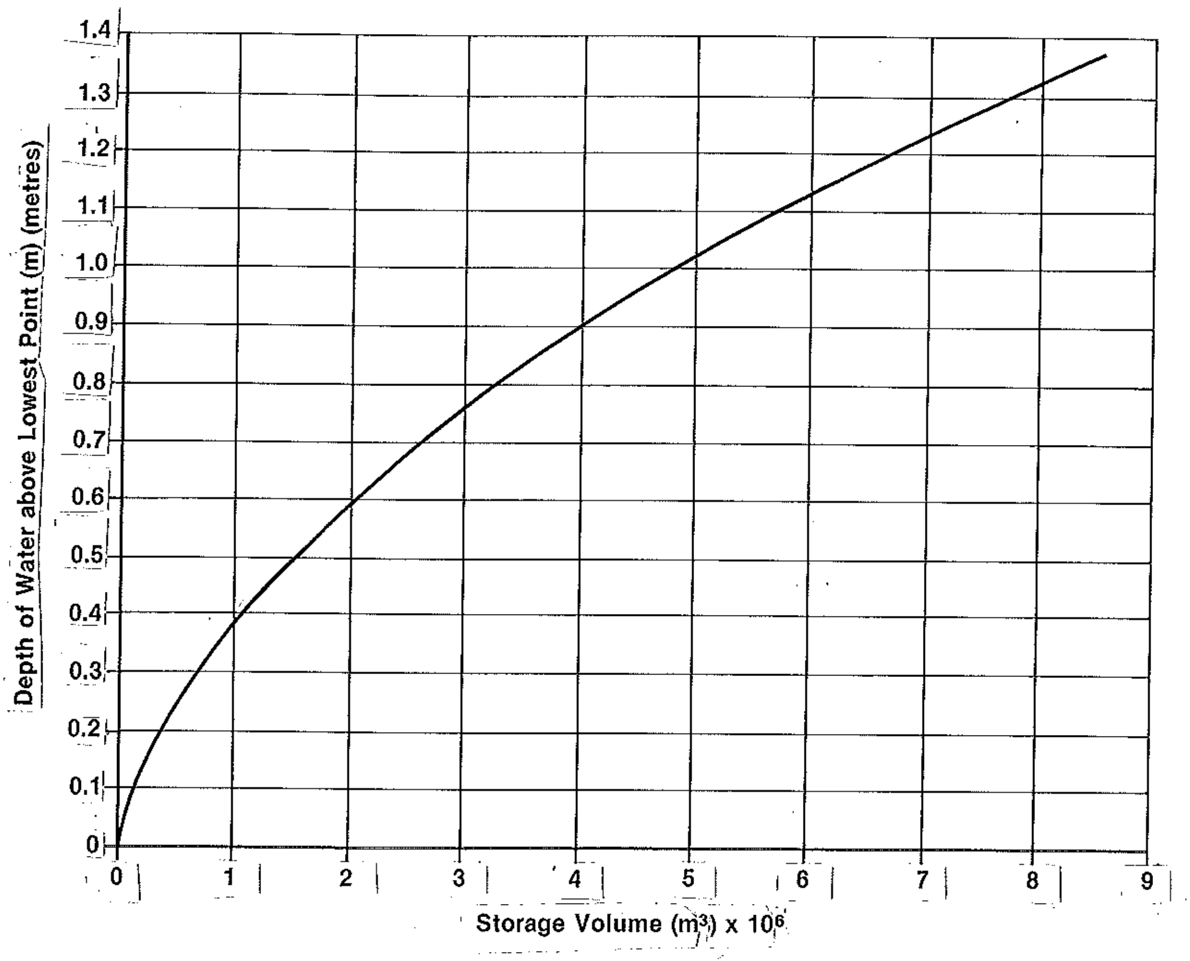

Figure 4. Pink Lake Capacity Versus Depth Curve.

Six sites were drilled on the surface of Pink Lake. Drilling was restricted to areas accessible by crystalliser pond roads, or from Eleven Mile Beach Road. Sites on the lake were numbered 1, 2, 3, 10, 13 and 14. Soil salt storages were seen to be related to profile depth within these bores. On the lake's edge, depths to bedrock were relatively shallow (less than 10 metres), whereas on the lake, the depths of alluvials above the bedrock often exceeded the rig's limit of drilling.

Estimates of total profile storage of water and salt was made for the deepest cored hole at each site (Table 2).

Total water storages were seen to vary from about (m^3/m^2) in the shallowest site, to about 17 m^3/m^2 at Site 9. Similarly, salt storages varied from about 1600 kg/m^2 at the shallow Site 11. Average water solute concentrations varied from 153 000 mg/l on the lake to about 2000 mg/l at Site 11.

Salt storages in the lake sediments may be as much as 18 x 10^6 tonnes, but this estimate will be highly dependent on the total alluvial volumes above the bedrock.

Water samples were taken from nested piezometers on the lake sites to examine any variation in water quality with depth.

Analyses undertaken on these samples are listed in Table 3. Although there is apparent variation in total salinity levels at different depths, the total ionic concentrations were seen to be very high (approaching 80% saturation). Consequently, these waters are seen as being suitable as brine for salt production, should expansion of this harvesting at Pink Lake be required.

Table 2. Soil and Water Salt Storages.

SITE	DEPTH DRILLED (M)	SALT STORAGE kg/m^3	WATER STORAGE m^3/m^3	AVERAGE GROUNDWATER CONCENTRATION $mg\ l^{-1}$
2	29.0	1580	-	-
3	19.0	1440	9.4	153 000
4	24.6	210	11.8	
5	16.3	150	10.4	14 400
6	2.4	14	0.8	17 500
7	22.1	100	16.9	5 900
8	4.4	10	1.8	5 600
9	22.0	1050	17.3	60 700
10	7.9	320	5.4	59 300
11	7.0	6	3.3	1 800
12	22.1	100	10.3	9 700
13	7.5	215	5.2	41 300
14	8.6	150	9.8	15 300

3.3 INFILTRATION RATES ON THE LAKE SURFACE

Six infiltration tests were carried out on the lake surface during summer 1985. Three were located near the salt crystaliser ponds (Drilling Site 1), and three on the north-east corner of the lake (Vitamins Lease). Steady (long-term) infiltration rates were variable both within and between sites. Values ranged from about 0.1 to 0.5 m/day, indicating that there may be a potentially high loss rate from brine ponds.

3.4 STREAM-FLOW CONTRIBUTION TO LAKE WATER

A site inspection of streams feeding the lake was made during winter 1984.

Table 3. Chemical Analysis of Groundwater in Deep Bores on Pink Lake. (ml/l)

	Na	K	Ca	Mg	Fe	Cl	HCO^3	SO^4	TOTAL IONS
SITE 1									
BORE PK 1	78750	1600	365	10000	4.2	142900	429.0	16000	250 000
BORE PK 2	85000	1800	355	-	-	-	-	-	-
SITE 2									
BORE PK 7	67500	1100	1205	8000	4.0	120300	274.5	11310	209 600
BORE PK 11	85000	1600	340	9750	4.3	150900	416.0	17900	265 900
SITE 3									
BORE PK 13	82500	1900	505	13000	4.1	150900	381.9	23500	272 700
BORE PK 14	87500	2000	250	13000	4.0	157500	397.7	22250	282 900
PINK LAKE SURFACE WATER (NEAR SATURATION)									
	130500	3350	210	14500	-	183400	700	23100	356 000

In the north-east, three minor streams were contributing water at rates estimated at less than 0.5 m^3/sec (50 000 m^3/day) immediately following heavy rainfall. Streams to the south and west of the lake were not accessible. Average salt concentrations of this stream-flow were about 300 mg/l (from electrical conductivity measurements). Consequently, salt input to the lake via stream-flow can be estimated at about 800 tonne/annum (assuming stream-flow contributes 50% of the lake water volume). This is thought to be a conservatively low estimate since stream-flow salinities may be higher in other surface water inflow than at other times during the winter flow period.

3.5 GROUNDWATER CONTRIBUTION TO LAKE WATER

Groundwater and salt inflow estimates to the lake are extremely difficult to quantify without undertaking a comprehensive drilling, hydraulic testing and monitoring programme.

This study would need to provide details of small-scale hydrogeology, distribution of hydraulic gradients, permeability, and spatial variation in salt concentrations throughout the contributing groundwaters.

Order of magnitude estimates of water and salt inflow to the lake can be obtained by considering bulk average hydraulic values and solute concentrations and using Darcy's Law:

$$Q = K\ i\ d\ P$$

where Q = flow of water to the Lake ($m^3\ d^{-1}$)
K = hydraulic conductivity ($m\ d^{-1}$)
i = average hydraulic gradient ($m\ m^{-1}$)
d - average aquifer flow depth (m)
P = length of flow section (m)

and $$Q_C = QC$$

where Q_C = salt contribution to the Lake by groundwater flow $kg\ d^{-1}$

C = average salt concentration of groundwater inflow $kg\ m^{-3}$

Values adopted are:

$K = 1.0\ m\ d^{-1}$
$i = 1 \times 10^{-2}\ m\ \ m^{-1}$
$d = 20\ m$
$P = 1000\ m$
$C = 5\ kg\ m^{-3}$ ($5\ 000\ mg\ d^{-1}$)

Then the water inflow is estimated as:

$$Q = 200\ m^3\ d^{-1} \text{ per km}$$

and $$Q_C = 2\ 000\ kg\ d^{-1} \text{ per km}$$

Assuming a contributing perimeter of 15 km, inflow estimates becomes:

Water inflow $Q = 1.1 \times 10^6\ m^3\ yr^{-1}$

Salt inflow $Q_C = 5500\ t\ yr^{-1}$

It must be pointed out that a considerable degree of error may be associated with this estimate. However, in the absence of further data, the value may be used to estimate probable inflows from the surrounding groundwater regime.

4. THE INTERACTION OF LAND USES RELATING TO PINK LAKE

4.1 LAND DEVELOPMENT

Land has been developed for road and railway construction, agriculture and industry within the catchment of Pink Lake.

The construction of the railway line between Pink Lake and Lake Warden is likely to have reduced (or stopped) surface water flows between the two lakes, although it is not known what effect it has had in flood periods. Roads surrounding the lake may result in increased yields of freshwater and sediment, although road compaction may have caused reduced seepage from the fresher shallow groundwaters.

Agricultural development can have a considerable impact on hydrological processes and salt movement. Removal of native vegetation and its replacement with perennial pastures leads to a reduction in evapotranspiration and an increase in recharge to soil water and groundwater. It may also result in increased duration and flows of groundwaters to the various water sinks (such as the terminal lake system), and mobilisation of salts stored in the previously unsaturated soils.

In addition, agricultural practice often requires the application of nutrients (superphosphate), and, on soils where the phosphate fixing capacity is small, a resultant discharge of plant available phosphorus may occur in streams and lakes.

A limited number of water samples were taken from the shallow observation bores, and from surface streams feeding the lake.

Analysis of these samples for nutrients showed very low levels of phosphorus (near to the limit of detection $<50\ \mu g/l$) and, consequently, no further analyses were undertaken. Apparently, surface-waters draining the sampled agricultural land were not adding significant amounts of phosphorus to the lake.

Shallow groundwaters were also low in phosphorus, indicating that phosphorus transport by groundwater flow to the lake was insignificant. The large quantities of biological mass on the lake-bed may also act to remove nutrient inflow to the lake.

4.2 SALT PRODUCTION

Salt has been harvested from Pink Lake for many years. It is reported as being of very good quality, and for lake-salt, having a relatively large crystal.

Lease areas on the lake for salt production amount to about 220 ha. In 1980, salt production was increased from about 1 000 tonnes/year to about 10 000 tonnes/year. Actual production by Western Salt Refineries Pty Ltd over the past six years is given as follows:

YEAR	TONNES
1978/79	2 000
1979/80	800
1980/81	9 000
1981/82	10 500
1982/83	10 000
1983/84	11 000

Assuming that there is total salt storage on the lake of about 1.1×10^6 tonnes, and that extraction rates for salt production exceed inflow rates by approximately 4 000 tonnes/year, then without considering any other sources/sink of salt on Pink Lake, the resource is being depleted at a rate of less than 1% per annum. This depletion rate is immeasurable in the short term. In the longer term, salt level reduction may be difficult to determine because of seasonal variations in climatic conditions affecting salt and water inflows.

Of concern to the salt producers (as well as to others) is a change in lake biology that may be brought about by changes in salinity, nutrient levels, etc. In particular, it has been reported that blooms of the phytoplankton *Coccochloris* in salt fields in Northern Queensland gave rise to brine viscosities which were undesirable for salt production (Jones et al, 1981).

The interaction between salt production and biological status is very complex. In order to ensure that the yields and quality of salt produced from Pink Lake are maintained, it may be necessary in future to determine any factors that alter the lake's biological environment.

4.3 ALGAL HARVESTING

The proposed algal harvesting project will involve initially in the pilot phase:

- the establishment of 10 ha of test ponds on the lake lease area; and
- the construction of pilot facilities for the production of approximately 20 tonnes per year dry weight of the algae in the first year. This is expected to increase to a production level of about 200 tonnes per year in the third year, following improvements in cultivation and harvesting techniques.

Water containing the algae will be drawn from the cultivation ponds. The concentration of algae will be increased by filtration to approximately 30% by weight. The remaining water will be recirculated to the cultivation ponds. It is not expected that any make-up water will be required for the cultivation ponds (Vitamins Australia, personal communication).

The salt concentration will be adjusted to levels sufficient to maximise algal growth within the lake's cultivation ponds. The ponds will also be subjected to nutrient injections prior to the harvesting operation.

The ponds will be constantly monitored during this phase. In particular, observation holes will be installed for monitoring the areas of lake adjacent to the ponds to ensure that there is no leakage of pond water to the lake.

The project will provide greater understanding of the lake/biota system, since algal harvesting is entirely dependent on the requirement to increase yields of the algae which causes the lake's pink colour. This will benefit the long-term management of the lake.

4.4 GROUNDWATER ABSTRACTION

Groundwater from quarternary sand aquifers in Pink Lake's south-eastern area is pumped to provide supplies for the Esperance township. Groundwater modelling studies carried out in 1981 by the PWD (Loh, personal communication) suggested that as much as 0.2×10^6 m^3 per year per hectare of water discharged from this aquifer into Pink Lake under zero pumping conditions.

Draw-downs, obtained by simulating expected abstraction for township supply, were predicted to cause reductions in inflow to the lake. In the long term, these inflow reductions may be as much as 50% of the estimated prepumping rates. However, it is not expected that groundwater abstraction from this aquifer will cause a reversal of groundwater flows from Pink Lake.

Groundwater levels in relation to pumping are continually monitored by PWD personnel.

5. SUMMARY AND RECOMMENDATIONS

The limited hydrological study programme has provided information relating to the water and salt balance components of the lake.

Drilling has shown that there is a considerable amount of saturated sediments beneath the lake surface which contain salts at high concentrations. The total amount of salt stored in this groundwater body may be as much as about 20 times that stored on the lake surface.

Although access limited drilling on the lake, it was apparent that at certain times of the year there was an upward hydraulic gradient, indicating that salts stored in the deeper soil profile may move to the lake surface. Rates of upward salt transport could not be determined without additional detailed hydraulic studies. Saline groundwaters appear to feed the lake groundwaters from the north. Again, rates of inflow could not be determined due to the limited data collected during the study. It is thought, however, that this input exceeds salt input to the lake from surface sources.

No drilling was undertaken in the south-east of the lake. Consequently, throughflow could not be determined, although it is thought that the lake is the drainage terminal.

Ponded infiltration rates on the lake surface during summer were as much as 1.5 m/day. This figure compares with apparent brine losses from the salt crystalliser pond during salt production.

This infiltration loss may be significant to algal pond construction and management procedures.

In summary, existing land uses on the lake and surrounding catchment are not expected to severely impact on the current hydrological and salinity status in the short term. Consequently, it is thought that routine assessment is not required given the existing uses. However, it may be required to resurvey salt storages on the lake surface in the longer term.

6. REFERENCES

Borowwitzka L J, (1981), The Microflora: Adaptions to Life in Extremely Saline Lakes, in W D Williams 'Salt Lakes', Proceedings of the International Symposium on Athallassic (Inland) Salt Lakes, Adelaide, October 1979.

Geddes M C, De Deckker P, Williams W D, Morton D W, and Topping M, (1981) On the Chemistry and Biota of Some Saline Lakes in Western Australia, in W D Williams, op cit.

Hurle D and Associates (1984), Preliminary Assessment of the Hydrology of Pink Lake, Department of Conservation and Environment, Unpublished Report.

Jones A G, Ewing C M, and Melvin M V, (1981), Biotechnology of Solar Saltfields, in W D Williams, op cit.

Morgan K H, and Peers R, (1973), 'Esperance-Mondrain Island' Geological Series - Explanatory Notes. Sheet SI/51-6, 10 International Index.

Walker G, (May 1981), Pink Lake Esperance WA, Assessment of Brine and Salt Reserves, Cheetham Salt, Unpublished Report.

PART 2

Appendix 1 of the Hydrology of Pink Lake.

SELECTED BORE DRILLING RECORDS

(From Geological Survey Records)

REGD NO 3230-II-D-29

BORE NAME : Esperance Exploratory No 4

LOCATION : 1:250,000 : SI/51-6 (Approx 2 km NW of Pink Lake)

DEPTH : 30.48 m

STATIC WATER LEVEL : 2.74 m

QUALITY : 4.3 m 875 m/l

21.3 m 980 m/l

DRILLING LOG

FROM	TO	
Metres		
0	0.6	Surface soil.
0.6	5.2	Soft limestone.
5.2	8.8	Fine sand, shells and limestone.
8.8	11.3	Fine soft limestone.
11.3	13.1	Limestone and shells.
13.1	16.8	Yellow limestone and shells.
16.8	22.3	Green and brown clay, sandy.
22.3	25	Clay various colours.
25	28.3	Brown clay, sandy.
28.3	30.5	White clay.

REMARKS: Bore filled in.

REGD NO 3230-II-D-45

BORE NAME : Exploratory Bore No 25

LOCATION : 1:250,000 : SI/51-6 (Approx 2 km NW of Pink Lake)

DEPTH : 21.3 m

STATIC WATER LEVEL : 1.8 m

QUALITY : Not recorded

DRILLING LOG

FROM	TO	
Metres		
0	1.2	No sample, driller reports dry grey sand.
1.2	7.6	Sand, calc, fine to medium grained, fossiliferous grey.
7.6	9.1	No sample, driller reports soft limestone.
9.1	9.8	Limestone, shelly, hard well consolidated fine to medium grained, grey, driller reports very dry hard clay.
9.8	21.3	Sandstone, calc, medium grained, fossil to shelly, possible glauconitic, pale olive green.

REMARKS: Clay kept blocking the hole leading into filter, water approx 1.8 m from ns.

REGD NO 3230-II-D-74

BORE NAME : Esperance Exploratory No 42 : Pink Lake

LOCATION : 1:250,000 : SI/51-6 (Approx 2 km NW of Pink Lake)

DEPTH : 27.7/15.2 Drilled/Measured

STATIC WATER LEVEL : 2.7 m

QUALITY : Not recorded

<u>DRILLING LOG</u>

FROM	TO	
Metres		
0	0.6	Surface soil, fine, black.
0.6	6.1	Sand, clayey, fine, grey.
6.1	11.3	Sand, fine, white.
11.3	21.3	Clay, sandy, grey.
21.3	27.7	Clay with coarse gritty sand.
27.7		Hard granite.

REMARKS: Watercut at 10.9 m rose 7.9 m to 3 m below surface; (?) graded metal filter pack 15.24 m to surface. Backfilled with crushed metal to 15.2 m. Bore developed; supply is very low from this very fine sand aquifer. Dismantled, abandoned and backfilled.

REGD NO 3230-II-D-51

BORE NAME : 156

LOCATION : 1:250,000 : SI/51-6 (Approx 2 km NW of Pink Lake)

DEPTH : 14.3 m Drilled/Measured

STATIC WATER LEVEL : 11.6 m

QUALITY : 840 m/l

DRILLING LOG

FROM	TO	
Metres		
0	6.1	Sand.
6.1	12.2	Grey silica and sand.
12.2	14.3	Limestone with fine sand.

REMARKS: Casing 100 m steel with 1.8 m of double mesh screen at bottom.

PART 3

Appendix 2 of the Hydrology of Pink Lake.

DETAILS OF BORES

	DEPTH DRILLED (M)	RELATIVE LEVEL TOP OF CASING (M.AHD)	RELATIVE LEVEL GROUND LEVEL (M.AHD)
SITE 1			
BORE PK 1	23.0	2.86	2.29
PK 2	10.0	2.86	2.30
PK 12	4.0	2.83	2.36
SITE 2			
BORE PK 6	3.0	2.60	1.83
PK 7	28.0	2.63	1.78
PK 11	14.0	2.48	1.77
SITE 3			
BORE PK 13	19.0	2.72	2.13
PK 14	10.0	2.75	2.20
PK 15	4.0	2.78	2.26
SITE 4			
BORE PK 3	24.2	7.64	7.16
PK 4	14.5	7.29	6.95
PK 5	3.9	7.45	6.99
SITE 5			
BORE PK 8	16.0	8.69	8.21
PK 9	7.0	8.82	8.30
PK 10	4.0	9.23	8.77
SITE 6			
BORE PK 31	1.8	6.34	5.83
SITE 7			
BORE PK 32	22.1	5.54	5.02
PK 33	13.0	5.57	5.04
PK 34	3.9	5.59	5.08
SITE 8			
BORE PK 22	4.4	4.94	4.52
SITE 9			
BORE PK 18	22.0	4.39	3.91
PK 19	16.0	4.34	3.81
PK 20	10.0	4.36	3.90
PK 21	4.0	4.32	4.06
SITE 10			
BORE PK 16	7.9	2.87	2.36
PK 17	4.0	3.03	2.38
SITE 11			
BORE PK 23	7.0	5.60	5.11
SITE 12			
BORE PK 24	27.1	7.60	7.11
PK 25	14.5	7.55	7.10
PK 26	7.0	7.51	7.09
SITE 13			
BORE PK 27	6.3	2.80	2.27
PK 28	4.0	2.76	2.27
SITE 14			
PK 29	8.5	2.36	1.93
PK 30	4.0	3.60	2.72

PART 4

Comments by the Geological Survey of Western Australia on the Salt and Water Balances as described in the Report to the Pink Lake Hydrological Study Group

by D Hurle and Associates

GEOLOGICAL SURVEY OF WESTERN AUSTRALIA

MINERAL HOUSE · 66 ADELAIDE TERRACE · PERTH · WESTERN AUSTRALIA · 6000

TELEPHONE (09) 222 3333
TELEGRAMS "WAMINES" PERTH
TELEX AA 95791 MINEWA
FACSIMILE (09) 325 1920

Please address all letters to: DIRECTOR

The Director
Department of Conservation
and Environment
1 Mount Street
PERTH WA 6000

Your Ref:
Our Ref: GS 261/84
Enquiries to: TTB:DCL
Telephone:

PINK LAKE HYDROLOGICAL STUDY

A draft report by the consultants engaged to carry out a hydrological study on Pink Lake, Esperance has been referred to this office for comment.

1. The report records the drilling of 34 bores on 14 sites but does not include descriptions of the lithology penetrated by drilling or provide details of the reduced water levels. The lack of an indication as to where granitic basement was struck has a bearing on estimates of the amount of salt stored below the lake. The absence of careful hydraulic head measurements on the bores precludes adequate review of head variations with depth and the assessment of hydraulic gradients on which rates of groundwater movement could be assessed.

2. The report does not include any assessment of the water balance of the lake which potentially provides a key to the salt balance. In consequence the description of the hydrology is incomplete.

The consultant has provided some of the components of the water balance and these are accepted in the solution of the balance equation below:-

Rainfall on lake + Streamflow into lake + Groundwater inflow + Seawater inflow = Evaporative loss + Hypersaline discharge.

Then if the mean annual rainfall is taken as 623 mm over a lake area of 10 200 000 m^2, the rainfall input becomes $6.35 \times 10^6 m^3$.

.../2

The annual streamflow is estimated by the consultant to be equivalent to half the volume of the lake (5 200 000 m^3) which becomes 2.6 x $10^6 m^3$.

The daily groundwater inflow has been estimated as 200 m^3 per km of lake periphery (15 km) so that the annual figure is 1.1 x $10^6 m^3$.

The volume of seawater entering the lake in a convective system is an unknown (A).

The annual pan evaporation as provided by the Meteorological Office is 1793 mm which can be corrected to lake evaporation by the factor 0.8 and applied to the area of the lake to derive a mean annual loss of 14.631 x $10^6 m^3$.

The convective discharge of hypersaline water by downwards movement (D) is an unknown and so the equation becomes:-

6.35 + 2.6 + 1.1 + A = 14.631 + D. (1)

In a directly parallel fashion a salt balance equation can be set up in which each of the water balance components is multiplied by the concentration of salt in that component (with the obvious exception of evaporation).

Thus if the salt concentration in rainfall is taken as mg/L, the weight of contained salt falling directly on the lake is 6.35 x 0.02 x 10^6 = 0.127 x 10^6 kg.

The mean salinity of streamflow has been taken by the consultant to be 300 mg/L so that the weight of salt introduced into the lake annually by this is 2.6 x 0.3 x 10^6 = 0.78 x 10^6 kg.

Similarly the mean salt content of groundwater inflow is 5000 mg/L and the weight of salt carried into the lake by this route is 1.1 x 5.0 x 10^6 = 5.5 x 10^6 kg.

If the concentration of salt in seawater is taken to be 35 g/l then for purposes of calculation the weight of salt introduced by convective inflow is 35A.

As evaporation does not remove salt, the only salt loss (apart from its commecial removal) is by convective downward movement through the bed of the lake. The salinity may be taken to be that of the lake water which is 214 g/L so that the weight of salt removed is 214 D.

..../3

The salt balance equation then becomes:

$$0.127 + 0.78 + 5.5 + 35A = 214\ D \qquad (2)$$

The solution of the simultaneous equations (1) + (2) yields a seawater inflow (A) of approximately $5.5 \times 10^6 m^3$ which introduces approximately 192 700 tonnes of salt to the lake. The annual convective outflow of hypersaline water (D) has a volume of approximately 931 $000 m^3$ and removes approximately 199 000 tonnes of salt.

Quite obviously this approach is subject to substantial errors due to the gross assumptions made both in the assessment of groundwater inflow and stream inflow. Thus if it is assumed that the annual streamflow input to the lake equals its volume rather than half the volume, equation (1) becomes:

$$6.35 + 5.2 + 1.1 + A = 14.631 + D$$

and equation (2):

$$0.127 + 1.56 + 5.5 + 35A = 214\ D.$$

When these equations are solved seawater inflow is reduced to $2.4 \times 10^6 m^3$ which introduces approximately 84 000 tonnes of salt and the convective hypersaline discharge becomes 427 000 m^3 and the salt removed is 91 000 tonnes of salt.

Despite numerical uncertainties the essential point to be made as a result of these calculations is that because lake evaporation exceeds the sum of the rainfall, groundwater and surface water inputs there must be an additional inflow from another source and the only one possible is the sea. Inevitably such inflow will bring with it a large weight of salt which probably grossly exceeds inflow from the sources discussed in the report.

3. The consultant has assessed the salt inflow to Pink Lake from groundwater and streamflow as 6300 tonnes/annum which, with the probable addition of a sea-salt input of at least an order of magnitude higher, makes the proposed salt extraction limit of 14 000 tonnes per annum look very conservative. It probably represents less than 20% of the annual inflow and is certainly less than 2% of the proven lake storage figure.

..../4

It is therefore recommended that the company be permitted to extract up to 25 000 tonnes of salt per annum for three years subject to a further assessment of the lake storage at the end of that period. If this remains at the level assessed by the consultants in 1985, then the extraction limit should be reviewed.

4. The recommendations with respect to the algal processor are entirely acceptable.

5. It is suggested that the forgoing comments be referred to the consultant prior to the finalisation of his report.

R D Gee
ACTING DIRECTOR

GE800SWD108,12,15
21 March 1986