GEOLOGICAL SURVEY OF WESTERN AUSTRALIA

RECORD 1986/13

HYDROGEOLOGY OF LAKE TOOLIBIN

by
M.W.MARTIN

DEPARTMENT OF MINES
WESTERN AUSTRALIA

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MINISTER FOR MINES
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ABSTRACT

Lake Toolibin is one of the few remaining freshwater lakes in the wheatbelt region of southwestern Australia, and provides an important habitat and breeding ground for many native water birds. Degradation of vegetation and salinization in the lake was noted in the late 1970s. From 1977 to 1986, investigations have been undertaken to describe the hydrology and hydrogeology of the lake system, and to formulate management options to preserve Lake Toolibin as a freshwater lake.

Groundwater discharge by capillary rise and evaporation (from the shallow, saline water table beneath Lake Toolibin), occurs when the lake is dry. This results in accumulation of salt in the unsaturated zone, and surface salinization occurs if there is no surface-water inflow to the lake for extended periods. Filling of the lake, by precipitation and surface inflow, results in hydraulic connection of the lake and groundwater system. This enables flushing of salt and its removal by downward and lateral flow of groundwater.

About 95% of the catchment has been cleared for agriculture. The data suggest that the groundwater flow system is not at equilibrium, and groundwater levels can be expected to continue rising. If the water table rises permanently to the floor of the lake, salinization will occur. The certainty or timing of this cannot be predicted, as it may be influenced by variation of the climate.

The continued survival of Lake Toolibin as a freshwater

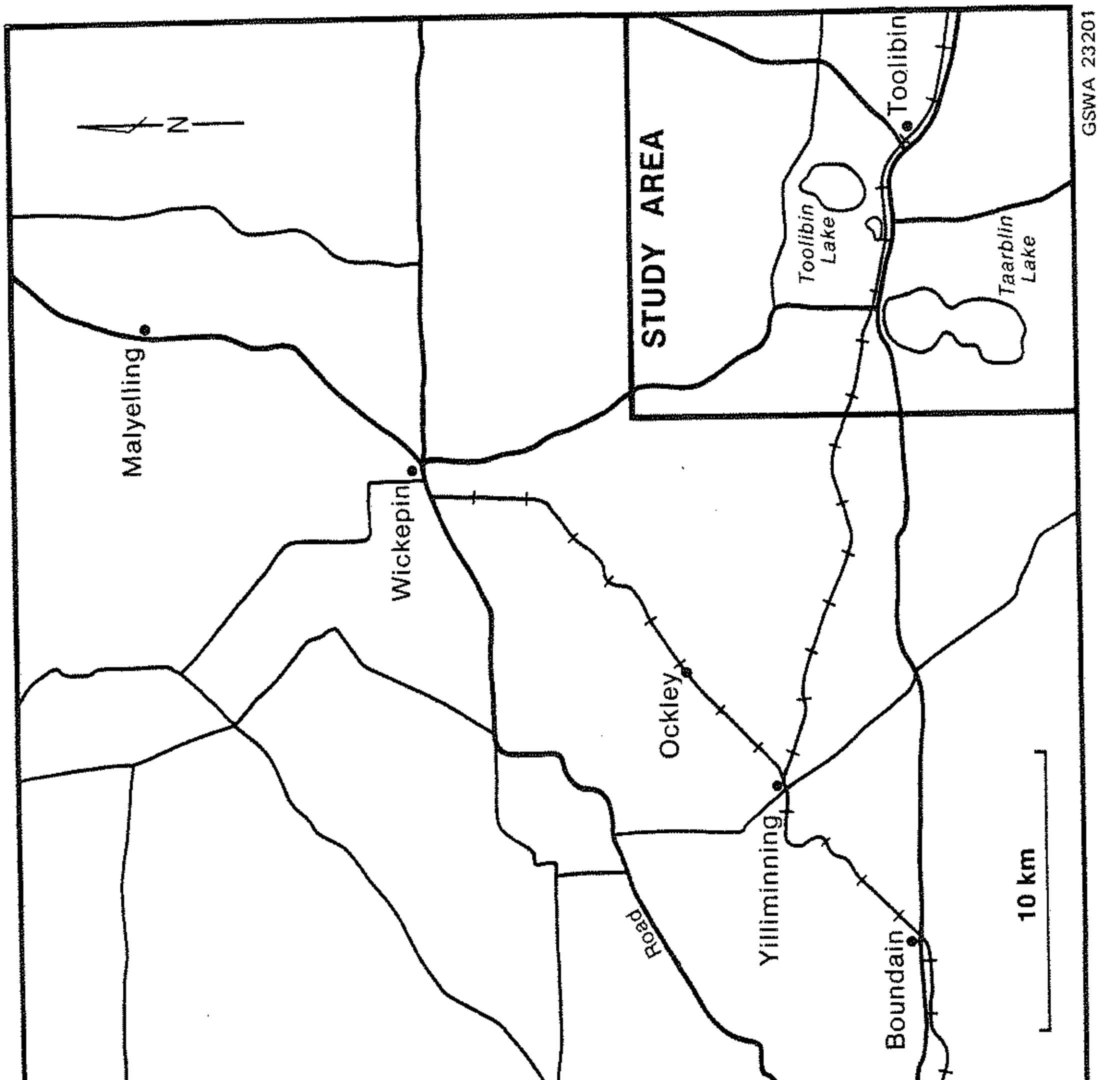


Figure 1. Location

lake is dependent on lowering groundwater levels beneath and around the lake. This may be achieved by planting high water-use vegetation, but may require initial lowering of groundwater levels by mechanical pumping until the vegetation becomes established. Further investigations are required to determine the practical and economic feasibility of lowering groundwater levels.

INTRODUCTION

Lake Toolibin, located about 45 km east from Narrogin (Fig. 1), is a shallow, ephemeral, freshwater lake within the Northern Arthur River drainage system. The lake is an important habitat for indigenous fauna, and provides an important breeding area for a wide range of native birds.

The climate is Mediterranean, with a mild wet winter and hot dry summer. Average annual rainfall for the area is 420 mm, and pan evaporation is 1800 mm.

The catchment for Lake Toolibin has an area of 440 km^2, and clearing of native vegetation within it has resulted in rising groundwater levels, the development of secondary salinization, and increased salinity of streamflow. These have led to degradation and death of vegetation on the western side of Lake Toolibin, and a declining trend in the use of the lake as a breeding ground (N.A.R.W.R.C., 1978).

The Northern Arthur River Wetlands Rehabilitation Committee (N.A.R.W.R.C.) was established in 1977 under the authority of the Minister of Fisheries and Wildlife. The main purpose of the committee is to recommend measures to preserve Lake Toolibin as a freshwater lake, and to rehabilitate other lakes and foreshores downstream to improve the carrying capacities, water quality, and the wildlife value of the system.

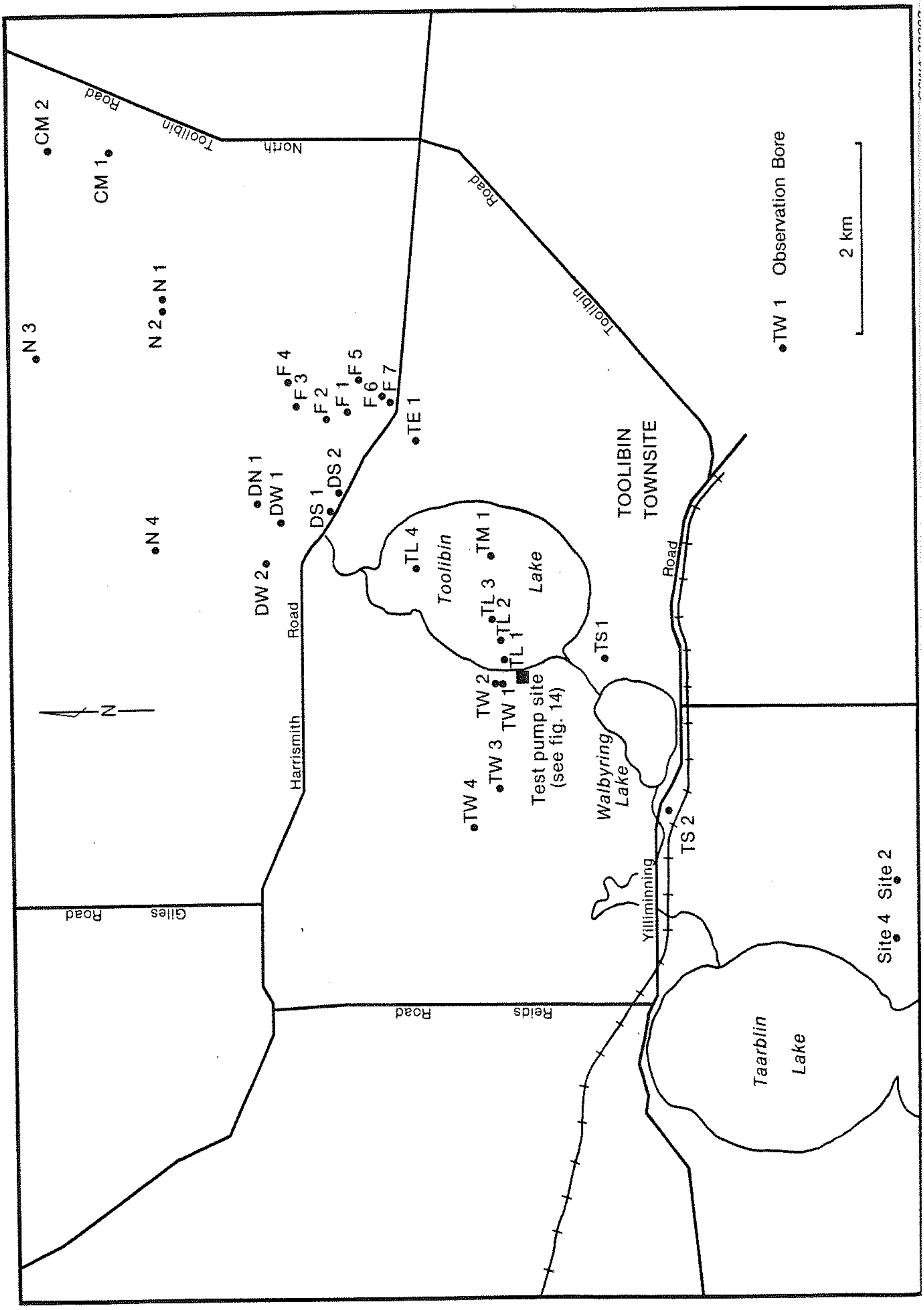


Figure 2. Location of Observation Bores

This report summarizes earlier hydrogeological investigations and describes the results of drilling, aquifer testing, and multiport-bore construction carried out in 1983 and 1985. Groundwater hydrograph data, prepared by the Hydrology Branch of the Water Authority of Western Australia, are also reviewed. The report proposes a groundwater flow system which describes the interaction of the lake and groundwater, and suggests several management alternatives to preserve Lake Toolibin as a freshwater lake.

PREVIOUS INVESTIGATIONS

Following a field investigation in July 1977, Furness (unpublished data, 1977) hypothesized that Lake Toolibin contained fresh water because it was perched on a clay layer above the regional groundwater table. He recommended further investigations to determine the nature of the sediments on the floor of the lake and the establishment of a piezometer network to monitor water levels in the vicinity of Taarblin and Toolibin lakes.

Interpretation of the results of shallow holes drilled at Taarblin (3.0 m) and Toolibin (2.5 m) suggested that both lakes are clay based, also the groundwater beneath the lakes is saline and at shallow depth (Furness, 1978).

Observation bores were constructed in and around the lakes system (Fig. 2), and monitoring of groundwater quality and levels commenced in 1977. The results of the shallow drilling at Lake Toolibin were summarized by Collins (unpublished data, 1982).

A seismic refraction survey, which was carried out at Lake Toolibin in 1980, indicated an unconsolidated layer (less than 3m thick) overlying indurated lake sediments or weathered granite. The depth to fresh granite ranged from

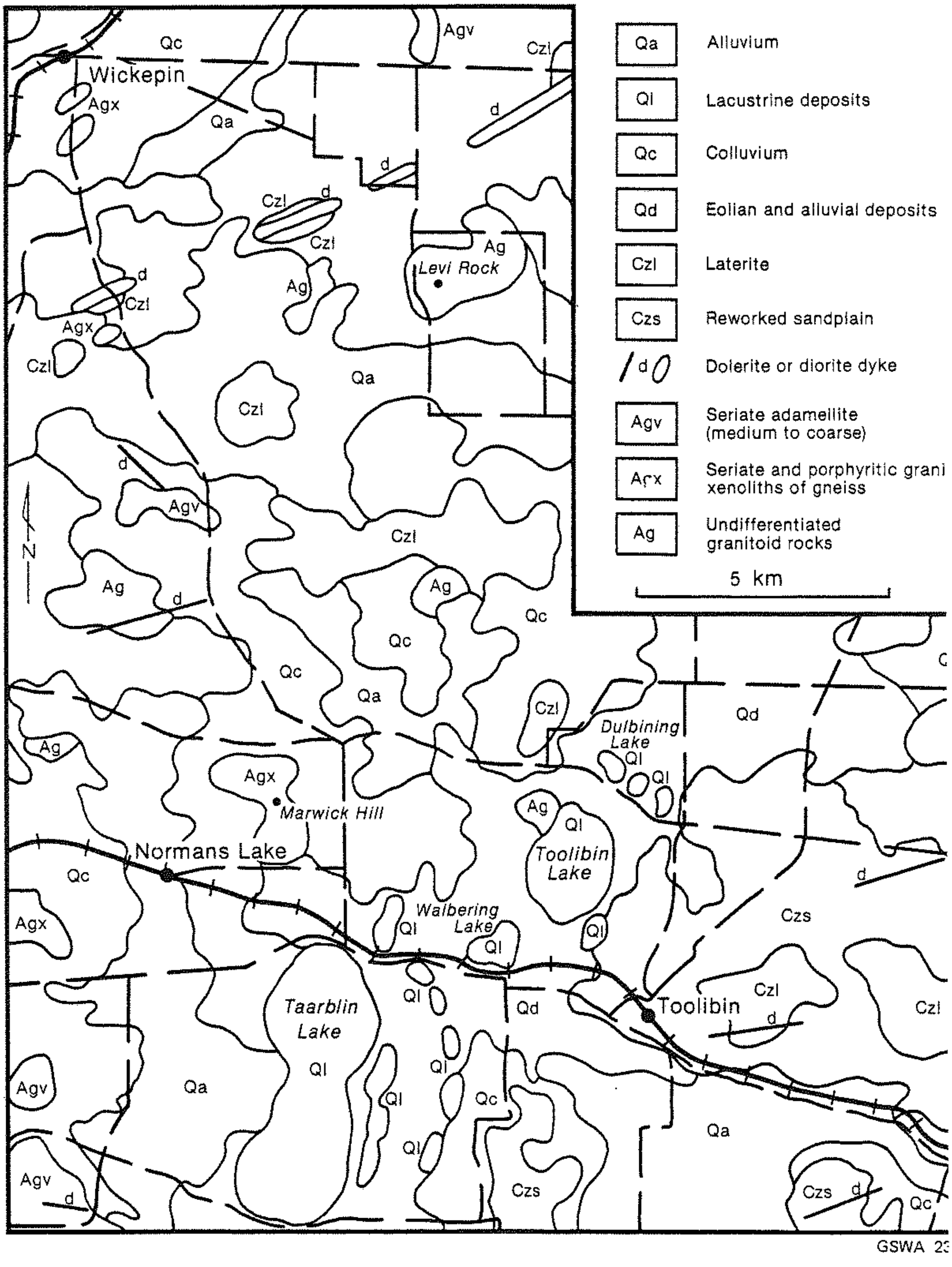


Figure 3. Geology

27 to 46m (Kevi, 1980).

Measures to alleviate salinization on the western edge of Lake Toolibin were investigated by Martin (1982) and Stokes (unpublished data, 1982). They suggested that a 200m wide strip of trees along the western bank of the lake may reduce or prevent further salinization. However, the calculations were based on assumed parameters, and a limited understanding of the groundwater hydraulics and the response of groundwater to usage by vegetation.

The Geological Survey of Western Australia completed a drilling and test-pumping program at the western edge of Lake Toolibin in April 1983. The results demonstrated that piezometric heads were decreasing with depth at the site, and indicated a downward flow of groundwater. This prompted construction of a multiport piezometer near the centre of the lake in May 1985 (Fig. 2).

GEOLOGY

The area is underlain by granitic rocks and minor dolerite dykes of the Archaean Yilgarn Block. Mapping of the region (Chin, 1986), indicates that the bedrock is predominantly granite, biotite granite, adamellite, granodiorite, and seriate to porphyritic, xenolithic granite and adamellite. The granite is weathered to a saprolite of varying thickness.

Much of the area is mantled by thin Cainozoic deposits consisting of laterite, colluvium, extensively reworked alluvium and sandplain, and lacustrine deposits associated with the lakes system (Fig. 3).

Dune systems are developed on the eastern sides of Toolibin and Taarblin lakes. Lake Toolibin is ringed inside the dunes by a narrow strip of poorly sorted,

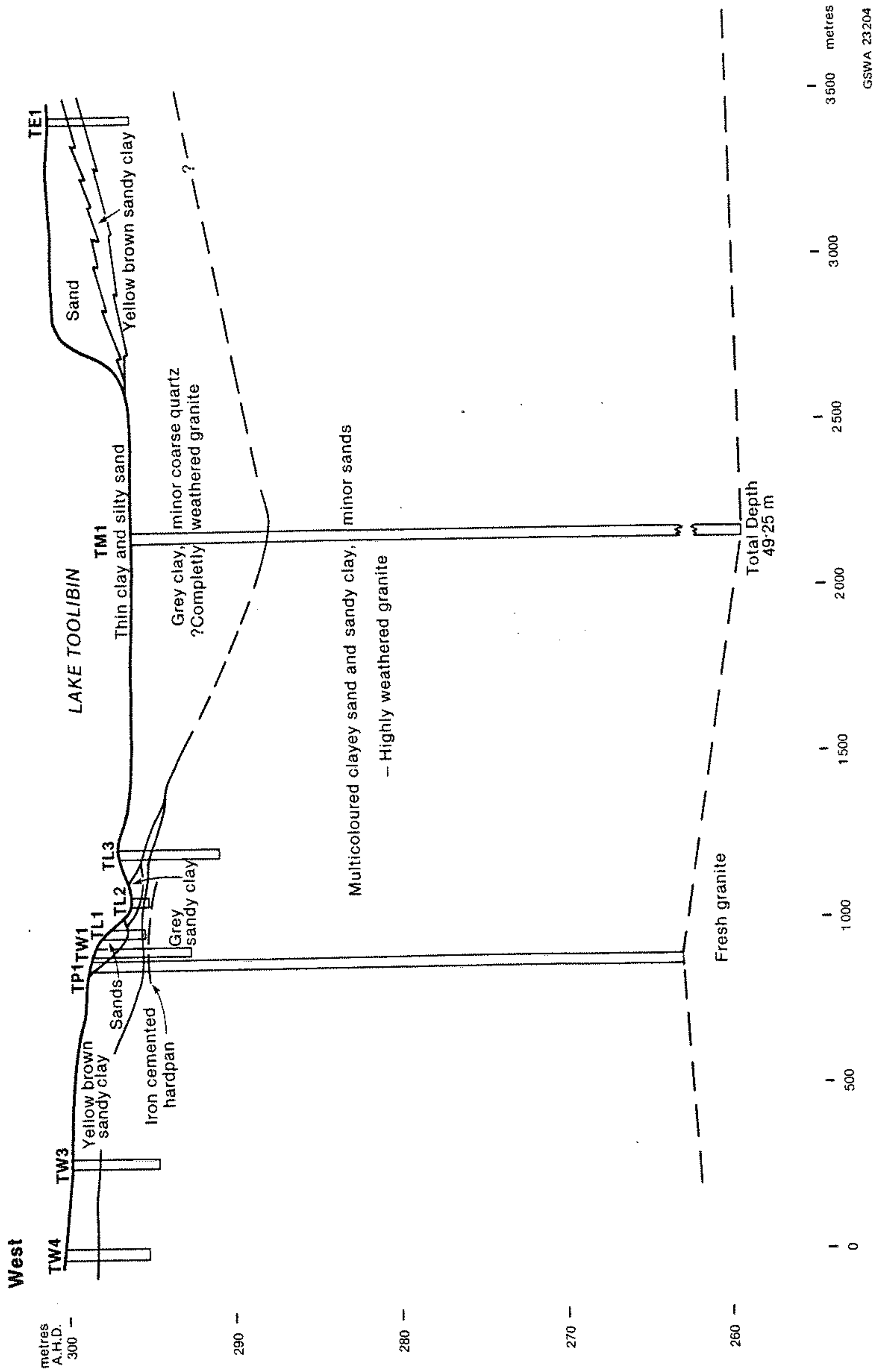


Figure 4. Geological Section

medium to very coarse, subangular to subrounded sand, composed of quartz and feldspar grains and granitic fragments. Detailed geological mapping of the lake system has not been undertaken, and the origins of the various deposits and their relationships are uncertain. A cored hole drilled near the centre of Lake Toolibin during 1985 intersected a profile which consists of a thin (10-70 cm) alluvial layer which is underlain by 8 m of grey, slightly sandy clay, then sands, sandy clays and clayey sands to 49.2 m. Examination of hand specimens suggests that the profile below 0.7 m is derived from the weathering *in situ* of the basement complex.

A west-east geological section for Lake Toolibin, which incorporates the work of Collins (unpublished data) and the more recent drilling, is shown on Figure 4.

The grey clay in the centre of the lake thins toward the eastern and western edges of the lake. In the east it is overlain by sand and clayey sands of the dune system, but to the west it grades to a sandy clay and is underlain by a red ironstone (iron-cemented sand ?) layer. On the western edge and bank of the lake, grey and brown sand overlies multicoloured sandy clay; the latter is derived from weathering of bedrock. Further west, the sand is absent and the profile appears to represent weathered bedrock.

HYDROGEOLOGY

Groundwater levels and quality have been monitored in shallow piezometers in and around the lakes since 1977. Additional bores, drilled in 1983 and 1985, have not been monitored regularly but provide information on vertical head variations over the full saturated interval.

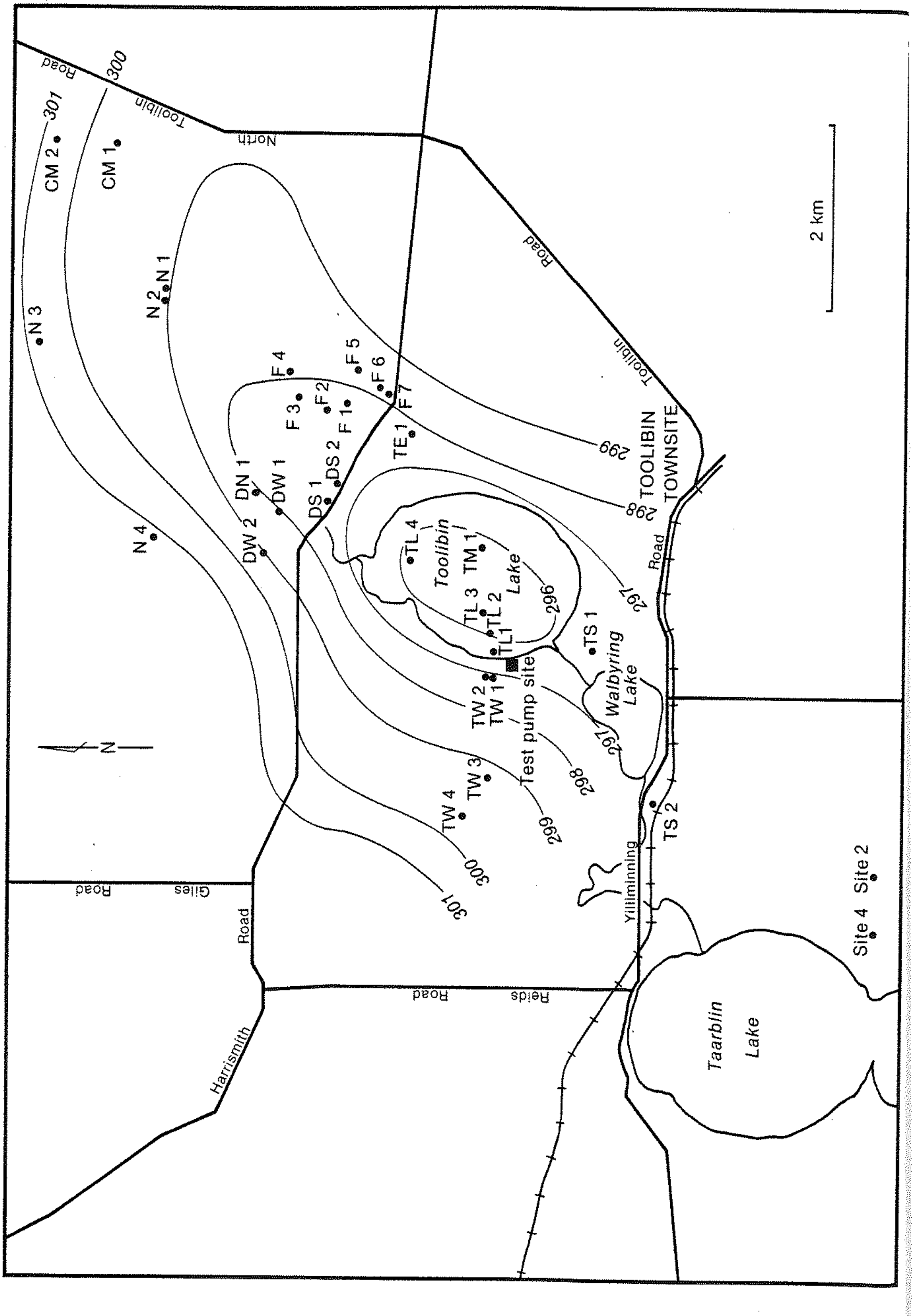


Figure 5. Water Table Contours, January 1978

GROUNDWATER FLOW

Water-table contours for January 1978, January 1982, and April 1985 (Figs 5, 6 and 7.) show a general pattern of flow at the water table towards the drainage system. Lake Toolibin had been dry for several years prior to 1978, and the 296m (A.H.D.) water-table contour was closed beneath the lake in January 1978. The lake filled in June 1981 and contained water until February 1983. The water table rose during this period, and the January 1982 contours are displaced in the direction of groundwater flow. The lake filled again in June 1983 and contained water until early 1985. By April 1985 it was dry, and the configuration of the water table was similar to that of January 1978.

The isopotential patterns over the full saturated thickness at the pump-test site on the western side of Lake Toolibin (Fig. 2) drawn for March 1983, September 1984, and April 1985 are shown in Figures 8, 9 and 10, respectively.

The flow pattern beneath Lake Toolibin has been described using piezometric head measurements from a closely spaced transect of bores at the western edge of the lake. If the flow direction over the full depth is not parallel to the section, then the isopotentials may indicate an apparent gradient. The aquifer is heterogeneous and local zones, where the transmissivity is higher, may cause convergence of flow as occurs near bore 3B.

The isopotentials drawn for March 1983 (Fig. 8) indicate that groundwater flow was downward and towards the lake. This suggested recharge and mounding of the water table in the superficial sands which fringe the lake. The steep vertical gradient, between the shallow observation bores and middle of the saturated zone, may indicate that the hydraulic conductivity beneath the sand is lower than at

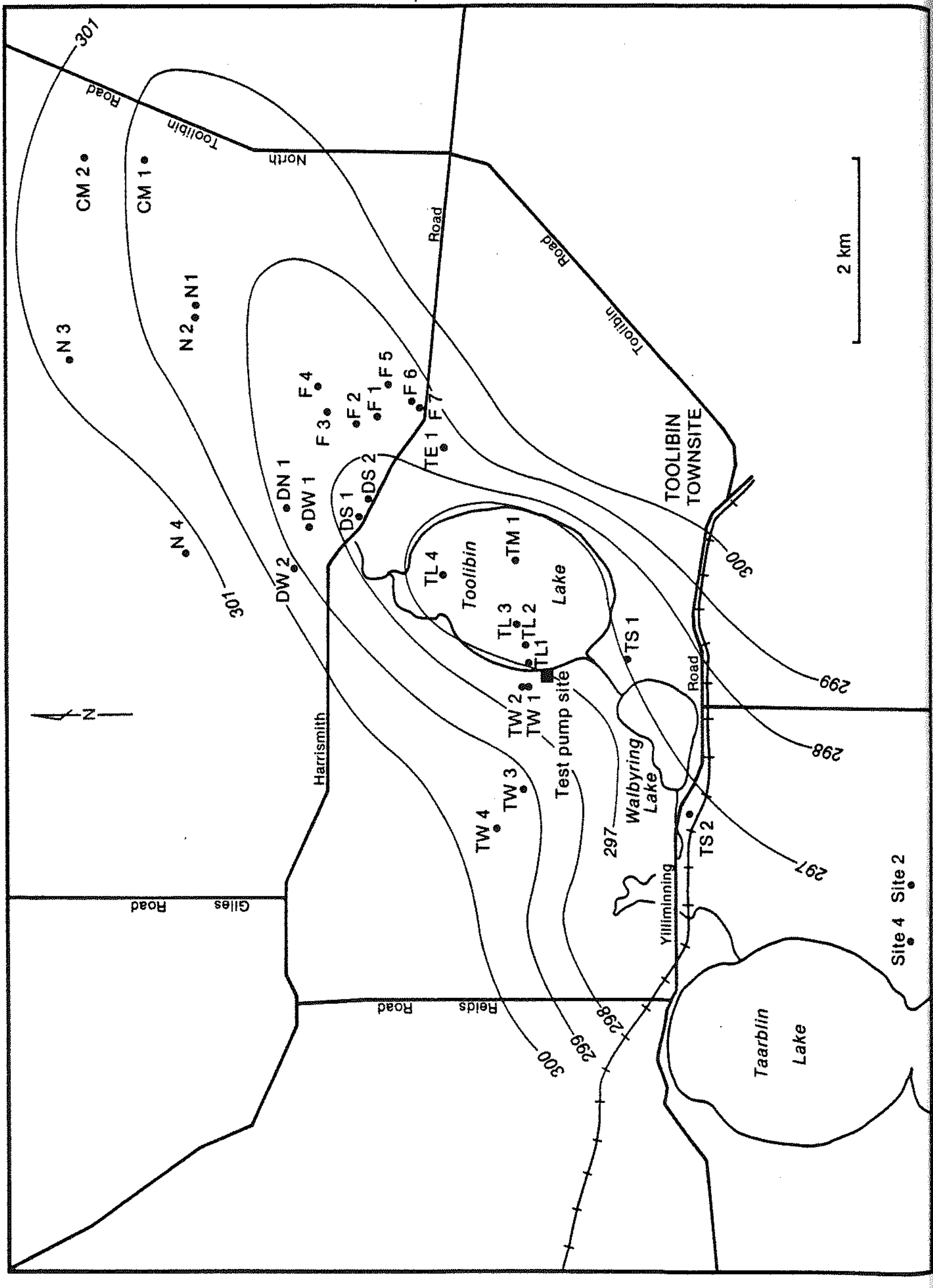


Figure 6. Water Table Contours, January 1982

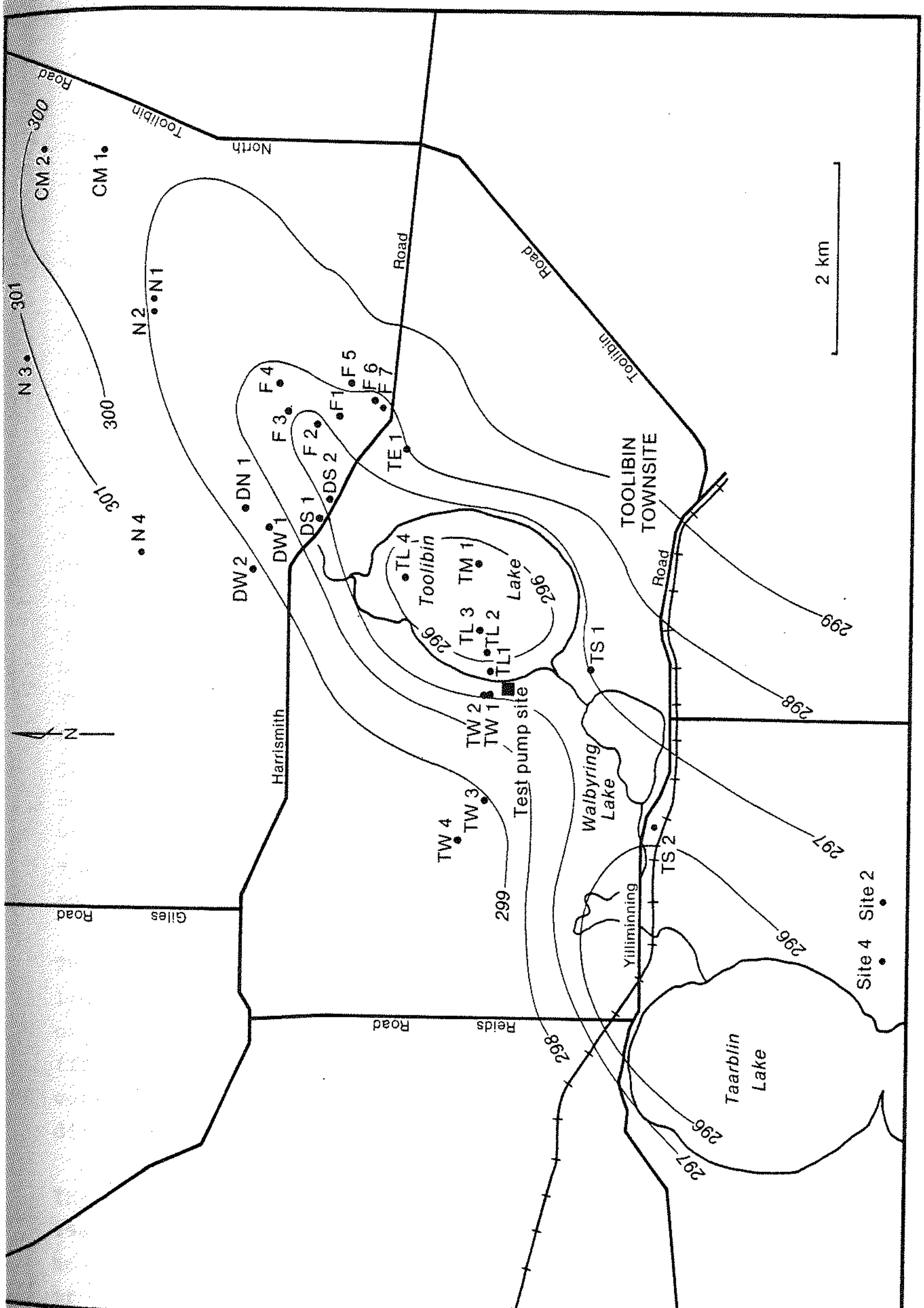


Figure 7. Water Table Contours, April 1985

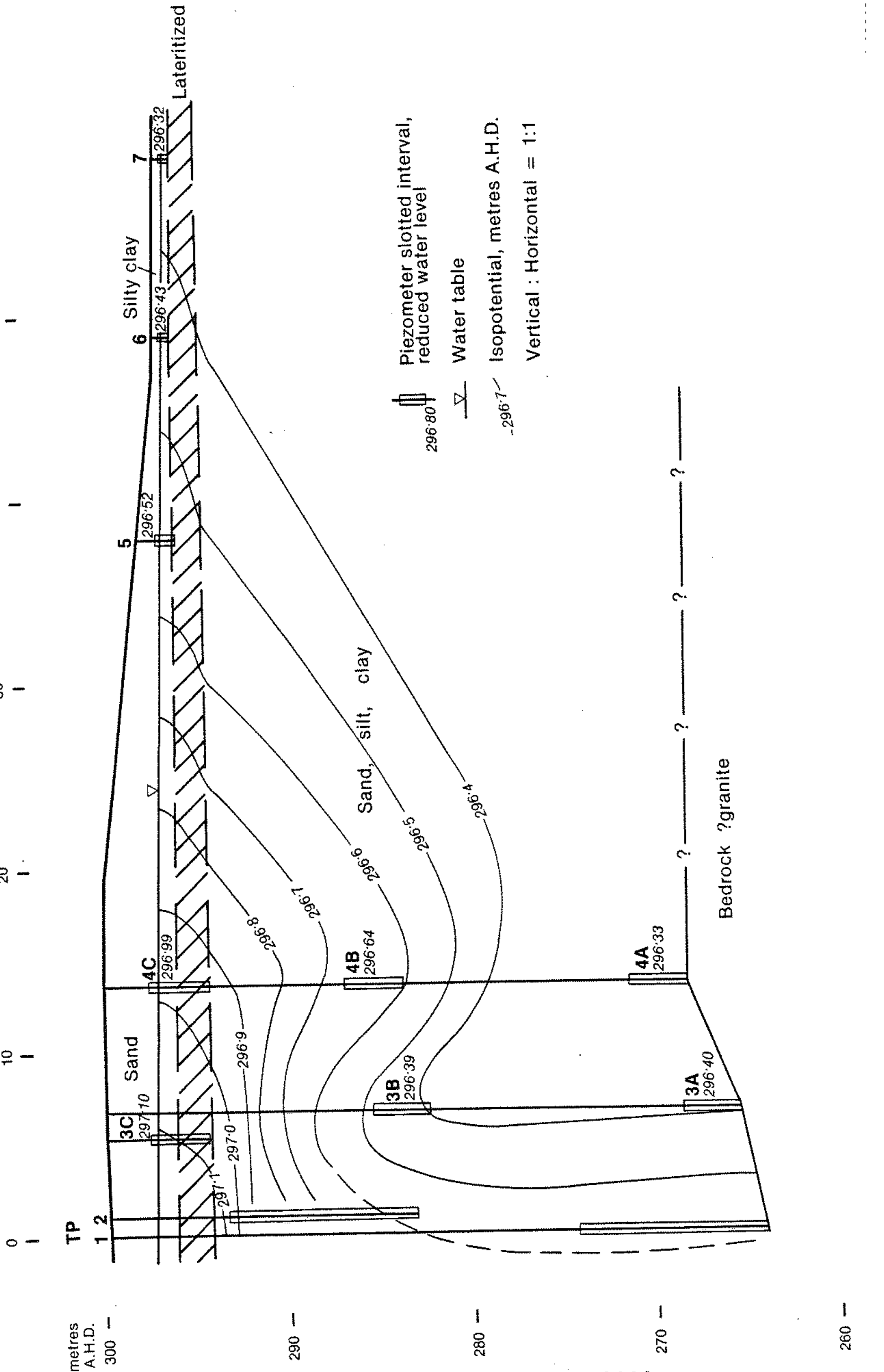


Figure 8. Isopotentials, March 1983

the base of the aquifer. The head difference between the top and bottom of the flow system was about 0.6 m. Lateral flow in the sand also occured.

By September 1984, the water table had risen about 0.4 m (Fig. 9) and the head at the base of the aquifer was about 1 m higher. Downward flow of groundwater was maintained but under a lower gradient. The head difference over the saturated interval was about 0.2 m.

The isopotential pattern for April 1985 (Fig. 10) indicates that groundwater outflow caused the potentiometric heads at the base of the aquifer to decrease by 0.7 - 0.8 m. The water table beneath the bank of the lake fell by about 0.5 - 0.6 m in response to water loss by evapotranspiration, lateral flow in the sands, and downward flow. Downward flow of groundwater was maintained but under a head difference of about 0.4 m. The water table had declined at a slower rate than the potentiometric head at the base of the aquifer, and the potentiometric gradient was now steeper than that of September 1984. This indicates that groundwater outflow at the base of the section exceeds the downward flow of water from the water table and the regional inflow to the section.

The persistence of decreasing heads with depth beneath the lake floor was confirmed in April 1985 after construction of a multiport piezometer near the centre of Lake Toolibin (TM1, Fig. 2). The depth intervals monitored and the corresponding potentiometric heads, corrected for salinity differences, are shown in Figure 11.

The head difference over the saturated interval in April 1985 was 0.17 m with a downward component of flow. The head measurements for February 1986 show a head difference of 0.23 m over the upper 22 m of the saturated interval with an upward component of flow, but over the lower 24 m

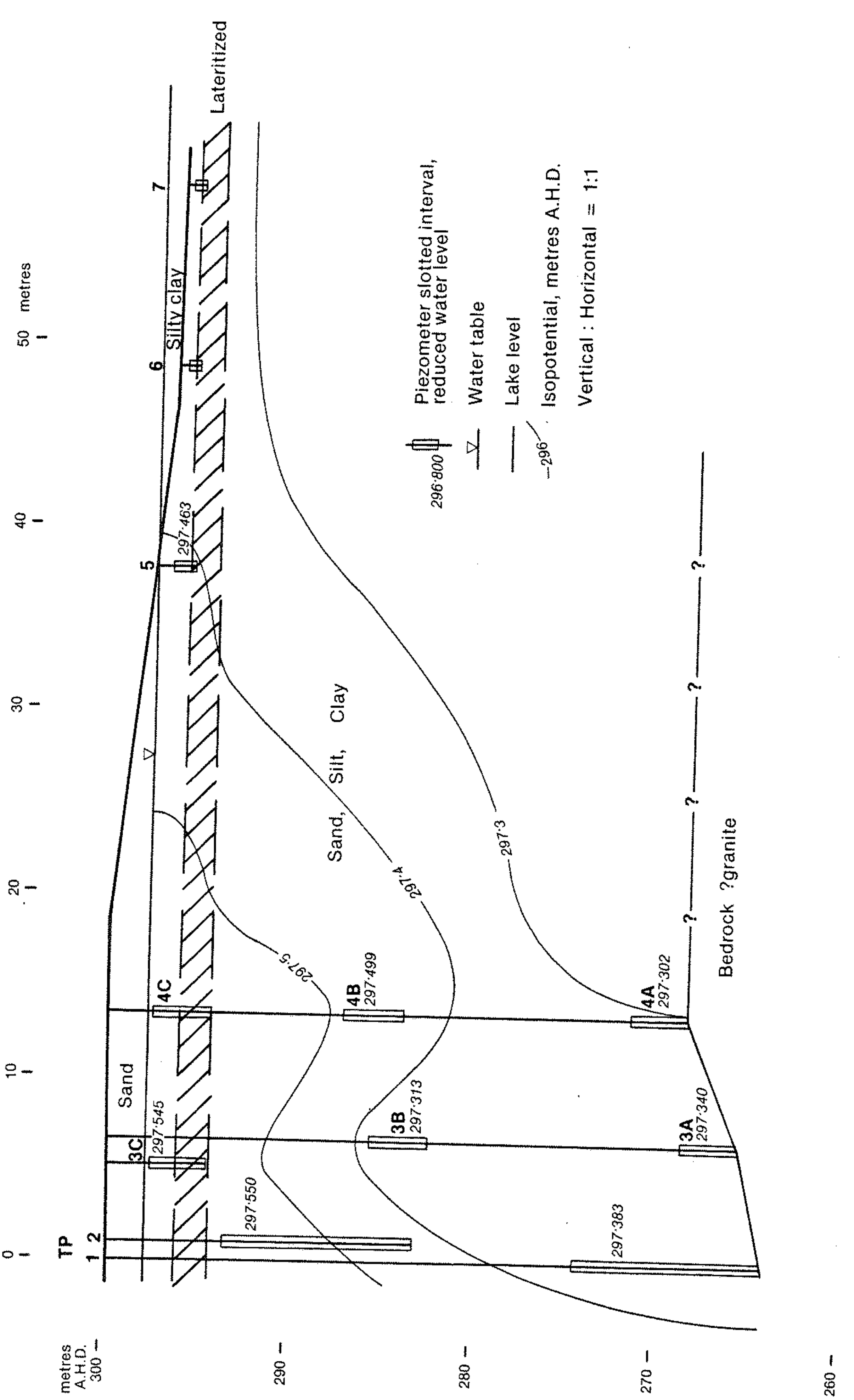


Figure 9. Isopotentials, September 1984

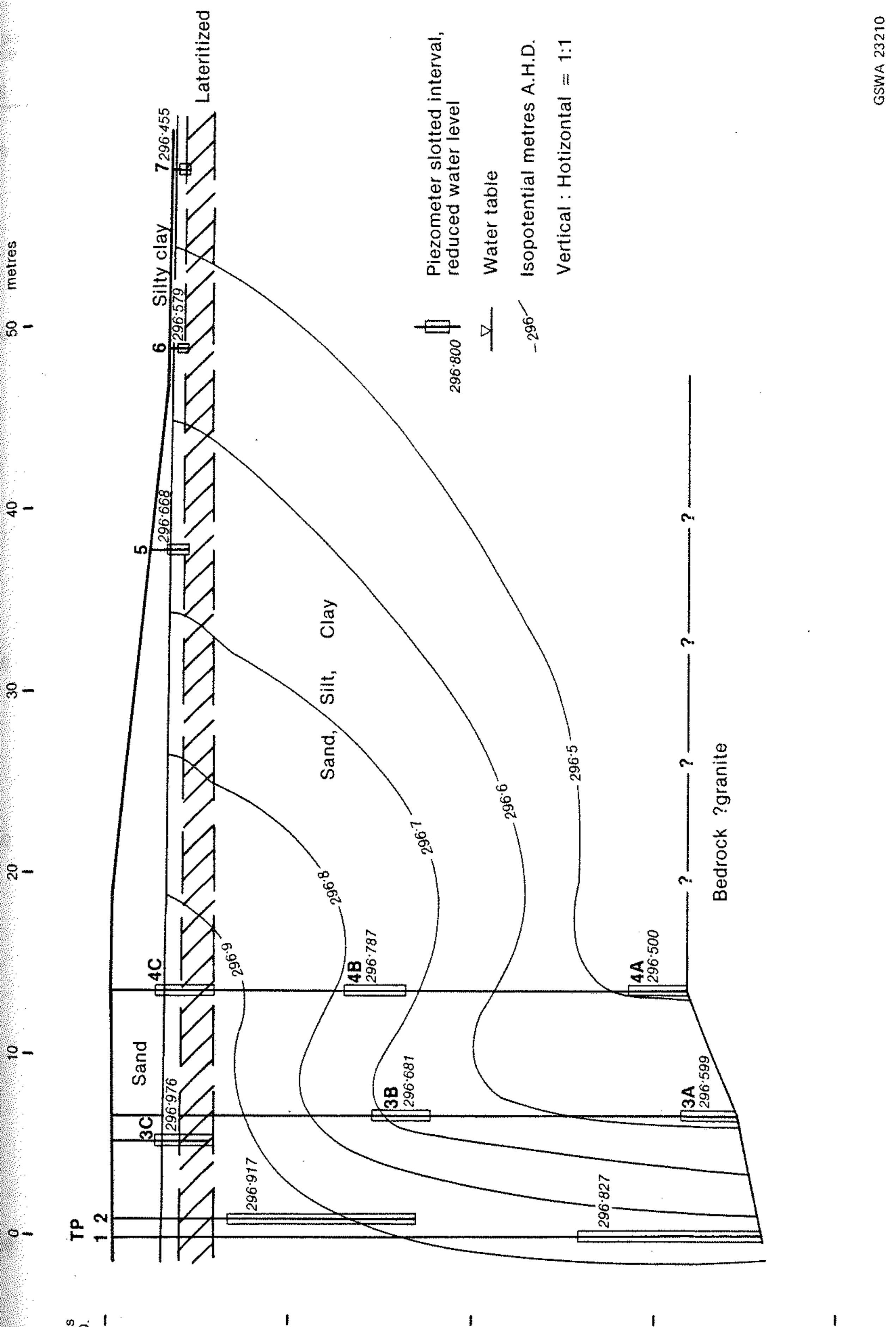


Figure 10. Isopotentials, April 1985

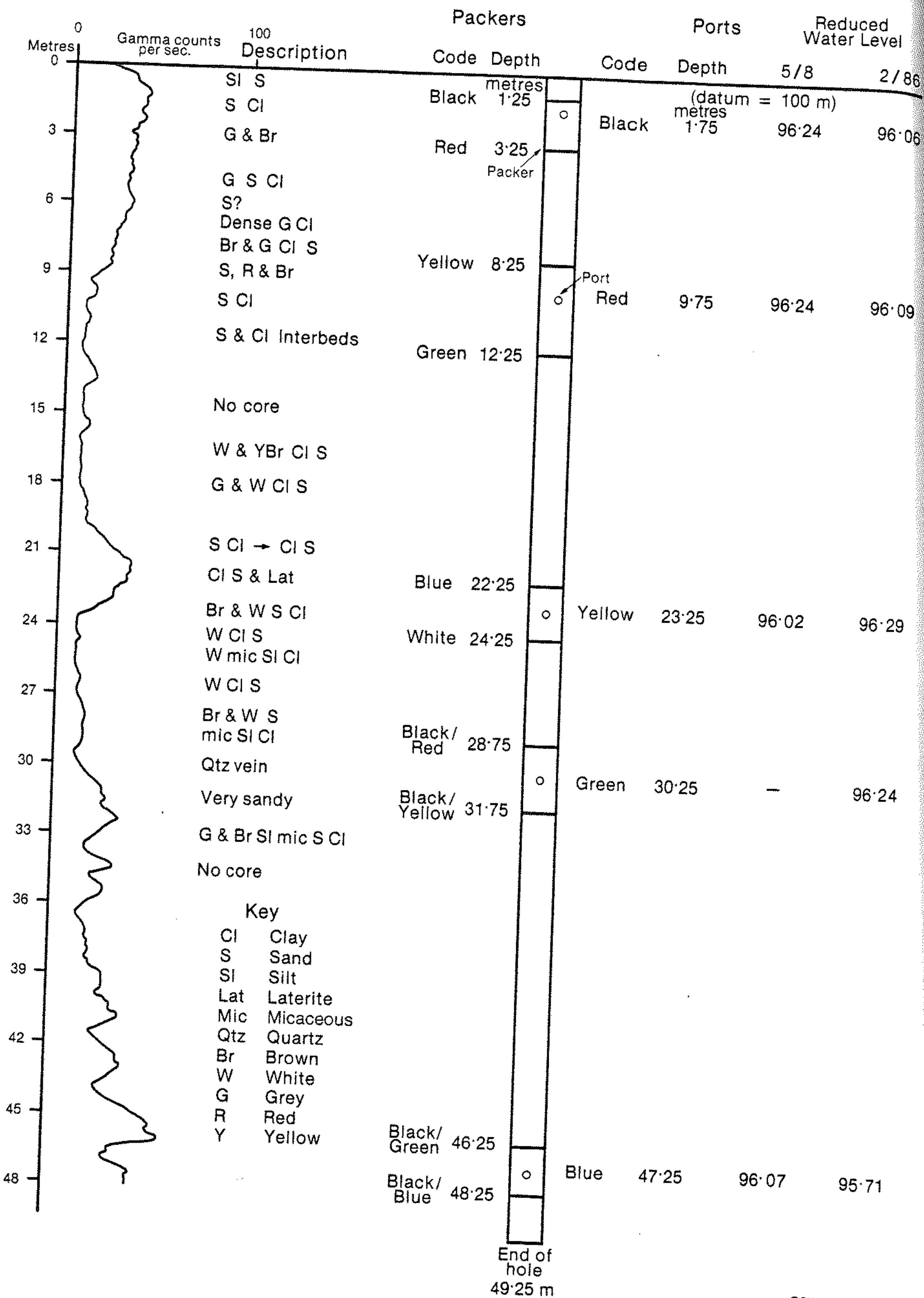


Figure 11. Multiport Bore

flow is downward, with a head difference of 0.58 m.

The potentiometric head measurements in and around Lake Toolibin suggest a complex groundwater flow system which appears to be controlled by the filling and drying sequences of the lake. Although there are no data for the vertical head distribution beneath Lake Toolibin when the lake is filled, its filling may result in an initial steep downward hydraulic gradient. After the lake has been filled for some time, the head distribution approaches a new equilibrium. During this time, the downward gradient decreases as groundwater flows to the base of the system and, possibly, groundwater outflow at the base of the system is reduced by ponding of water or reduced evaporation in the discharge areas further downstream. From the available data it appears that, on initial drying of the lake, the heads at the base of the flow system decline at a faster rate than the water table, thus increasing the downward hydraulic gradient. This may reflect increased evaporation in the discharge areas, and implies that there is a higher hydraulic conductivity in the lower half of the saturated zone. After the lake has been dry for some time, discharge of groundwater from the water table (by capillary rise and evaporation) results in upward flow in the upper half of the saturated zone. Downward flow of groundwater appears to be maintained in the lower half of the saturated zone.

As groundwater levels in Lake Toolibin decline, due to evapotranspiration, salt accumulates in the unsaturated zone and may be deposited on to the surface by capillary rise. Inspection of the dry lake floor in April 1985 showed that salt crusting was present only in areas which were sheltered by overhanging vegetation or fallen timber, less than about 1 m above the lake floor. This suggests that light precipitation and possibly even heavy dew is sufficient to recycle salt to the unsaturated zone, and

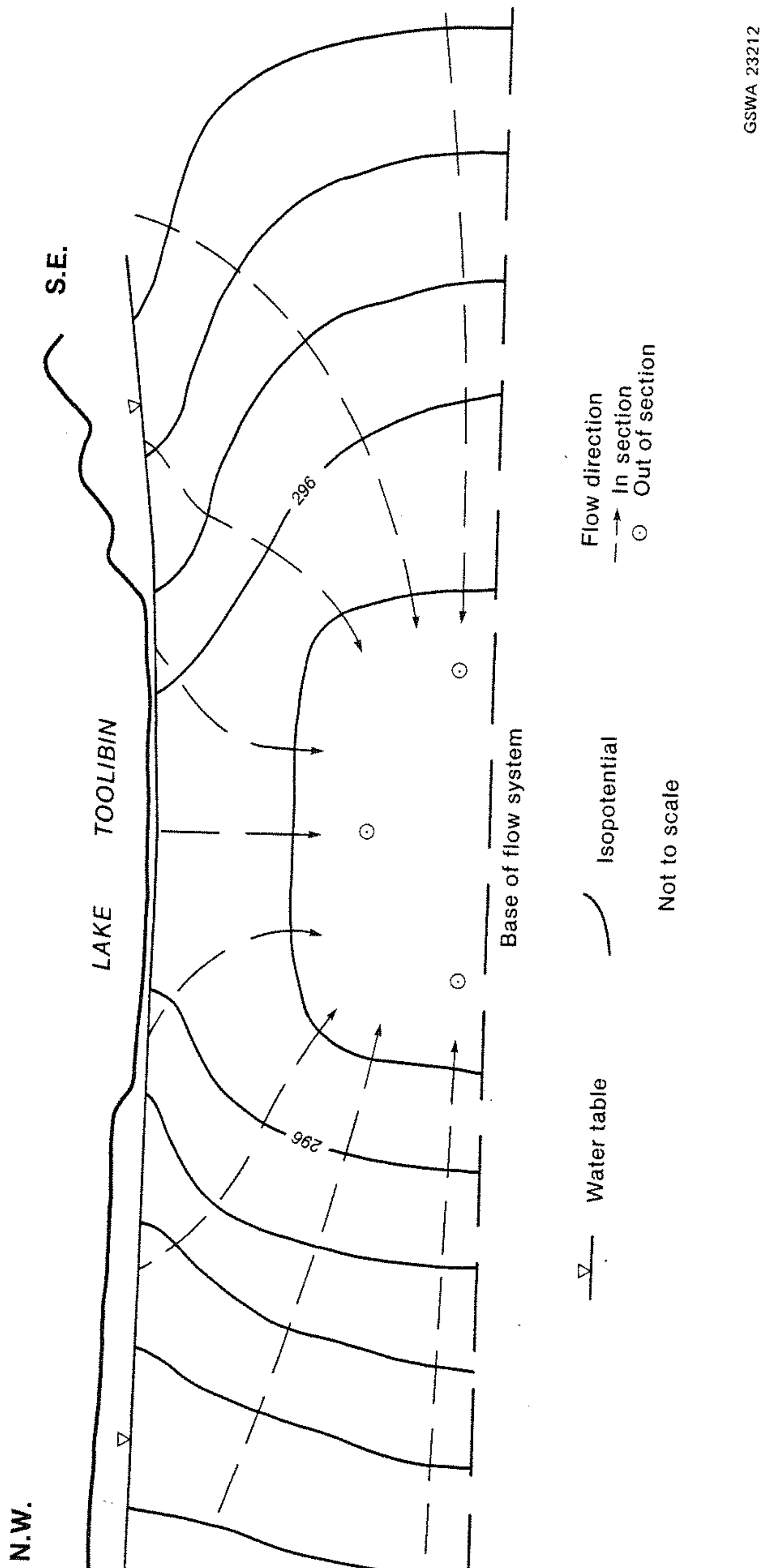


Figure 12. Groundwater Flow, Schematic Section NW - SE

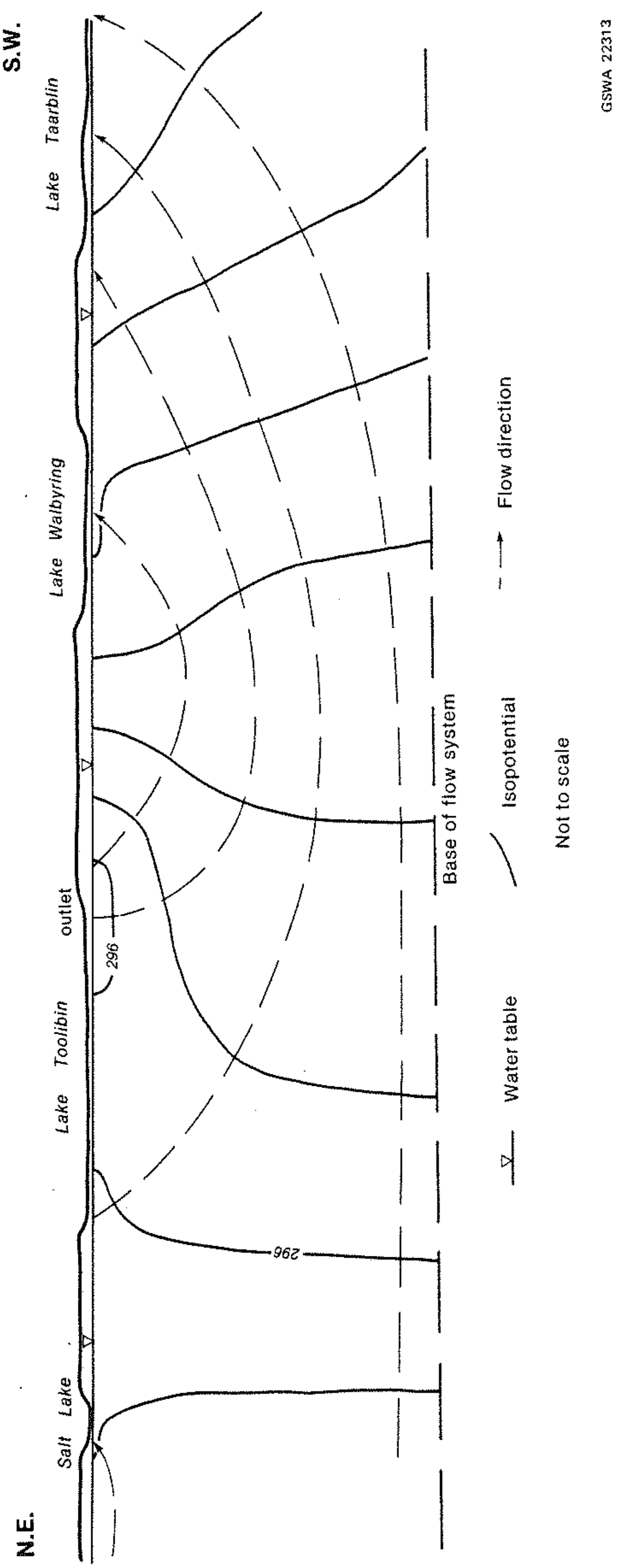
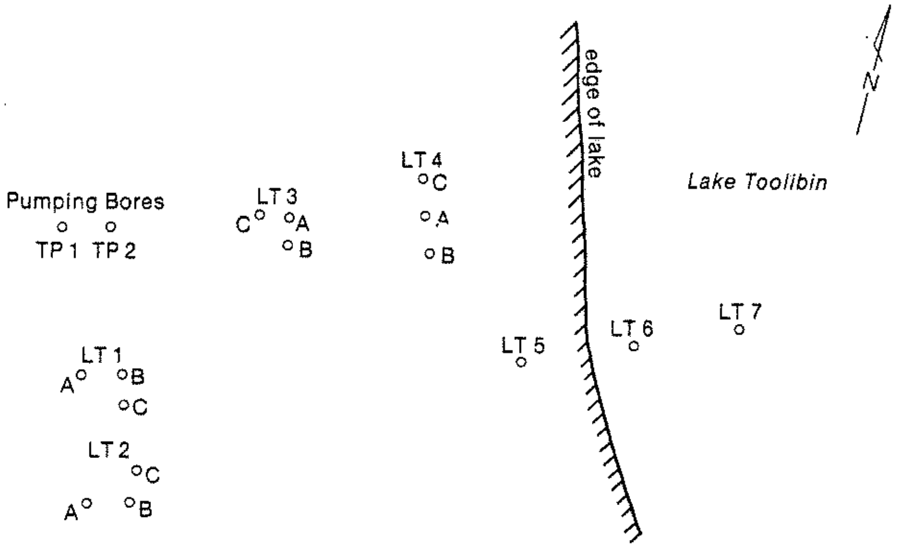


Figure 13. Groundwater Flow, Schematic Section NE - SW



Bore No.	Distance from PB 1(metres)
TP 2	1·0
1A	7·27
1B	7·38
1C	8·11
2A	14·22
2B	14·27
2C	13·54
3A	6·64
3B	6·73
3C	5·34
4A	13·50
4B	13·66
4C	13·52
5	38·16
6	49·24
7	59·20

Not to Scale

GSWA 23214

Figure 14. Test Pumping Site, Bore layout

possibly to the saturated zone in areas which are not sheltered.

The grey clay sequence found in the upper 8 m of the multiport bore may be present over much of the lake floor. Examination of this clay suggests that it may impede movement of groundwater. It is possible that the extent of the clay layer limits the spread of salinization on the lake floor.

A generalized groundwater flow system is shown in schematic sections across Lake Toolibin (Fig. 12) and along the flow direction (Fig. 13); the flow system represents a period when recharge to groundwater occurs. As the lake may contain at least 1 m of water for 70% of the time (Stokes and others, 1985), this may be the predominant groundwater flow system. There are insufficient data to determine either the flow system during periods of groundwater discharge from the water table, or the net groundwater balance for Lake Toolibin. The interaction of the lake and groundwater system is complex, with recharge when the lake fills and discharge when it is dry. As the discharge appears to be by capillary rise and evaporation, the groundwater system will be accumulating salt from the lake.

Throughflow of groundwater from the catchment apparently passes beneath Lake Toolibin and discharges into Lake Walybring and Lake Taarblin. Minor groundwater discharge also occurs at the salt lakes and salinized areas to the north of Lake Toolibin. Salt crusting occurs at these sites, and the absence of permanent free-standing water in these lakes indicates that evaporation exceeds the groundwater discharge.

TEST PUMPING

Test pumping was conducted at the western edge of Lake

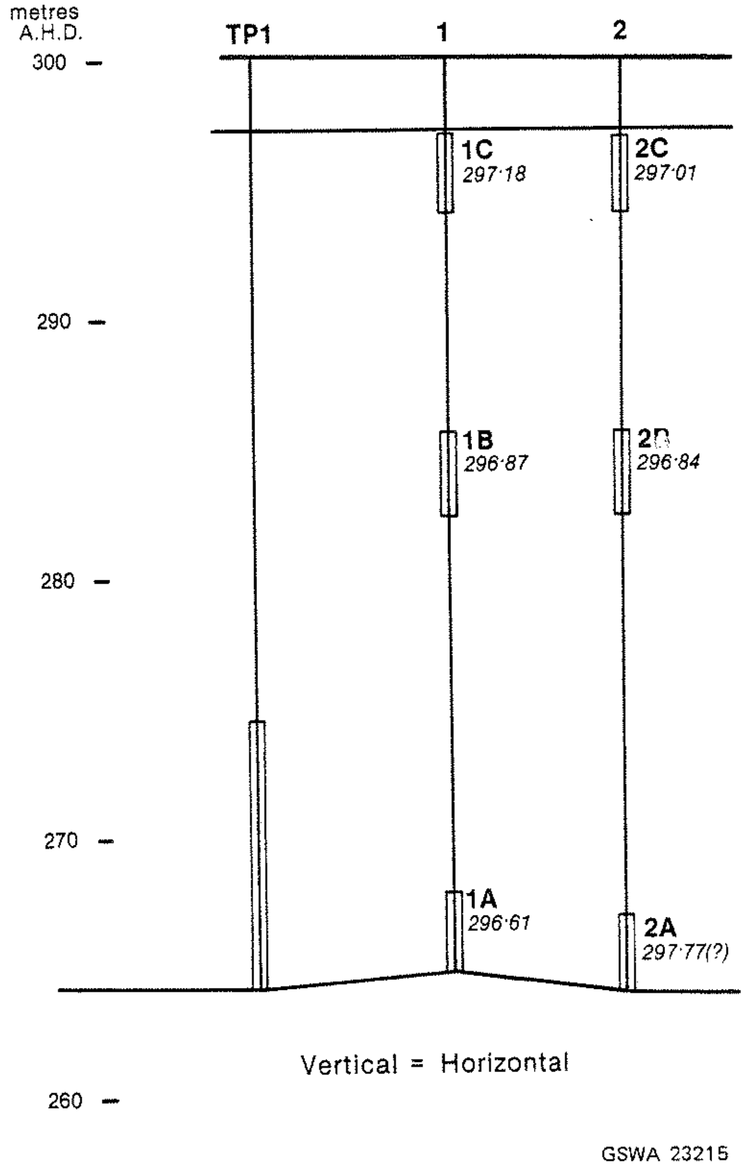


Figure 15. Pre-pumping water levels

Toolibin in March 1983 to determine whether the water table could be lowered by pumping from the aquifer.

Two production bores were constructed. One slotted over the basal 10 m of the aquifer and the other over 10 m in the upper part of the aquifer, with the intention of pumping each and observing the response at the water table.

The upper production bore had a low yield (less than 3 m^3/d), and was not tested. Observation bores (Fig. 14), open to the upper, middle and base of the saturated interval, were constructed in directions parallel to (Fig. 8) and at right angles (Fig. 15) to the apparent flow direction from the pumping bores.

The deep production bore was pumped at a constant rate of 34 m^3/d for eight hours and water levels were monitored in the observation piezometers. The drawdown, water levels and isopotential pattern at the end of pumping are shown on Figures 16 and 17. The greatest drawdown occured at piezometers 1A and 2A, (3.3 m and 3.2 m, respectively), at the base of the aquifer and at right angles to the pre-pumping flow direction. The drawdown at the orthogonal pair of piezometers at the base of the aquifer (3A, 4A) was 0.6 m and 0.16 m. A similar pattern, as occurred at the base of the aquifer, was observed for those piezometers near the middle of the aquifer but with smaller drawdown. In the water-table piezometers, the only measurable drawdown was 0.13 m in 1C, although a response was observed in bore 2C, it was less than the accuracy of measurement.

The shape of the potentiometric contours for the base of the aquifer at the end of pumping (Fig. 18), indicates that the hydraulic conductivity is lower in the direction of regional flow than in the orthogonal direction. However, analysis of the test-pumping data by the Theiss

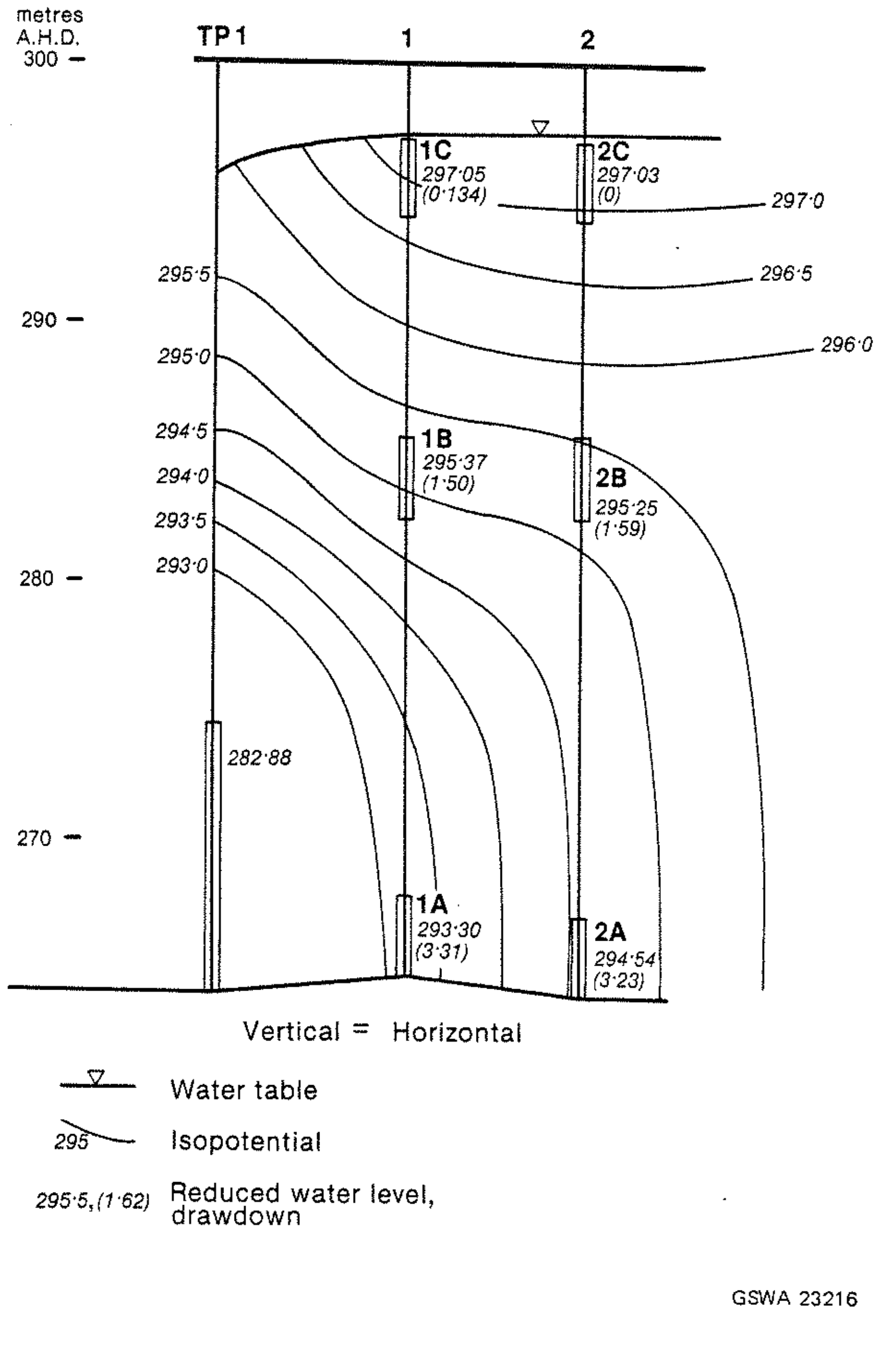


Figure 16. Isopotentials, t = 480 min.

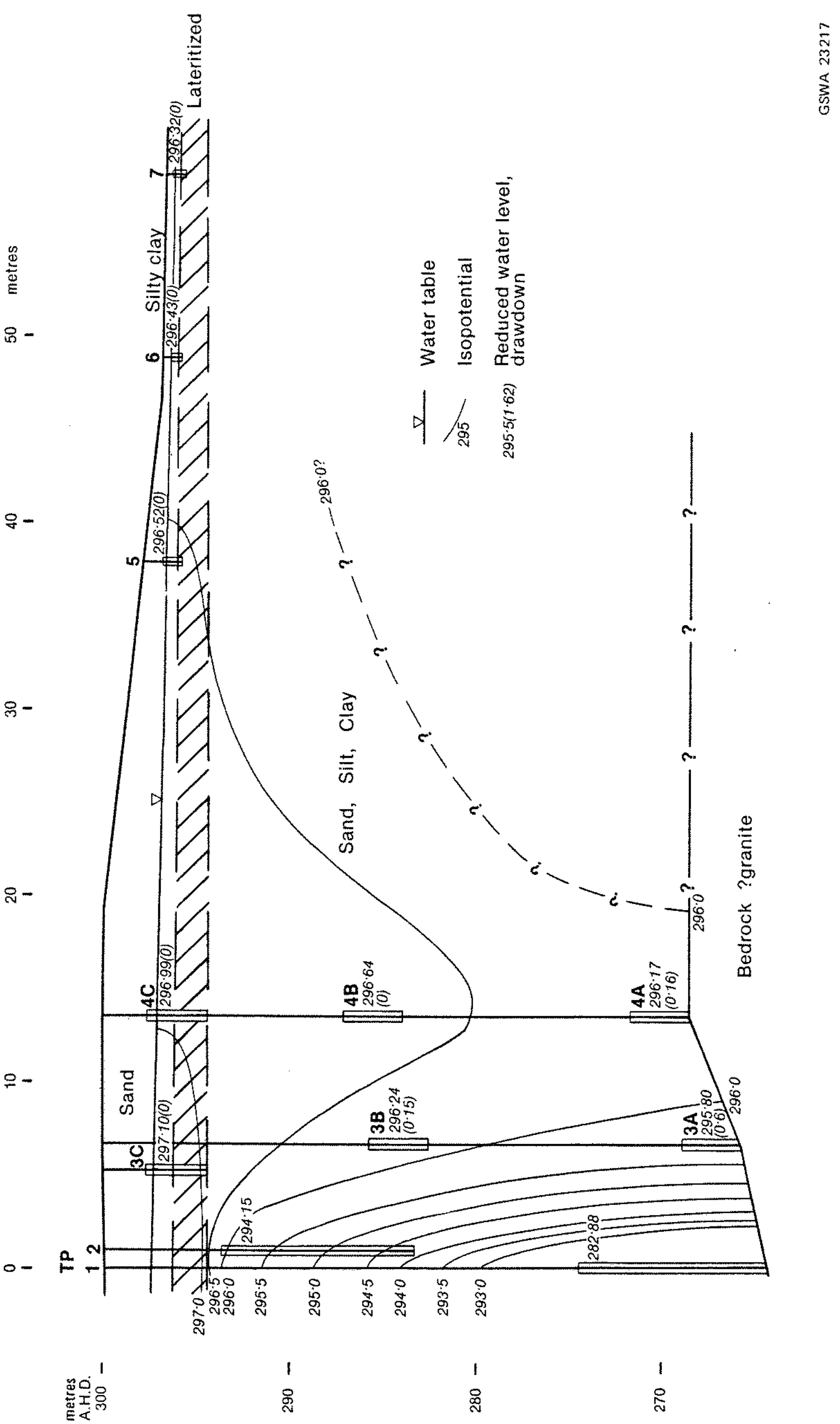


Figure 17. Isopotentials, t = 480 min.

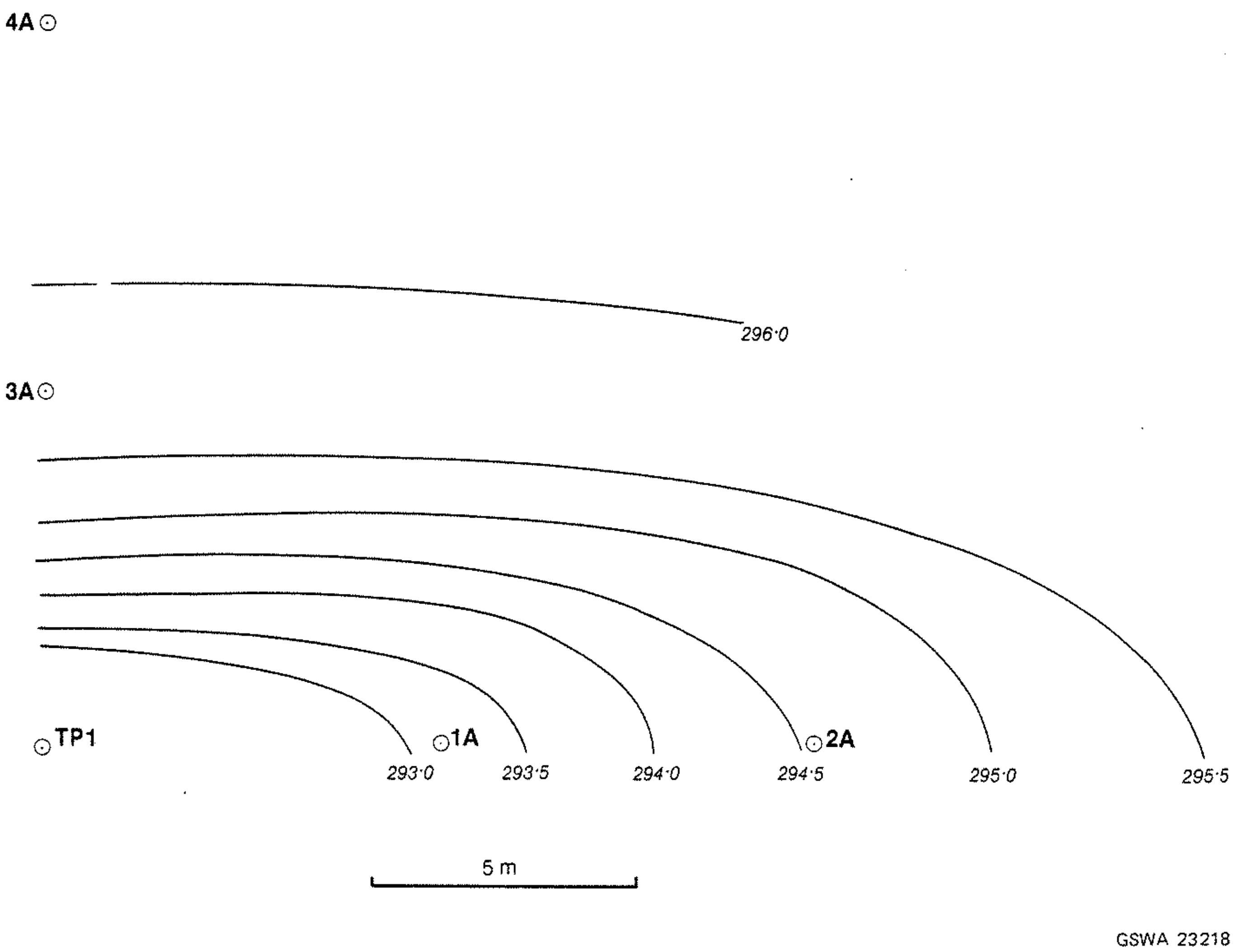


Figure 18. Apparent Isopotential Pattern at the base of the aquifer, t = 480 min.

method indicates a hydraulic conductivity in the prepumping flow direction three to five times that in the orthogonal direction. This apparent anomaly is probably due to a combination of the heterogeneity of the aquifer and the short distance between the observation bores and the production bore. The higher transmissivity zone, indicated by the shape of the prepumping isopotentials, could produce this effect locally during pumping.

Evaluations of aquifer parameters are unreliable, because of the short duration of pumping, the close proximity of the observation bores to the production bore, and the heterogeneity of the aquifer.

The isopotential pattern at the end of pumping indicates downward flow from the water table and horizontal flow at the base of the aquifer. This together with the low yield of the shallow production bore and lowering of the water table in bore 1C suggest semi-unconfined conditions for the aquifer. Under these conditions, there is significant flow in the upper part of the aquifer and a lowering of the water table in response to pumping. From the results of this test it is not possible to predict the extent to which the water table can be lowered by pumping. The results indicate that pumping reduces the heads at the base of the flow system and induces downward flow of groundwater. This appears to be an important mechanism for removing salt from the lake. A bore located on the lake bed and pumped for a period of 7 days or more would be required to assess the feasibility of lowering the water table beneath Lake Toolibin by pumping.

WATER-LEVEL CHANGES

The bores in the study area can be classified into two groups on the basis of water-level trend during the period of record (Fig. 19).

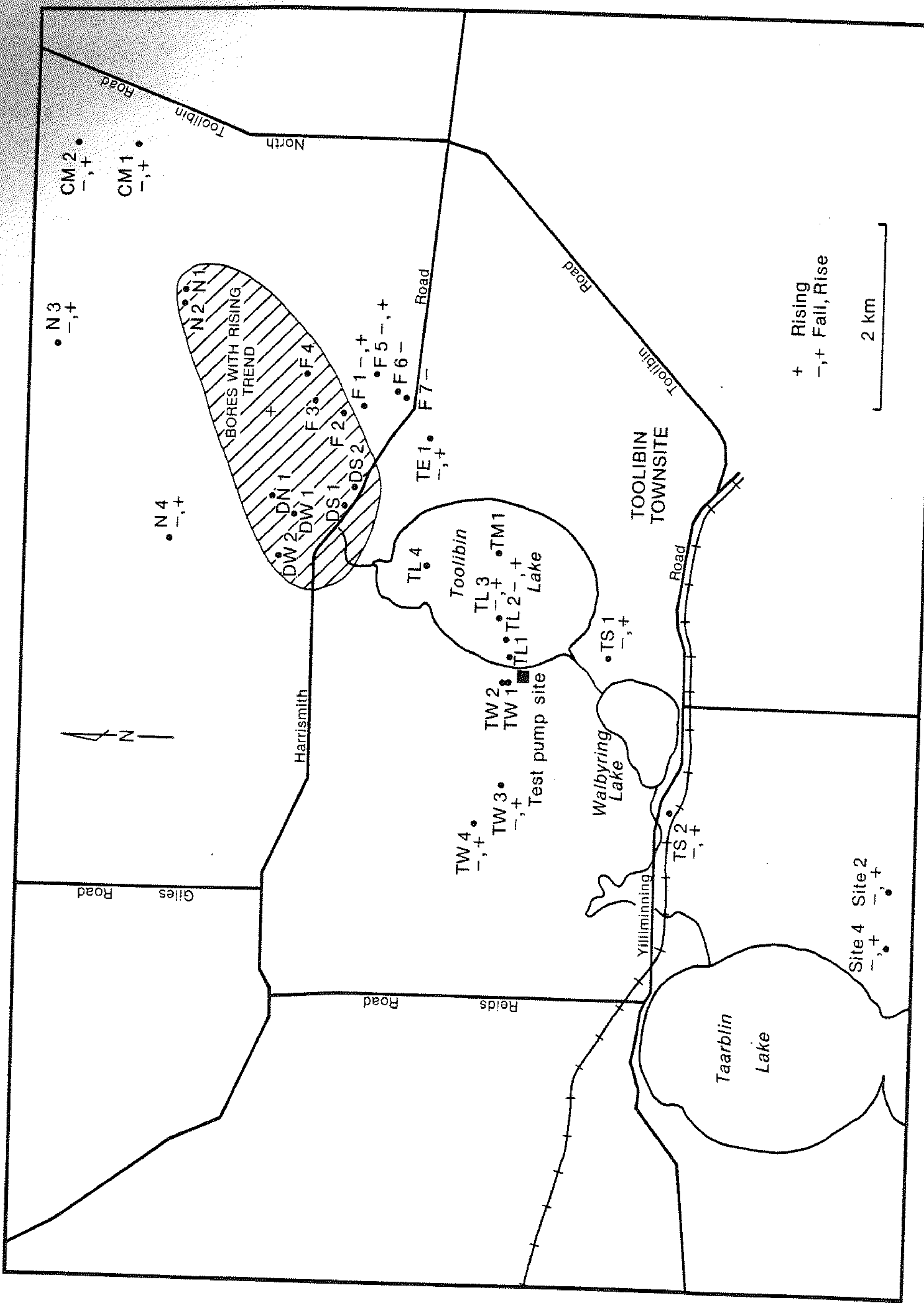


Figure 19. Distribution of Trends in Piezometric Levels

A constant rising trend occurred in bores in the drainage valley to the north of Lake Toolibin. The rate of rise ranged between 2.8 cm/yr and 6.8 cm/yr and averaged 4.6 cm/yr (Fig. 20).

The water levels in the remaining bores, except F6 and F7, declined between 1977 and 1980 and rose during the remainder of the record (Fig. 21). This trend is in accordance with the variations in rainfall over the period.

Bores F6 and F7 show a general water-level decline during the period of record. This may be an apparent trend because the latter part of the record is based on a few observation points, or it may be due to a reduction in throughflow related to a local change in land use. The trend from 1977 to 1983 is similar to that in the bores which show a decline followed by a rise in piezometric levels.

Because of the short period of record, definition of the long-term trend of water levels in the catchment is uncertain. This is because the post-clearing rate of water-level increase is likely to approach equilibrium conditions, slowly, and the response during the short period of record may be dominated by seasonal variations in recharge.

The long-term rainfall record for Wickepin, when plotted as a ten year moving average, shows a marked decrease in rainfall since the early 1960s (Fig. 22). This and the persistent rising trend of piezometric levels, for those bores to the north of Lake Toolibin, indicate that equilibrium conditions may not have been reached yet, and that water levels can be expected to continue to rise in the catchment. If the saline groundwater permanently rises to the floor of Lake Toolibin, then the lake will become salinized.

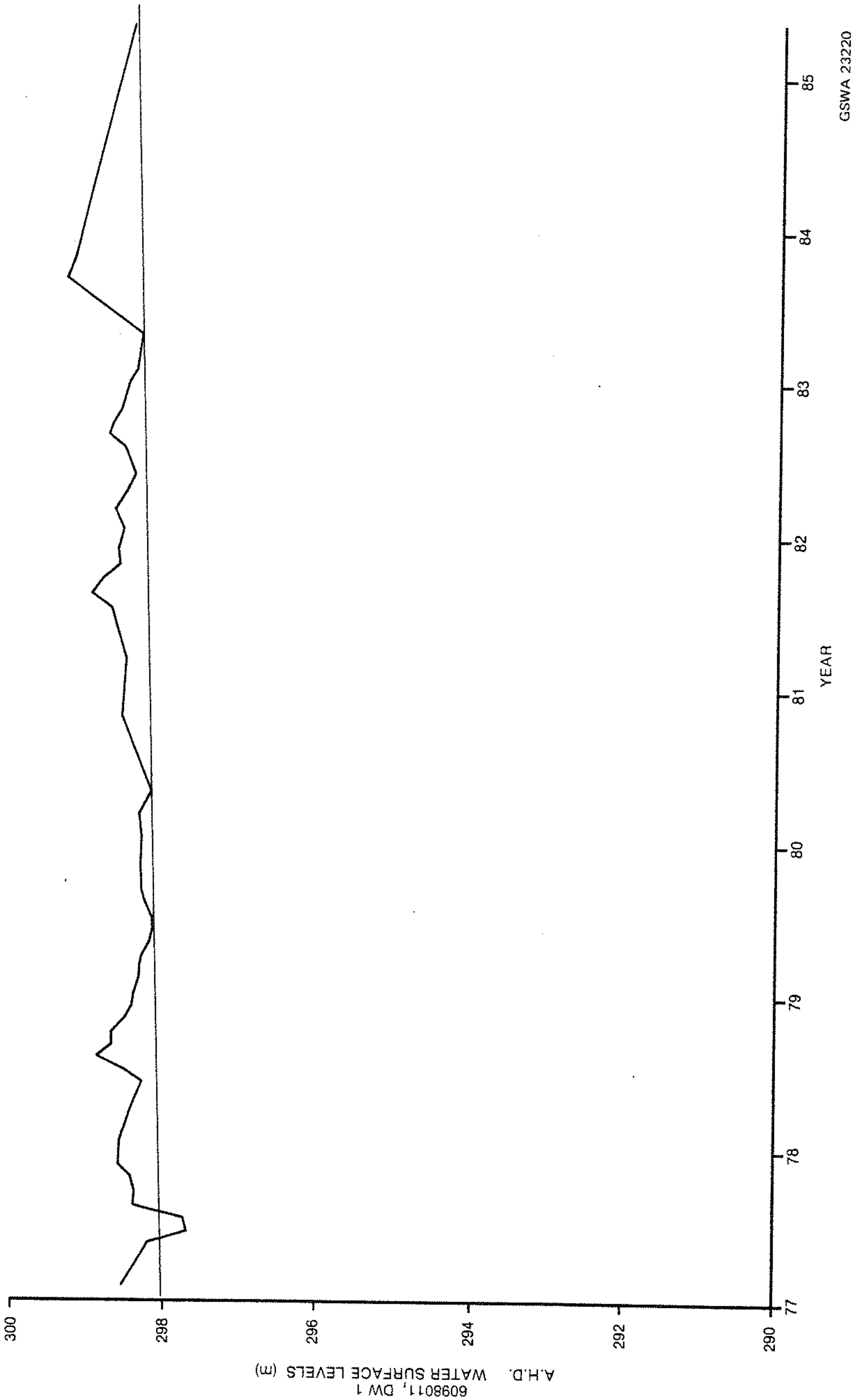


Figure 20. Groundwater Hydrograph, Continually Rising Trend

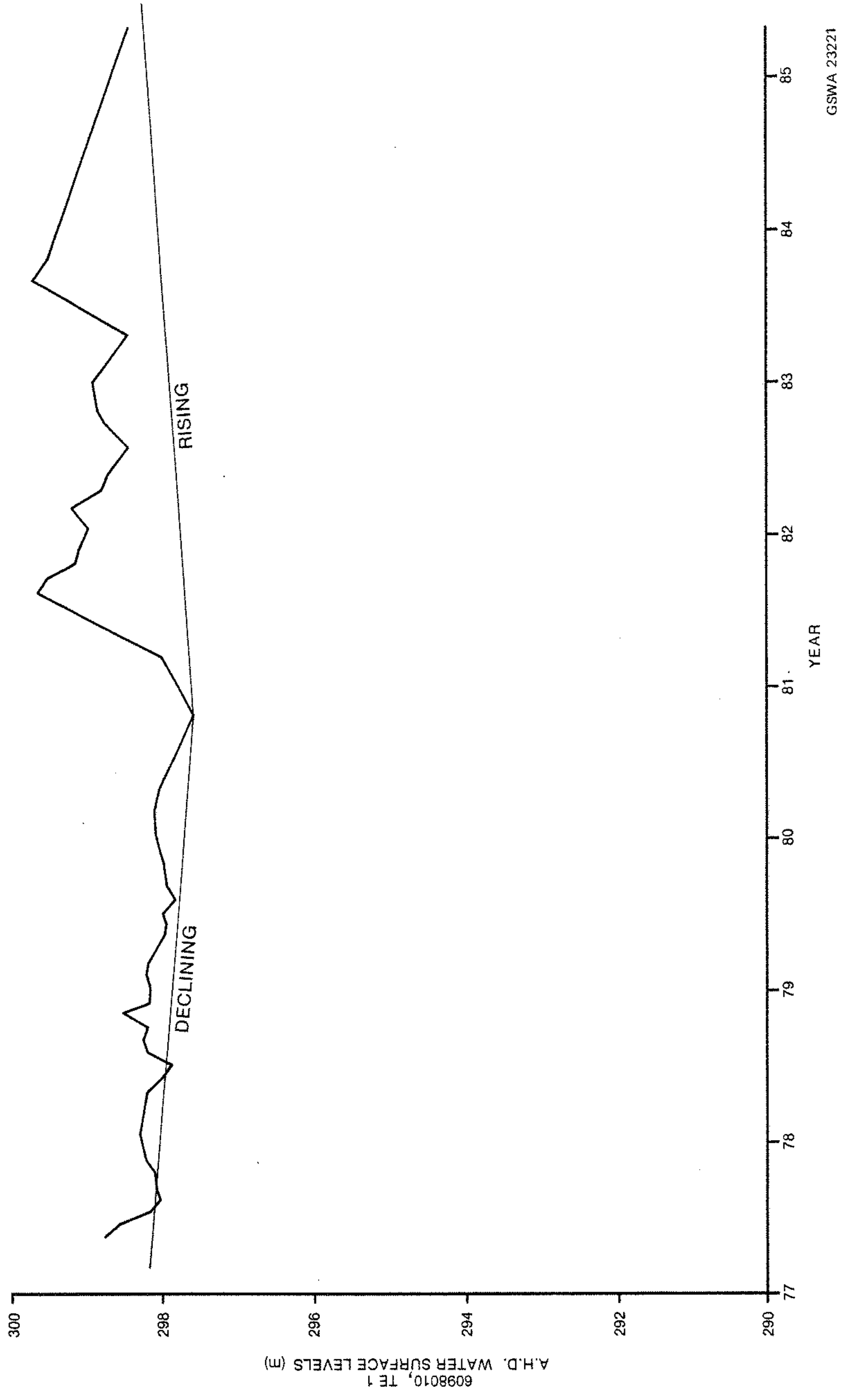


Figure 21. Groundwater Hydrograph, Declining to Rising Trend

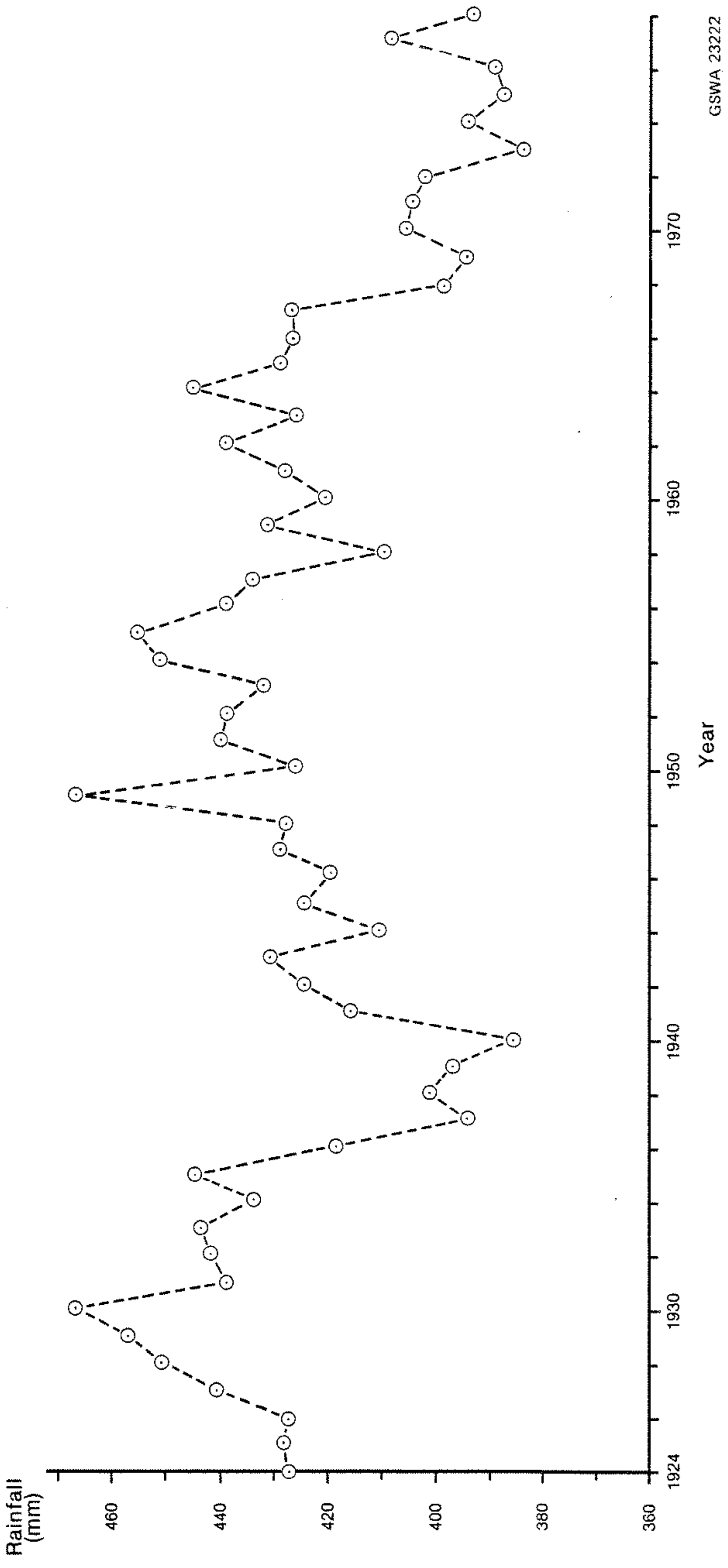


Figure 22. Wickepin Annual Rainfall, Ten-Point Moving Average

GROUNDWATER SALINITY

Groundwater salinities in the area are generally high, in the order of 18,000 mg/L to 20,000 mg/L, but reach a value of about 60,000 mg/L in the bores in Lake Toolibin. No trend or pattern to the groundwater salinity variations is evident. The occurrence of high-salinity groundwater in the shallow bores in Lake Toolibin indicates that salt is concentrated near the water table and in the unsaturated zone by evapotranspiration when the lake is dry. This salt is presumably flushed to the groundwater system after rainfall and when the lake fills with water.

CONCLUSIONS AND RECOMMENDATIONS

The information provided by the limited number of bores at Lake Toolibin suggests that the survival of the lake as a breeding ground for native birds is threatened by the encroachment of salinization.

During the period of record, the maximum depth to which the water table has fallen when the lake was dry is less than 2 m below the lake floor. During this time, salt is redistributed in the unsaturated zone, and salt crusting occurs at sheltered sites on the lake floor. Precipitation and surface flow into the lake enables flushing of this salt to the saturated zone and its removal from the lake by downward and lateral flow of groundwater.

Although groundwater levels have not permanently risen to the floor of the lake, the evidence suggests that the groundwater flow system is not in equilibrium with the post-clearing increase in recharge, and groundwater levels can be expected to continue rising.

Under the present regime, where there is seasonal inflow of surface run-off to Lake Toolibin, the viability of the lake as a breeding ground may continue, provided that groundwater levels do not permanently rise to, or above, the floor of the lake.

A sequence of years in which there is no inflow may cause the vegetation within the lake to die, due to a rise in soil salinity. The loss of vegetation may induce or accelerate a rise in the water table beneath the lake. Subsequent filling and flushing of the lake may return lake salinities to the present level, however, the vegetation loss is liable to reduce the suitability of the area as a nesting ground.

The hydrogeology of the Lake Toolibin system is complex, and a comprehensive drilling program would be required to improve the understanding of the groundwater flow system. However, it is unlikely that such a program can be justified on economic grounds. A few key bores near the southern end of Lake Toolibin may be sufficent to indicate where upward flow of groundwater occurs and to delineate areas where salinization may occur. Monitoring of the piezometers in and around Lake Toolibin should continue on an annual basis. The monitoring should be conducted at the end of summer.

Management options to ensure the survival of the lake as a breeding ground should be framed in the anticipation that Lake Toolibin will become salinized at some time in the future. The certainty or timing of this event cannot be predicted as it is largely dependent on the vagaries of the climatic pattern.

For the continued survival of Lake Toolibin as a freshwater lake, it will be necessary to ensure that groundwater levels are maintained below the floor of the lake. While planting vegetation may lower groundwater levels beneath the plantations, it may be difficult to establish vegetation on the lake floor because of high soil salinities and prolonged periods of inundation. The pumping test at Lake Toolibin suggests that dewatering by pumping will lower the water table, however, the test results do not allow prediction of the effect of pumping. Further investigations on dewatering cannot be recommended until practical and economic considerations of such a scheme have been assessed.

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