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**Groundwater Model for an
Island Aquifer: Bribie
Island Groundwater Study**

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Research Report No. CE 44
September, 1983

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GROUNDWATER MODEL FOR AN ISLAND AQUIFER:
BRIBIE ISLAND GROUNDWATER STUDY

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RESEARCH REPORT NO. CE 44

Department of Civil Engineering

University of Queensland

September, 1983

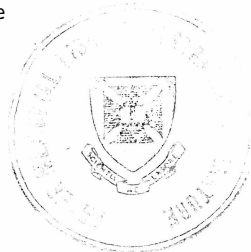
Synopsis

Bribie Island is a large sand island with population centres at its southern end. The town water supply is extracted from the unconfined aquifer by means of a long trench excavated below the water table. Demand is increasing and there is a need for the evaluation of the water resource and the development of management strategies to optimise the supply. This report describes the development and calibration of a steady, regional groundwater model of the unconfined aquifer of southern Bribie Island. The model is used to assess the current situation and to determine the effects of a proposed recharge scheme.

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1. INTRODUCTION

Bribie Island is approximately 65 kilometres north of Brisbane and is one of three large sand islands which skirt Moreton Bay (Figure 1). Urban development has been restricted to the southern part of the island. Present permanent population is approximately 6100 but can rise temporarily to around 40 000 during peak holiday periods. The population is increasing and is expected to reach 20 000 by the year 2001. The island's water supply is obtained from the aquifer by means of a long trench excavated below the water table. Increasing demand for water has resulted in a need for the evaluation of the island's groundwater resources and the development of management strategies to optimise the supply. The study described in this report was the first stage in a long term programme designed to meet this need. The specific objective of this study was the development of a steady state model describing the groundwater pattern in the southern portion of the Bribie Island aquifer. The report comprises

- (i) a description of Bribie Island including its climate, topography and geology;
- (ii) a description of the existing water supply system which includes a history of groundwater developments on the island and summaries of previous investigations;
- (iii) presentation of the mathematical basis for the regional groundwater model;
- (iv) details of the procedures adopted to calibrate the model;
- (v) some example applications of the model.

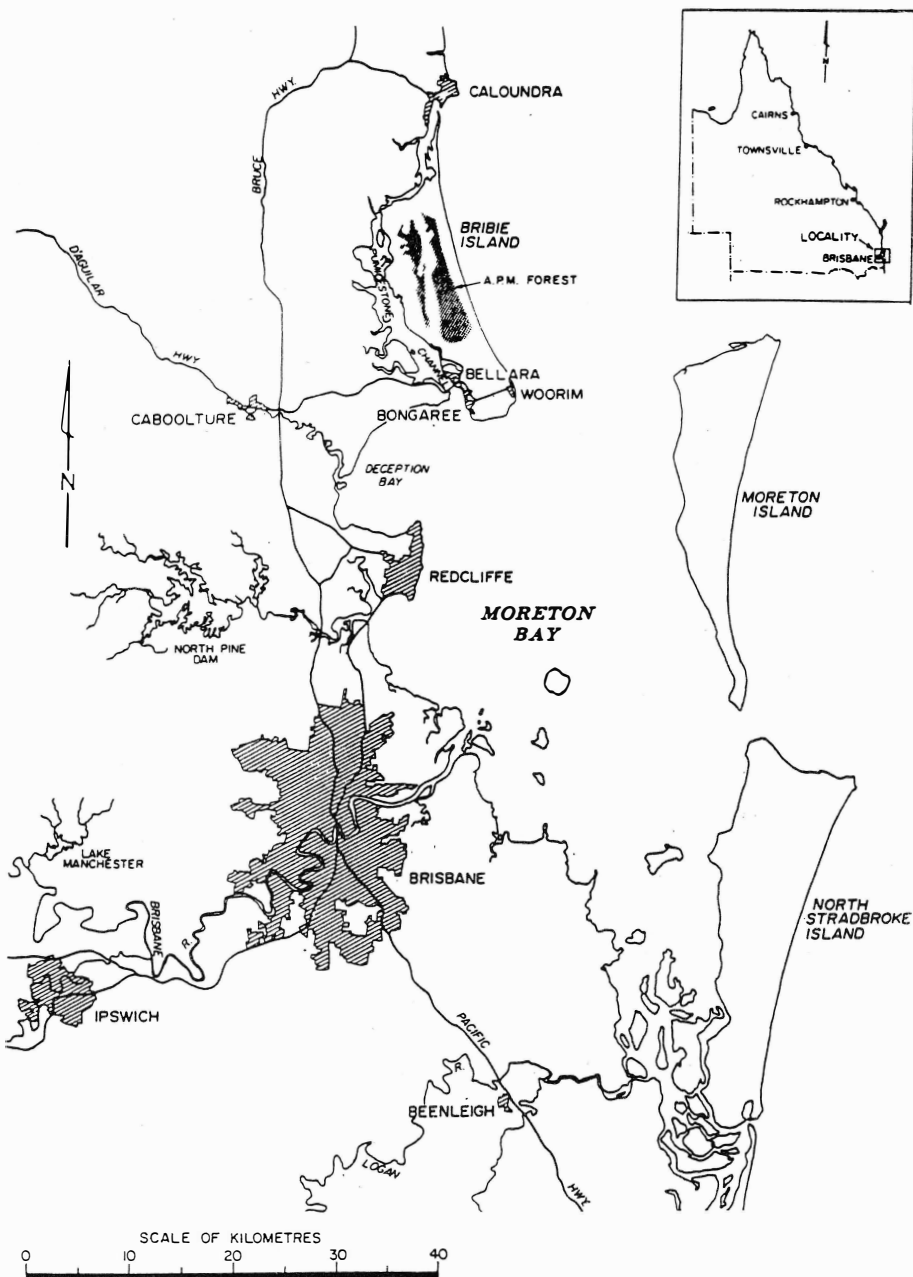


FIGURE 1 : Locality plan

2. DESCRIPTION OF BRIBIE ISLAND

2.1 Location

Bribie Island is situated just off the south-east coast of Queensland, approximately 65 km north of Brisbane (see Figure 1). The narrow waters of Pumicestone Channel separate the island from the mainland.

Bribie Island is one of three large islands which skirt Moreton Bay, the other two being North Stradbroke Island and Moreton Island. All three islands are substantially composed of sand. However Moreton Island and North Stradbroke Island mainly comprise massive vegetated dunes rising to about 200 m above sea level. Bribie Island, by contrast, has low relief, a significant proportion of the island being less than 5 m above sea level.

With an approximate area of 144 km², Bribie Island is about 30 km long and has an average width of about 5 km.

2.2 Population

Urban development on the Island is confined to fairly narrow strips along the east and west coast of the southern portion. Most of the remainder of the island is either vacant Crown land or land owned and leased by Australian Paper Manufacturers (APM) for forestry. The APM pine forest covers a significant proportion of the northern part of the island, as shown on Figure 1.

The main population centres are Bongaree, Bellara and Banksia Beach on the west coast and Woorim on the east coast (see Figure 1). All of the island, except for a portion in the north, is administered by the Caboolture Shire Council.

The present permanent population on the island is approximately 6 100. However Bribie Island is a popular holiday resort and the population can rise temporarily to around 40 000 during peak periods because of holiday and day visitors.

The island's permanent population has been increasing rapidly since the opening in 1963 of the Bribie Island Bridge across Punicestone Channel. It is expected to reach 20 000 by the year 2001 (Inter-departmental Committee (1982)).

2.3 Climate

Bribie Island experiences a subtropical climate, with mean monthly maximum temperatures ranging from 29^oC in summer to 20^oC in winter.

Rainfall tends to be concentrated into the warmer half of the year, although winter rainfall is not insignificant. The wettest months are December to March when rainfall can be intense. The island is occasionally subjected to cyclonic disturbances.

Records of rainfall are available from the Bureau of Meteorology for two stations located on the island. For the station at the Bongaree Post Office, records began in 1931 while records for the University of Queensland Research Station commenced in 1978. Annual and monthly rainfall statistics for Bongaree are shown in Tables 1 and 2 respectively.

TABLE 1 : Annual rainfall - Bongaree

Period of Record	Annual Rainfall		
	Mean (mm)	Maximum (mm)	Minimum (mm)
1932 - 1981	1334	2472 (1974)	725 (1944)

TABLE 2 : Mean monthly rainfall - Bongaree

Month	J	F	M	A	M	J	J	A	S	O	N	D
Mean (mm)	173	190	178	108	105	84	70	49	46	102	103	132

The nearest station at which records of evaporation are available is at Brisbane. Records of evaporation from a Class A Pan are available from 1965 to date. These records indicate that the mean annual evaporation at Brisbane is some 1570 mm. Table 3 shows the variation in evaporation during the year.

TABLE 3 : Mean monthly evaporation - Brisbane

Month	J	F	M	A	M	J	J	A	S	O	N	D
Mean (mm)	180	142	142	117	83	66	72	100	131	157	176	202
Average Daily (mm/d)	5.8	5.1	4.6	3.9	2.7	2.2	2.3	3.2	4.4	5.1	5.9	6.5

2.4 Topography

Bribie Island has very low relief. A large proportion of the island is less than 5 m above sea level and the highest point is only 12 m above sea level.

Because the island is flat, surface drainage is poorly developed.

Large parts of the island are either swanpy or subject to inundation during the wetter months.

Some direct drainage occurs through a number of small tidal inlets along the west coast of the island. The largest of these inlets is Dux Creek which is surrounded by extensive mangroves for most of its length.

Several lagoons are located along the east coast. These lagoons are normally closed to the sea by sand deposits and provide direct drainage only after heavy rain. Freshwater Creek in the south-east of the island also flows only after substantial rain.

2.5 Geology

Bribie Island consists of Quarternary sand deposits overlying an impermeable clay horizon or the Early Jurassic Landsborough Sandstone. The clay horizon is probably the weathered soil profile of the Landsborough Sandstone. No outcrops of the sandstone occur on the island.

The island has been formed by the deposition of sand supplied by the longshore drift which, in this part of the coastline, moves sand from south to north. The interior of the island contains several raised ridges representing old frontal dunes. On the southern tip of the island, a series of old beach lines indicate fairly recent states of coastal accretion.

The Quaternary sand deposits of the southern portion of the island comprise of three main geological units, namely:

- (i) Holocene accretion ridges and swales;
- (ii) Holocene to Pleistocene undifferentiated sediments;
- (iii) Pleistocene accretion ridges and swales.

The approximate boundaries of these three units are shown in Figure 2.

All three units are lithologically similar except that the last two units contain a well developed horizon of dark humus - cemented sand. This sand is referred to as peaty sand. The peaty sand horizon occurs in thicknesses up to 9 m and represents up to 80% of the total sand depth.

The sediments of the Holocene accretion ridges and swales, which contain little or no peaty sand, are generally located south of the Bongaree - Woorim Road except for a narrow strip up the east coast (see Figure 2).

The total thickness of the sand deposits on the southern part of the island varies from about 5 m near Bongaree to some 25 m at both the southern coast and in the middle of the island near Dux Creek. Further details are available in Ishaq (1980) and Walker (1983).

2.6 Groundwater Occurrence

Groundwater occurs within the intergranular spaces of the Quaternary sand deposits on the island. The unconfined aquifer so formed is recharged by infiltration of rainfall and drained by seepage to the sea around the island's perimeter.

The proportion of rainfall which recharges the aquifer is that proportion remaining after interception by evaporation, plant transpiration

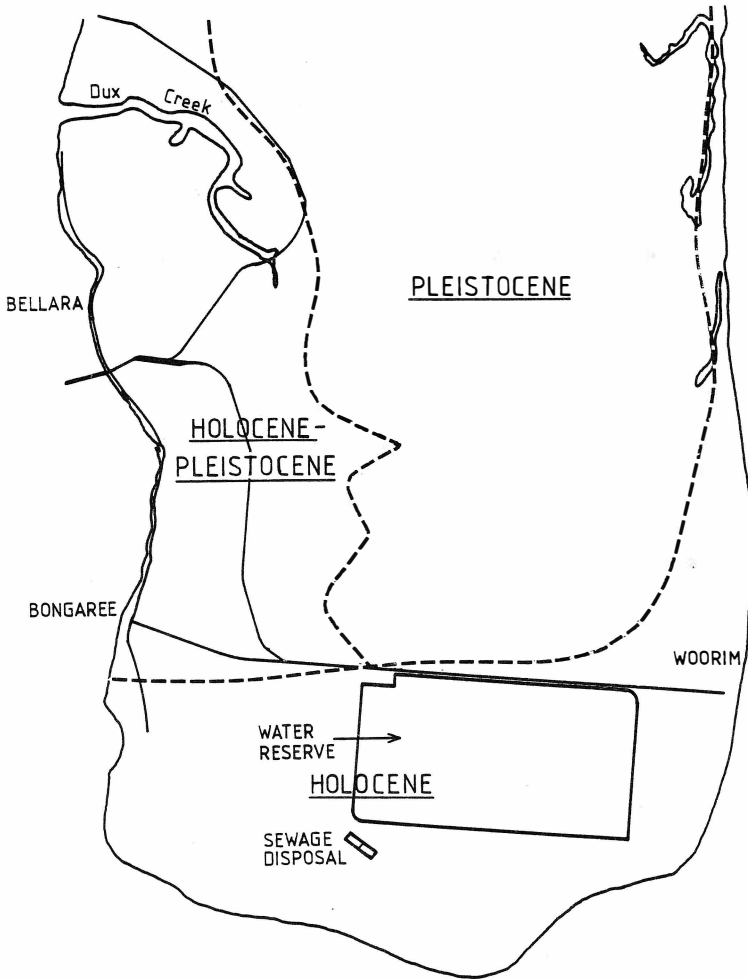


FIGURE 2 : Bribie Island - approximate geological boundaries

and surface runoff. Because of the low relief of the island interception by surface runoff is limited.

3. EXISTING SYSTEM

3.1 Groundwater Extraction

A reticulated water supply scheme serving the urban centres on both sides of the island was completed in 1962. Groundwater is extracted from a water reserve south of the Bongaree - Woorim Road (see Figure 3). After treatment, the supply is pumped to the urban areas.

Groundwater was originally extracted from six bores on the eastern side of the reserve. As demand for water increased due to the rapid expansion in population on the island, augmentation of the supply became necessary. In 1966-69, 21 additional bores were drilled in the water reserve. The results of short duration pump tests to determine bore performance were disappointing.

In 1971, because of continuing problems with clogged screens in the six production bores and because substantially increasing the supply capacity would require equipping a large number of additional bores, pumping from a trench dug to below the water table was adopted. This method of extraction has continued to the present. The trench system has been extended as demand for water has increased. The extent of the trench in 1981 is shown in Figure 3.

Records of daily quantities of groundwater are kept by the Caboolture Shire Council. Annual consumption has increased substantially from 65 ML in 1962 to 275 ML in 1972 and to 908 ML in 1981.

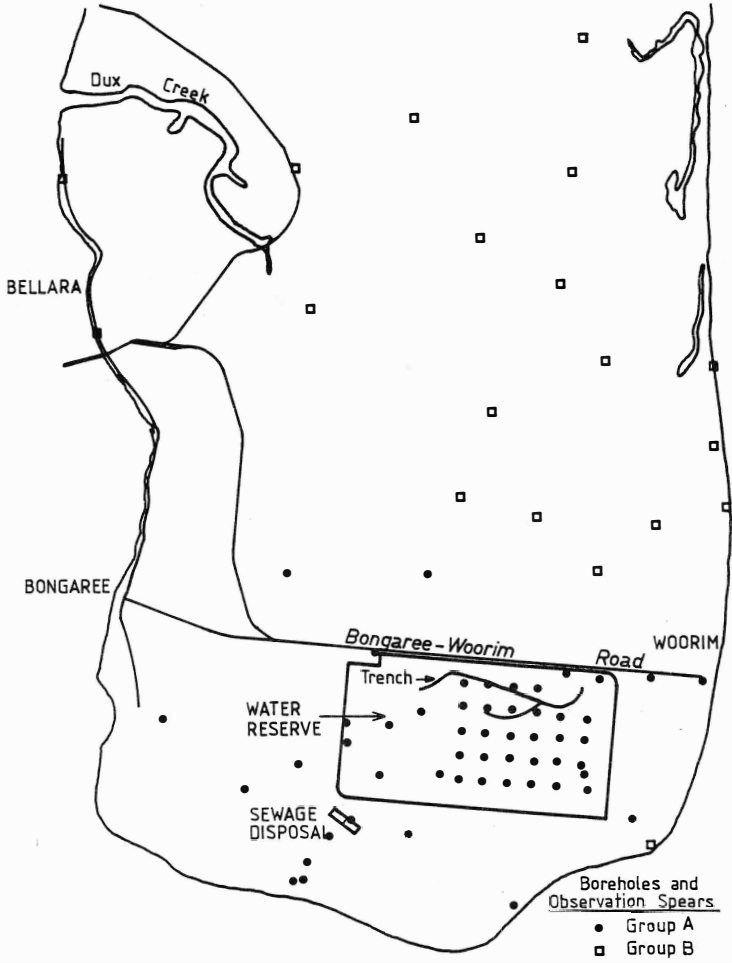


FIGURE 3 : Bribie Island water reserve

3.2 Sewage Effluent Disposal

A sewage scheme was commenced in 1974 initially serving Bongaree and Woorim. Extension of the scheme to Bellara and Banksia Beach was completed in 1980 and 1981 respectively.

All sewage is piped to a treatment plant located in the south-western corner of the water reserve. The effluent from the treatment plant is generally broadcast over prepared plots south-west of the plant (see Figure 3) and infiltrates to the aquifer. At present the total area covered by the plots measures some 60 m by 350 m.

Daily quantities of effluent discharge are recorded. Annual effluent discharge has increased, as would be expected, in a similar manner to groundwater extraction. In 1981 the annual effluent discharge was 592 ML; 65% of total water use.

3.3 Records of Water Table Position

A total of 76 observation bores and spears exist on the southern portion of Bribie Island, as shown in Figure 3. No observation bores are located on the rest of the island. Of the total number, 54 are located south of the Bongaree - Woorim Road.

Some water level records dating back to the 1960's are available for a number of the bores in the water reserve. In 1980 an expanded regular water level measuring programme was initiated. Since the middle of 1980 regular monthly measurements have been taken for most of the bores south of the Bongaree - Woorim Road. A number of readings are also available for two bores located just north of the Bongaree - Woorim Road. The bores

for which a number of readings is available are marked as Group A on Figure 3. Apart from these records the only other water level measurements available are two sets of measurements for another 26 bores taken during a hydrogeological investigation in 1979/80.

Therefore regular records of the water table position are available only for the portion of the aquifer south of the Bongaree - Woorim Road.

3.4 Previous Groundwater Investigations

Three main groundwater investigations concerning the water supply scheme on Bribie Island have been undertaken. They comprise two hydrogeological investigations of the southern part of the island (Lumsden (1964) and Ishaq (1980)) and a report which included a review of the performance of the water reserve (J. Wilson and Partners (1979)). These investigations are discussed below.

3.4.1 1963-64 Hydrogeological investigation

The Geological Survey of Queensland carried out a hydrogeological investigation on the southern part of the island in 1963-64. A total of 28 holes were drilled and logged, of which only 6 were completed as observation bores. The present water reserve was established following recommendation in the investigation report (Lumsden (1964)).

Lumsden provided two figures of 4 m/day and 13 m/day for the average hydraulic conductivity of the aquifer, based on permeameter tests and grain size distribution respectively. No details of either of these methods are given. However, neither method generally provides confident

estimates (Todd (1980)). Lumsden also suggests a water balance for the southern part of the island but gives no basis for the adopted figures. He suggests that, of the average annual rainfall, 5 to 10% becomes surface runoff, 50% is lost by evapotranspiration, and the remaining 40 to 45% infiltrates to the aquifer.

3.4.2 1979 Water balance investigation of water reserve

John Wilson and Partners (1979) reviewed the performance and adequacy of the water reserve, trench system, pumping plant and water treatment processes. The recommendations of the report concerning the source of supply included:

- (a) fully develop the water reserve by extending the trench system;
- (b) extend the sewage disposal areas along a line south of the water reserve to reduce the groundwater flow out of the reserve; and
- (c) ensure that the area immediately north of the Bongaree - Woorin Road opposite the water reserve is not developed in a manner which will affect groundwater flow to the reserve.

To provide an understanding of inflows and outflows associated with the aquifer underlying the developed eastern half of the water reserve, John Wilson and Partners investigated a water balance for the period January 1978 to January 1979. This period was chosen because, based on bore water level records, the water table was in a similar location at both the beginning and the end of the period, implying no net change in aquifer storage.

Terms were evaluated in a water balance equation,

Loss in aquifer = groundwater extracted + outflow to the sea
- recharge by rainfall - inflow from the northwest,

for the rising water table section (January 1978 to June 1978) and the falling water table section (June 1978 to January 1979) of the period, using water level records for the water reserve bores, an estimated specific yield, rainfall records and a number of simplifying assumptions. Hydraulic conductivities for both the inflow and outflow areas were estimated during the calculations.

From the water balance investigation, John Wilson and Partners concluded:

- (a) 42% of rainfall for the investigation period recharged the aquifer;
- (b) hydraulic conductivity in the southern part of the water reserve is estimated as 30 m/day;
- (c) hydraulic conductivity in the northern part of the water reserve is estimated as 13 m/day; and
- (d) some 75% of groundwater extracted during the investigation period originated from either north of the reserve or from the western half of the reserve.

3.4.3 1979-80 Hydrogeological investigation

The Geological Survey of Queensland conducted a second hydrogeological investigation on the southern part of the island in 1979-80 (Ishaq (1980)). A total of 26 holes were drilled and logged, all of which were completed as observation bores. The locations of these boreholes were spread over a larger area than for the earlier investigation.

The main objective of this investigation was to determine a suitable area for an additional water reserve. To do this, the extent and nature of the sand deposits were identified from the borehole logs. A description of the sand deposits based on Ishaq's detailed description has already been presented (see Section 2.5). Ishaq's recommendations included:

- (a) extend the existing water reserve to the south and west to include a greater part of the clean sand deposits south of the Bongaree - Woorim Road, and consider relocation of the sewage disposal area to allow early use of the expanded area;
- (b) assess a further two areas with potential for developing groundwater supplies, namely, a strip along the east coast north of Woorim which is devoid of peaty sand and in an area south of the APM pine forest where a significant thickness of clean sand occurs beneath the peaty sand horizon;
- (c) conduct long term pump tests in existing and proposed water supply areas to obtain more accurate estimates of hydraulic conductivity and specific yield;
- (d) study further the proportion of rainfall recharging the aquifer;
and
- (e) consider research into the use of treatment effluent for artificial recharge.

Ishaq provides a number of values of hydraulic conductivity additional to those given in earlier investigations. The hydraulic conductivity deduced from the average grain size distribution of 50 samples of non-peaty sand collected during the investigation by applying the empirical Hazen's formula is 17 m/day. Ishaq states that the peaty sand has a lower hydraulic conductivity but does not offer any estimated values.

Ishaq also analysed the data from pump tests for two bores in the water reserve conducted by John Wilson and Partners in 1966. The values of hydraulic conductivity obtained using drawdown and recovery measurements in the pumping bore and adjacent observation bores vary between 15 and 75 m/day. Ishaq considers these results unreliable as the pump tests were conducted over only 8 hours.

The water balance for the southern part of the island is given by Ishaq. Of the average annual rainfall Ishaq suggests that only 13% recharges the aquifer and the remainder is lost either by evapotranspiration (82%) or surface runoff (5%). The adopted proportion of rainfall recharging the aquifer is significantly less than the proportion provided by either Lumsden or John Wilson and Partners. The water balance given by Ishaq is based on the main assumption that average evapotranspiration loss is equivalent to the potential evapotranspiration as estimated from pan evaporation records.

3.5 Need for a Regional Groundwater Model

Increases in the water requirements of the rapidly expanding population on Bribie Island will ultimately be met by construction of a supply system from the mainland, the provision of which will be costly. It is therefore important to utilise the groundwater resources on the island efficiently. To do this a clear understanding of the island's groundwater hydrology is necessary.

Previous investigations, in particular the hydrogeological investigations, have identified in some detail the nature and extent of the sand deposits on the southern part of the island but have not adequately identified hydrologic aspects of the groundwater. This is

supported by the most recent investigator, Ishaq (1980) who recommends further testing and study of the groundwater system.

Therefore, the decision was made to develop a steady-state regional groundwater model of the aquifer and to attempt to calibrate the model using the available data. As the extent of the aquifer has been identified only in the southern portion of the island and as this portion contains all existing and probable future areas from which groundwater will be extracted for urban water supply purposes, the model is confined to the southern part of the island.

4. MODELLING APPROACH

4.1 Mathematical Background

The thickness of the unconfined aquifer on Bribie Island is small relative to its areal extent. The Island's width is over 300 times the average aquifer thickness. The island is also flat. Therefore groundwater flow is essentially horizontal and two-dimensional. An equation that describes two dimensional groundwater flow in an unconfined aquifer can be obtained by combining Darcy's Law and the conservation of mass principle. This gives (e.g. Bear (1972))

$$\frac{\partial}{\partial x} (Kb \frac{\partial h}{\partial x}) + \frac{\partial}{\partial y} (Kb \frac{\partial h}{\partial y}) = S \frac{\partial h}{\partial t} + \frac{Q}{A} - R \quad (1)$$

Under steady-state conditions, Equation (1) becomes

$$\frac{\partial}{\partial x} (Kb \frac{\partial h}{\partial x}) + \frac{\partial}{\partial y} (Kb \frac{\partial h}{\partial y}) = \frac{Q}{A} - R \quad (2)$$

The storage coefficient, S, does not therefore appear in steady state solutions.

The mathematical representation of steady-state groundwater flow on southern Bribie Island consists of Equation (2) together with appropriate boundary conditions. Most of the boundary of the aquifer on southern Bribie Island is the island's coastline where the time-averaged piezometric head is equivalent to mean sea level. Using mean sea level as the datum the conditions for the coastal boundary can be written

$$h = 0 \quad (3)$$

A boundary, not coinciding with a physical boundary of the aquifer is required across the island to separate the southern portion, where some data is available, from the rest of the island where data is lacking. The boundary chosen is approximately perpendicular to both coastlines. Its location was selected to be compatible with the adopted discretization for numerical solution.

For steady-state groundwater flow on a long rectangular island the groundwater streamlines become straight and normal to the coastline as the mid-section is approached. A boundary across the island coinciding with a streamline will, by the definition of a streamline, be a boundary across which no flow occurs. Therefore, it is considered reasonable to assume the condition that no flow occurs across the selected boundary across Bribie Island. This boundary condition can be written

$$\frac{dh}{dn} = 0 \quad (4)$$

where n = unit length in the direction normal to the boundary.

See Appendix A for definitions of terms.

4.2 Numerical Model for Regional Groundwater Analyses

An analytical solution to Equation (2) applied to the Bribie Island aquifer is not presently feasible. Various numerical methods were considered and a decision was made to use a finite-difference method.

In the finite difference method the solution domain is discretized by the use of a suitable grid. The intersections of the grid lines define the grid points or nodes. The governing differential equation is replaced by a set of difference equation written for each node. For a square grid with grid spacings of Δx , the difference equation for a typical internal node can be written (Hunt (1976))

$$\sum_{i=1}^4 \left(\frac{T_i + T_0}{2} \right) (h_i - h_0) = Q - R (\Delta x)^2 \quad (5)$$

where T = transmissivity = Kb

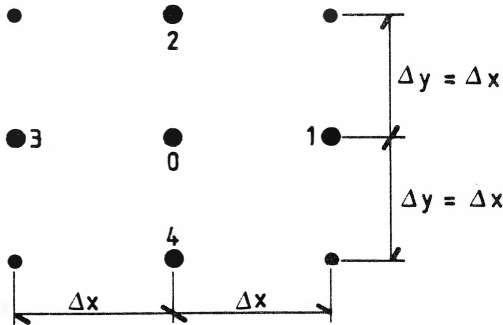


FIGURE 4 : Typical internal node

A 250 m grid was chosen following a recommendation by Walker (1983). This grid allows reasonable approximations to the coastline and to the extraction trench (see Figure 5). The position of the grid boundary modelling the coastline south-east of the water reserve was chosen during the calibration. The reason for the choice is given in Section 5.

Special forms of the difference equation are required to model the boundary conditions. At nodes located along the coastline as modelled, the boundary condition is satisfied by setting $h_0 = 0$. At nodes located along the northern boundary (parallel to the adopted x-axis) the boundary condition $\partial h / \partial n = 0$ is satisfied by setting $h_2 = h_4$ and $T_2 = T_4$ in Equation (5).

The equations that result from writing the appropriate difference equation for each node form a set of simultaneous linear equations with the nodal values of h as the unknowns. These equations are solved by the iterative, SOR (successive over-relaxation) method.

Because of the topography of Bribie Island, a conditional boundary condition had to be introduced to model the low areas which may form swamps. If the computed value of h for an internal node was greater than the ground level, the standard difference equation was replaced by a boundary condition equation in which h was set equal to the ground level.

Valid interpretations of the numerical, regional groundwater model depend on an appreciation of its limitations. Firstly, the model is based on the Dupuit approximation and local differences between field values and model values must be expected where the seepage velocities are not essentially horizontal or where there exist seepage faces. Secondly, in the model, point or line extractions or recharges modelled by nodal Q terms are assumed to be distributed over the grid area, $(\Delta x)^2$. Thirdly, the

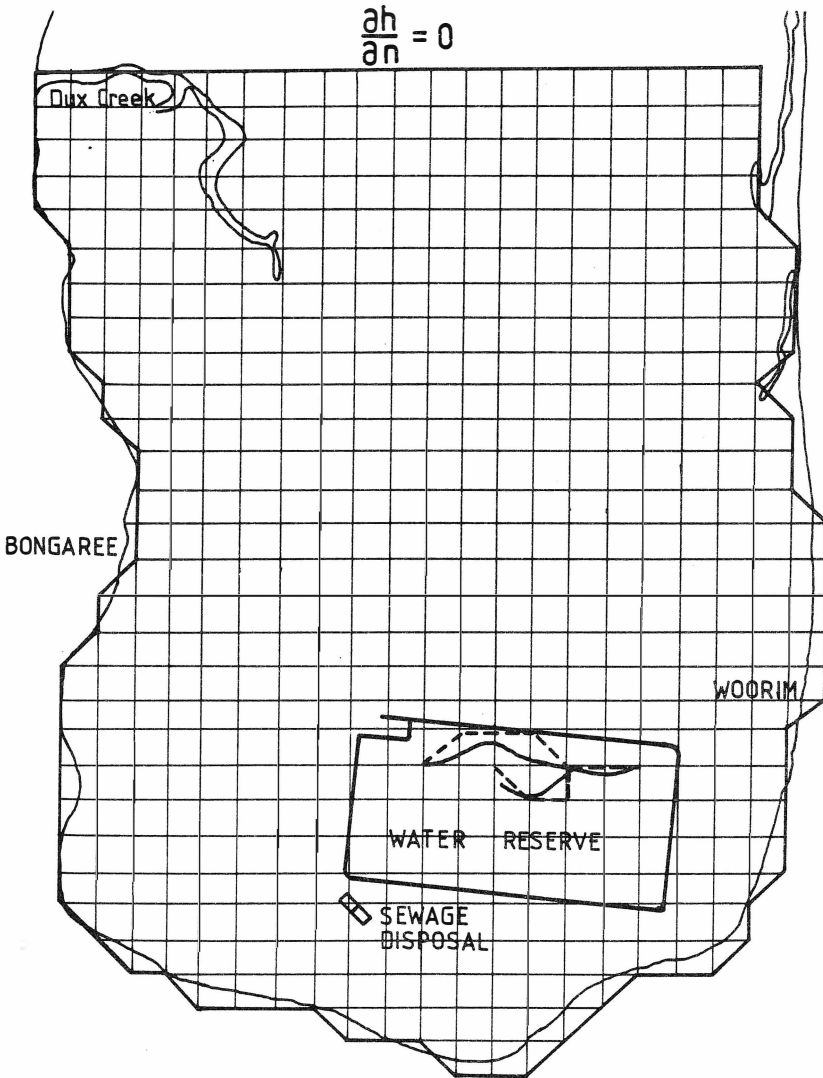


FIGURE 5 : Finite difference grid 250 m spacing - southern Bribie Island

regional model ignores the effects of the salt-water wedge which intrudes into the aquifer along the coastline. Therefore, in the case of Bribie Island, significant differences between model results and field values must be expected locally in particular regarding the head values in and immediately adjacent to the trench, adjacent to the sewage recharge area and close to the coastline. The regional groundwater model is valid if it can successfully model the general pattern of observed water table levels away from these local effects. Other models can be used to investigate these local effects. Such studies are being done and will be described in future reports.

5. CALIBRATION OF NUMERICAL MODEL

The mathematical basis for a numerical regional groundwater model is well known and accepted. The real challenge in any application is the calibration of the model so that it accurately models the particular aquifer under study. No model can be a properly calibrated without adequate field data. In the case of Bribie Island the data required include the extraction from the trench and other extractions from the aquifer; the recharge and the locations of recharge for the sewage effluent; physical details such as ground surface levels and the depth to the impermeable layers; net recharge from rainfall and the hydraulic conductivity throughout the aquifer.

Available data for Bribie Island were not collected for the purposes of this particular mathematical model. A decision was made at the beginning of the study to obtain the best possible calibration with the available data and to use the model itself to determine the extra data that would be required for a better calibration. Despite the inadequacy of the available data for the purpose and the assumptions that had to be made for the

calibration, the resulting model is judged to be satisfactory and has proven a useful tool for evaluating the aquifer.

In the calibration the Geological Survey levels (Ishaq (1980)) for the ground surface and the impermeable layer surface were adopted and were interpolated to the node points. The Geological Survey water table levels were not adopted as a basis for calibration as these were levels taken at a particular point in time and were not necessarily representative of a steady state condition. The representative steady state condition was determined from an analysis of a 19 month period from June 1980 to December 1981 of the recorded water levels in the observation bores. The mean levels over this period were calculated. Full details are given in Walker (1983). Some of the mean values had to be discarded as unreliable because they indicated local maxima or minima at points where there was no evidence of local recharge or extraction. The steady state 'field' contours to be used in the calibration were then drawn from the acceptable mean levels.

Averaged values of 2500 m³/day for trench extraction and 1500 m³/day for effluent recharge, derived from Caboolture Shire Council records, were adopted for the calibration. Local recharge and extraction, for example, at the golf course or at spears for local watering either by the Council or by homeowners, were neglected in the calibration. Furthermore no data are available on the effects of dewatering procedures during the expansion of the sewage system along the western side of the island and any effects of this dewatering have been neglected.

While it is recognised that the assumption of a constant value for the hydraulic conductivity throughout the study area is invalid because of the presence of the peaty layers north of the Bongaree - Woorim Road, the lack of data to enable a more precise calibration meant that this

assumption was reasonable for the initial calibration attempts. The reliable data are restricted to the readings taken in the region south of the Bongaree - Woorim Road and therefore the calibrated model should be considered as valid only for predictions of groundwater levels in this region. Given the assumptions and restrictions already mentioned, the criterion for successful calibration was the goodness of agreement between computed contours and the adopted 'field' contours in the region south of the Bongaree - Woorim Road. The values that were unknown and were required to calibrate the model were the hydraulic conductivity of the sand and the average recharge to the aquifer from rainfall.

Earlier estimates of hydraulic conductivity ranged from 4 to 75 metres per day for extreme values with realistic values from about 10 to 30 metres per day. Estimates of the recharge from rainfall ranged from about 180 to about 500 mm per year. The model was calibrated by varying the recharge and the hydraulic conductivity until the best overall fit between the model results and the steady state results were obtained. The best overall agreement was obtained with a recharge value of 300 mm per year and a hydraulic conductivity of 25 metres per day (see Figure 6). These values appear to be reasonable as they lie in the middle of the ranges previously suggested.

The best fit was decided by subjective judgement based on visual comparisons of computed contours with the 'field' contours. No attempt has been made at any objective, numerical justification of the choice of parameters. It is the authors' firm opinion that the use of engineering judgement was the best basis of decision given the quality of the field data.

The model boundary south of the water reserve where the condition $h = 0$ is applied was adjusted during the calibration until the best fit

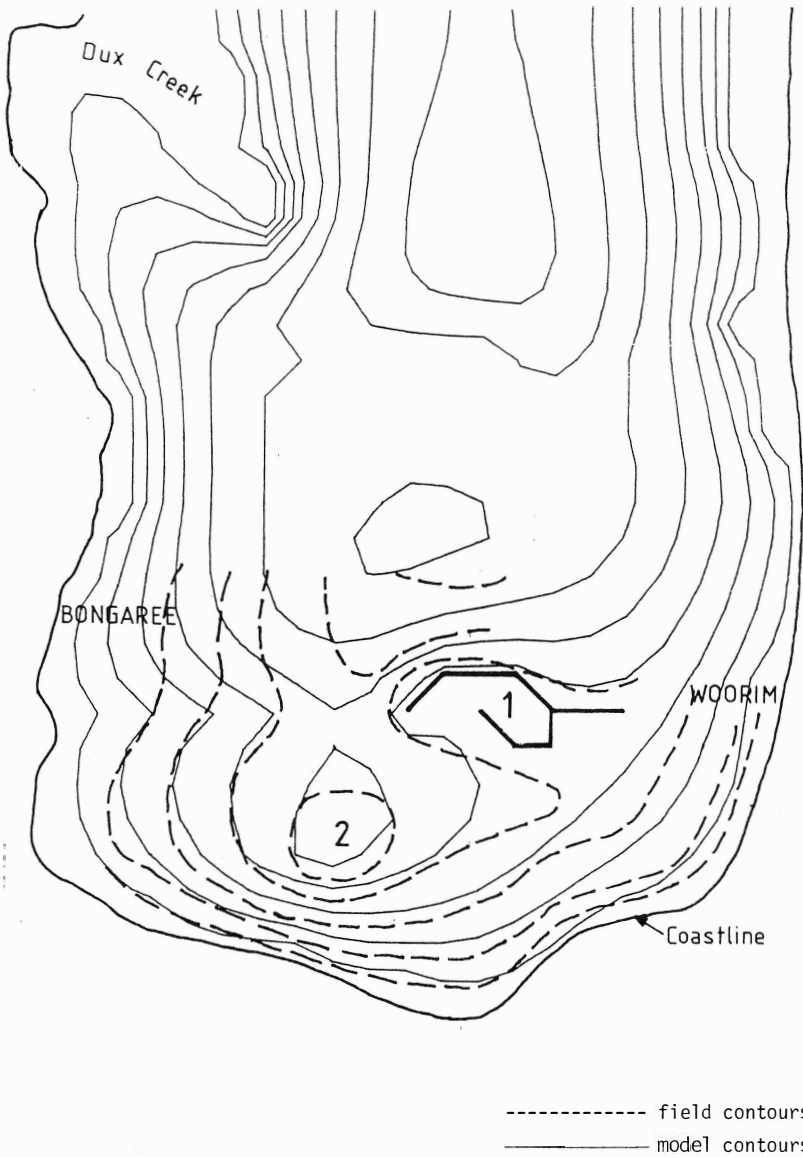


FIGURE 6 : Field and model contours for calibration period

between the computed and the field contours for $h = 0.5$ was obtained. This produced a better match between the model and field contours because it overcame the inability of the model to reproduce certain local effects. Because the model is based on the Dupuit assumption it neglects the possible existence of a seepage face along the coast. If a seepage face exists, the groundwater level along the coast will be higher than the sea level. The model also neglects the presence of the salt water wedge beneath the fresh water adjacent to the coast. The existence of a salt water wedge results in a steeper water table gradient adjacent to the coast than would be predicted by the model.

6. ASSESSMENT OF THE CALIBRATED MODEL

Given the available data and the assumptions adopted (including assumptions that R and K are constant), the calibrated model gives the best overall representation of the average water table levels through the calibration period for the area south of the Bongaree - Woorim Road (Figure 6). There are some local differences between the computed and the 'field' contours which required an explanation and there are some reasons for questioning the adopted value for K .

The most noticeable difference between the computed and 'field' contours in the water reserve is that between the 2.0 m contours immediately south of the trench. If a lower value for K (e.g. 20 m/day) were adopted, the agreement between the computed and 'field' contours would be greatly improved in this area as shown in Figure 7. However, the agreement is significantly worsened in the vicinity of the effluent disposal beds. The higher value of K is necessary if the adopted effluent rate and 'field' contours are to be compatible. Another reason for questioning the value for K comes from an analysis of a pump test. Although most of 1966 - 1967

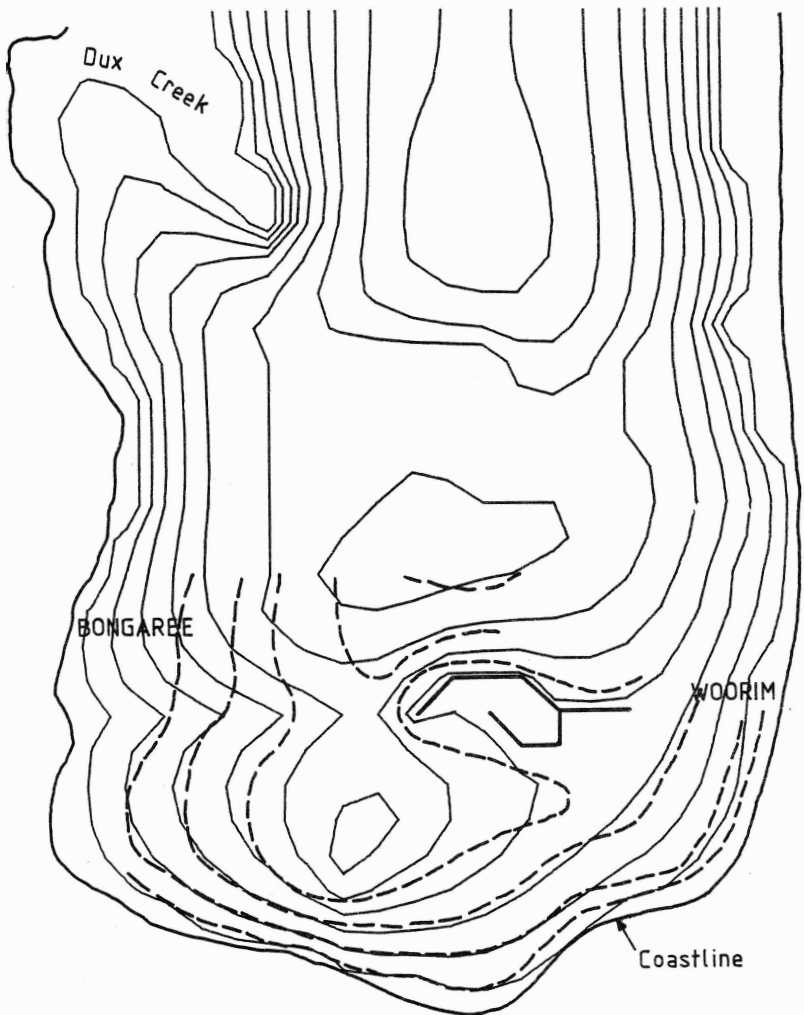


FIGURE 7 : Model contours ($K = 20$ m/day, $R = 300$ mm/year)

pump tests were conducted over only 8 hours (see Section 3.1), one 24 hour test was done on a bore in the water reserve and the results are suitable for parameter estimation. The Theis, match-point method (see Todd (1980)) was used to analyse the results and yielded a value for T of 232 m³/day. A saturated thickness of 14 m was assumed and the derived value for K was 17 m/day. Either K varies from the effluent disposal beds to the trench or there are some errors in the data used. This question can be resolved only by further field tests and data acquisition.

Another significant difference between the computed and 'field' contours occurs inland from Bongaree (see Figure 6). The 'field' contours were based on only two boreholes in this region and cannot be considered as well defined. Furthermore, the 'field' contours indicate that the water table gradient decreases approaching the coast which cannot be the case under the assumed conditions for the calibration period. It is possible that local extraction (e.g. dewatering during construction of the seepage system or by council and domestic spears for watering) occurred and could be the explanation for the differences. Available evidence suggests that, under normal conditions, local extraction is not significant and the authors believe that the model gives the better result in this area.

North of the Bongaree - Woorim Road the field data are so sparse that the model cannot be considered as calibrated for this area and applications of the model in this region should be treated with caution. However, the model will give a better indication than any other available analysis of the possible effects of changes in the region.

7. APPLICATIONS

7.1 General

The model may be used,

- (i) as an aid in understanding and assessing the groundwater flows through the aquifer under present conditions, and
- (ii) as a basis for predictions of future performance under changed conditions.

7.2 Current Situation

Since December 1981, the trench system has been expanded and the average rates for extraction and effluent disposal have increased to 3600 m³/day and 2100 m³/day respectively. The results of an analysis for these conditions (with K = 25 m/day and R = 300 mm/year) are shown in Figure 8. These results indicate that the area from which recharge flows to the trenches is about 4 km². With an assumed recharge from rainfall of 300 mm/year, rainfall recharge reaching the trench accounts for about 3300 m³/day of the total extraction. The balance comes from a flow towards the trenches from the effluent disposal area.

About 50 percent of the 4 km² area is north of the trench and lies outside the water reserve. This fact should be an important consideration in future land use plans for this area. The model indicates that the flow in the south-east corner of the water reserve is towards the coast. The possibility of recharging with treated effluent in this area should be considered. The effects of effluent recharge on water quality would have to be evaluated and is a topic for proposed future research. The model indicates that the average Darcy velocity from the existing disposal area

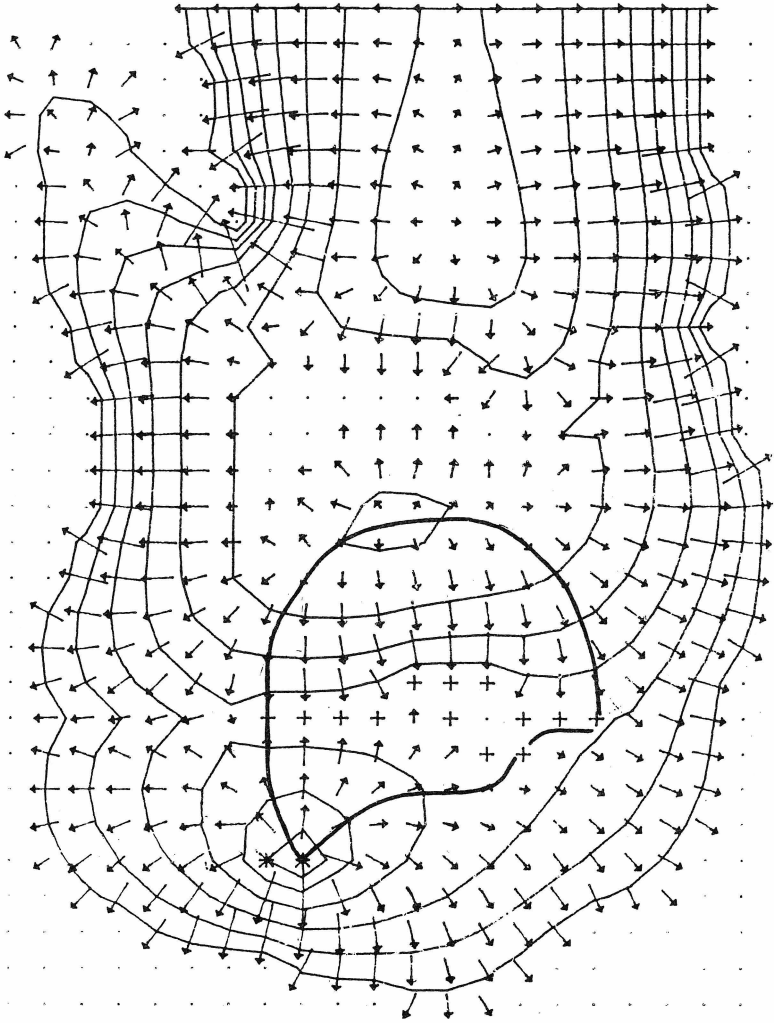


FIGURE 8 : Model results for early 1983 conditions

towards the trench is about 18 m/year. If a porosity of 0.2 is assumed, the average linear velocity of fluid particles is about 90 m/year and it would take at least 10 years for a fluid particle to travel from the existing disposal beds to the trench. There is no need for immediate concern about the effects on water quality under present conditions.

7.3 A Proposed Recharge Scheme

As an example of the application of the model in planning future developments, an analysis was done for 25 percent increases in extraction and effluent rates with part of the effluent used as recharge across the south-east corner of the water reserve.

The values used in the analysis were 4500 m³/day for extraction from the trench, 1800 m³/day for effluent recharge at the existing site and 800 m³/day distributed equally to three nodes across the south-east corner of the water reserve. The values of 25 m/day for K and 300 mm/year for R were retained. The results (Figure 9) show that the use of strategically located recharge beds will improve water table levels between the trench and the sea despite the 25 percent increase in net extraction. The use of treated effluent water for strategic recharge warrants further investigation. A major objective of any future studies must be an evaluation of the effects of effluent recharge on the aquifer.

8. CONCLUSION

A steady regional groundwater model of the aquifer of southern Bribie Island has been developed and calibrated against existing data. While the model could be significantly improved if further field tests

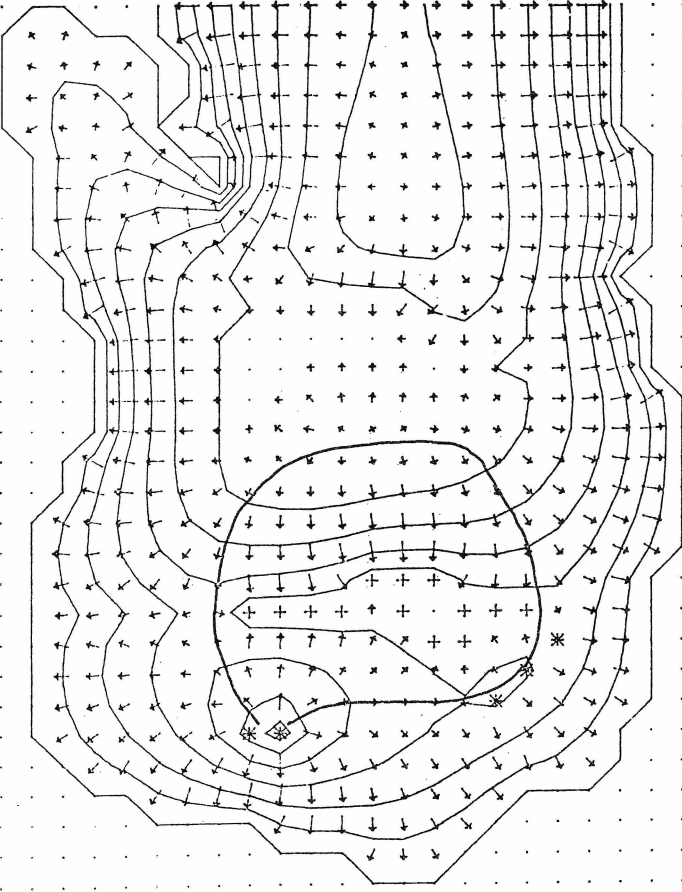


FIGURE 9 : A proposed recharge scheme

were done for the evaluation of model parameters, the model is considered sufficiently accurate for assessing the performance and potential of the existing water reserve. Results obtained from the model show that,

- (i) a significant proportion of the water currently extracted comes from the area north of and outside the water reserve, and
- (ii) extraction rates can be increased and water table levels maintained if treated effluent is used to recharge the south-east portion of the water reserve.

Because of the scarcity of data in the northern part of the region modelled, the accuracy of the model in this region is unknown. While the model will give better indications than any other available method of the possible effects of changes in this region, the results should be used with caution.

10. ACKNOWLEDGEMENTS

The authors acknowledge the advice and help given by the following organisations (and, in particular, the individual members of those organisations with whom we dealt):

Caboolture Shire Council

The Water Research Foundation of Australia

Department of Local Government

Queensland Water Resources Commission

Geological Survey Office

The authors thank Mr B. Kotecki and Mr R. Nilsson of the Civil Engineering Department for their valuable contribution to the project.

APPENDIX A - NOMENCLATURE

<u>Synbol</u>	<u>Meaning</u>
A	area over which withdrawal occurs
b	saturated thickness
h	peizometric head
K	hydraulic conductivity
Q	withdrawal rate
R	rate of recharge from rainfall
S	storage coefficient
t	time
T	transmissivity
x	horizontal Cartesian coordinate
y	horizontal Cartesian coordinate
Δx	grid spacing

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