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# Using Pumps and Syphons to Control Salinity at a Saline Seep in the Wallatin Creek Catchment

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## Resource Management Technical Report No.91

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The contents of this report were based on the best available information at the time of publication. It is based in part on various assumptions and predictions. Conditions may change over time and conclusions should be interpreted in the light of the latest information available.

# Table of Contents

# 1. Abstract

A saline hillside seep was chosen in the Wallatin Creek catchment to determine the role of pumps and syphons for reclaiming saltland. Pumping tests were used to estimate the effective area of reclamation and the economics analysed using a spreadsheet model (PUMPS).

A groundwater balance suggested that the catchment’s average recharge rates are about 5 to 10 mm/yr, while discharge rates are about 30 to 40 mm/yr. Groundwater flow occurs mainly within a confined to semi-confined, saprolite aquifer. Pumping the aquifer could reduce groundwater levels across the saline area. However, this is uneconomic under present conditions. The legality of disposing of the saline (4,490 mS/m) groundwater is also a problem. There are currently no clear guidelines for the disposal of saline water outside gazetted, Water Authority controlled catchments. This should be a priority research and legislative issue if pumping is to become a useful saltland management method.

# 2. Introduction

Saline hillside seeps are not common in the eastern wheatbelt. However, many have developed in the higher rainfall areas to the west (> 350 *mm/yr).* The Wallatin Creek catchment has been described by McFarlane and George (1987) as being more typical of the western wheatbelt, owing to its geologic and geomorphic history. Saline seeps were investigated at five sites within the Wallatin Creek catchment using seismic refraction methods (Kevi, 1987) and were found to be caused by basement highs. However, at Harvey's sub-catchment, drilling and seismic surveys could not locate a bedrock anomaly. This paper discusses the processes responsible for the development of the saline seep on Harvey's sub-catchment and describes the results of experiments conducted to determine the nature of the saprolite aquifer responsible for the seep.

## *2.1 Aims*

The hillslope was initially drilled to determine whether or not a bedrock high was responsible for the development of the hillside seep. The aims of this investigation were:-

(i) to characterize the hydraulic properties and chemistry of the groundwater system;

(ii) conduct a preliminary groundwater and solute balance;

(iii) determine rates of recharge and discharge; and

(iv) determine whether groundwater pumping or syphoning could be used as an economically viable method of salinity control for hillside seeps.

# 3. Background

## *3.1 Location*

Harvey's sub-catchment is located at the head of the Wallatin Creek catchment (Figure 1), approximately 20 km NW of Doodlakine (31°27' N - 117°43' E). The sub-catchment has an area of 237 ha and is comprised of soils developed on the Ulva, Booraan and Cougar landforma (after Bettenay and Hingston, 1961 and McArthur, 1987) (Table 1).

**Table 1 • Land Results of Harvey's Sub-Catchment**

| Landform | Soils | | Area (ha) | % |
|---|---|---|---|---|
| Ulva | (sandplain) | yellow sandy earths | 6 | .3 |
| | (gravels) | gravels and earthy sands | 24 | 10 |
| Booraan * | (clays) | sandy clay to clay sands | 124 | 52 |
| Collgar | (duplex) | sandy A horizon over clay subsoil | 30 | 13 |
| Saline Seep | (saline) | secondary salinity | 53 | 22 |
| * Booraan erosional surface (Booraan deposit similar to Collgar on this hillslope) | | | 237 | 100 |

Secondary salinity has developed across an area of about 53 ha, although approximately 20 ha of this land is marginally productive. Within the sub-catchment a series of smaller hillslopes were identified which contribute surface and groundwaters from separate segments. In this report the western hillslope is referred to as Harvey's hillslope (Figure 12). It has an area of 50.25 ha of which 8.25 ha is salt-affected and severely eroded.

## *3.2 Geology*

The Wallatin Creek catchment is centrally located within the Kellerberrin batholith, which is comprised of Archaean senate and porphyritic adamellite (Chin, 1986). The rocks are characterized by their lack of gneissic foliation and metamorphic recrystalization in comparison with rocks outside the batholith. Rocks from near Doodlakine and Merredin have Rb-Sr isochrons of 2,734 ± 269 million years before present (Chin, 1986).

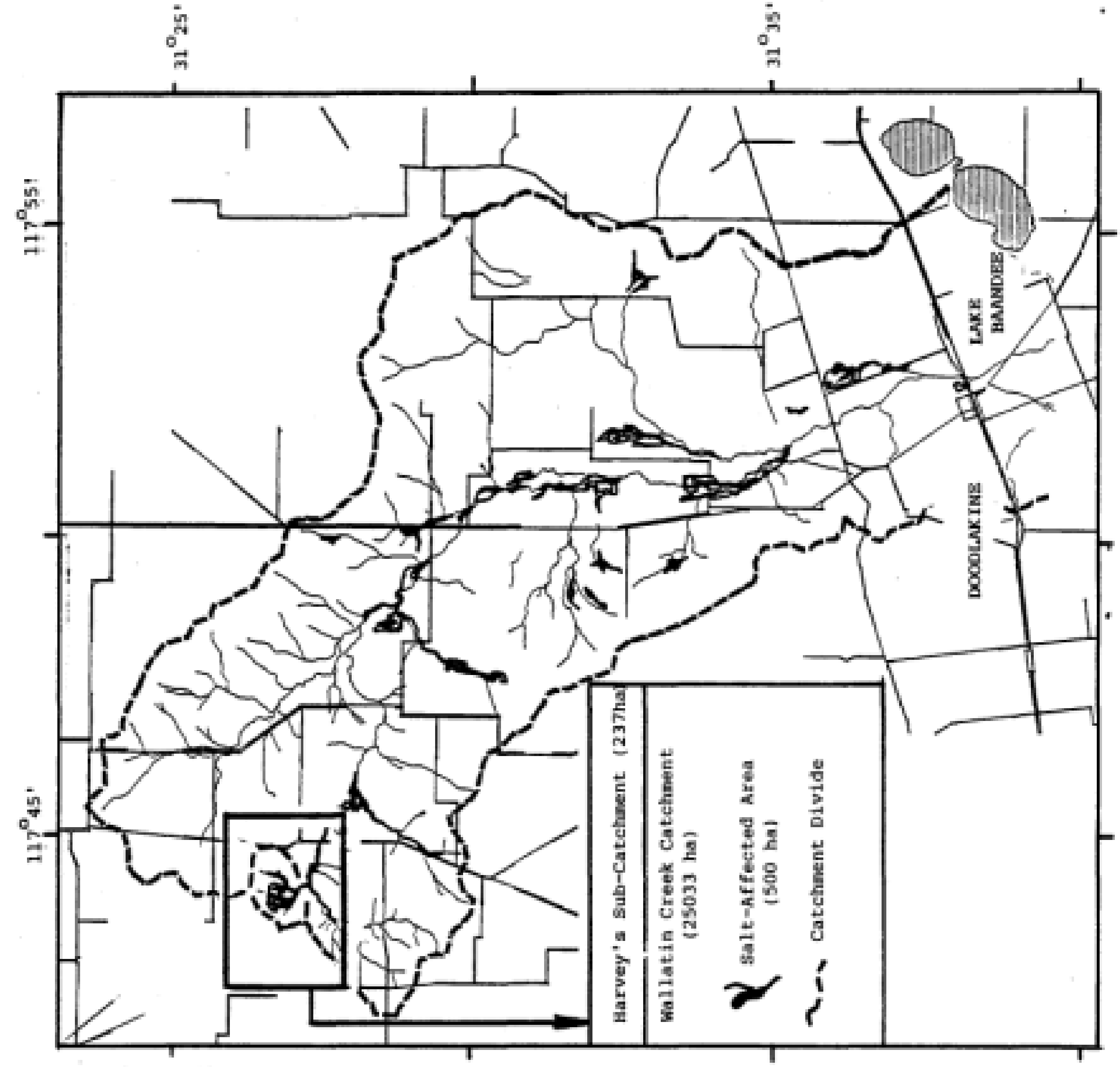



*Figure 1: Harvey's Sub-catchment – Wallatin Creek Catchment*

At Harvey's hillslope, samples obtained nearby suggest the basement is comprised of a medium textured senate adamellite. Two Proterozoic dolerite dykes with a predominant E-W direction have been observed five kilometres north and 400 m south of the catchment. Within the hillslope a large quartz vein strikes NE-SW between boreholes H3C and H2B (Figure 12). Silcrete rubble occurs throughout the salt-affected area.

# 4. Materials And Methods

## *4.1 Drilling*

Boreholes were drilled using a Gemco HM12 rotary air-blast drilling rig. Piezometers were installed at each drill site. They were constructed from 50 mm PVC casing, using a commercially slotted screen over the lower two metres. A sand filter-pack was placed alongside the slotted section. Several metres of bentonite, cement and back-filled drill cuttings were then placed above the filter-pack to the surface. The location of bore sites were chosen to allow a long and short duration pumping test to be carried out and provide groundwater information through a cross-section of the hillslope (Figure 12).

Drill hole cuttings obtained from the airstream of the drilling rig were sampled and described on site. Samples were taken at one metre intervals to determine their physical (grain-size) and chemical properties (Section 4.3). Groundwater levels were monitored in seven piezometers on the hillslope from 1986-1990.

A production well (12 m deep) was located about 17 m, or two aquifer thicknesses away from bore H2S, using 110 mm PVC casing and has a 9 m commercially slotted PVC screen. An apperture of 1 mm was chosen for the slots, following grain size analysis of the saprolite aquifer materials. The bore was slotted for the full thickness of the aquifer and developed by jetting and over-pumping for approximately 16 hours.

Class 6 - polythene pipe (AS1159 - 1979) with an internal diameter of 40 mm was chosen for the syphon to be used in the production well. An operating head of approximately 5 m was considered appropriate for a discharge of 0.37L/sec or 32 kL/day (Sections 5.3 and 6.5).

## *4.2 Geophysics*

Three geophysical techniques were used to aid the interpretation of geologic features on the hillslope. Ground traverses were conducted using electromagnetic induction terrain conductivity meters Geonics EM34 and EM31, McNeill, 1980) and a proton precession magnetometer (Geonics G856). The traverses were carried out on north-south lines spaced 75 m apart across the sub-catchment. Stations were established on a 20 m spacing on each traverse line across the 50 ha area surveyed. The area surveyed corresponds to the area over which contour lines have been drawn on Figure 12.

The ground magnetic survey was carried out with the sensor mounted on a two metre pole. A base station was established at the beginning of the survey and returned to on three occasions to check for drift of the magnetic field.

The electromagnetic induction surveys were carried out on the same traverse lines as the magnetics survey. The EM31 and EM34 have different operating frequences and depths of penetration (McNeill, 1980). Preliminary drilling and seismic survey results suggested that the E2434 should be operated with the 10 m coil spacing with the coils in a vertical orientation. In this position most of the signal should be from a zone about 15 m deep (McNeill, 1980). Measurement of the profile's terrain conductivity is recorded as a ratio of the electromagnetic fields emitted by the receiver and induced in the earth. Both machines read directly in milli Siemens per metre (mS/m) although calibration is essential.

The seismic survey of the study area was conducted along two parallel lines of 200 m length. Refraction patterns were determined from geophone intervals of 20 m (normal distribution) and 3 m (weathering distribution). The energy source was provided by 12 sticks of GN6O gelignite for the normal distribution spreads and three for the weathering spread. Data was collected on a McSEIS - 1.500, 12 Channel logger and analysed using the reciprocal method. Details of the survey and its results are given in Kevi (1987).

### *4.3 Soil Chemistry and Petrology*

Soil samples collected during the drilling of holes H2B and H2S were analysed for electrical conductivity, chloride content (%) and pH from 1:5 soil-water extracts. Electrical conductivity of the soil solution and saturation percentage were obtained from soil-water extracts of laboratory cores (B. Wren, personal communication, 1988). Soil samples were also obtained across the hillslope to determine the levels of soil salinity within and adjacent to the salt-affected area. Details from the drill-logs are summarized graphically in Figure 4.

Samples of siliceous rocks (silcretes) obtained from the discharge area were cut into thin sections and optically examined and analysed with a Scanning Electron Microscope. Analyses were conducted by the author under the supervision of Dr C. Butt at the CSIRO, Floreat Laboratories.

### *4.4 Groundwater Chemistry*

Groundwater samples were collected from all of the piezometers and annually examined for electrical conductivity and pH. Samples were also analysed for the major cations and anions as well as nitrate, strontium, bromide and silica. The analyses were conducted by the Chemistry Centre of Western Australia and CSIRO.

### *4.5 Pumping Tests*

Pumping tests were carried out to determine the hydraulic properties of the aquifer and overlying aquitard. Tests were conducted on the production bore H2P and observations made on shallow and deep bores (H2SC, B) located 17 m E and on deep bores, H2A (200 m NW) and H2B (160 m E).

An initial four-step, multi-rate test was conducted to determine the optimum pumping rate for the production well. Thirty minute steps (S30) of discharge rates (Q) of 80, 120, 160 and 180 kL/day were carried out. A plot of Q and S30 was used to set the test rate (Figures 2 and 3).

The initial rate chosen (120 kL/day) from the Q v S30 method for the constant discharge rate tests proved to be inaccurate, as the maximum available drawdown (9.5 m) was reached after only 300 minutes of pumping. A second test at Q ~ 80 kL/day was then carried out for 1,440 minutes. A third constant-rate test was run later for 22.1 days at 32 kL/day. Only the results of the Q - 80 and 32 kL/day tests are discussed.

Analysis of the pumping test data was conducted using the methods outlined in Kruseman and de Ridder (1983). Two methods were chosen to describe the short and long duration tests. Observation bores responses suggested the 1,440 minute test showed a confined response and was best analysed using Theis and Jacob's methods, while the 22.1 day test was analysed using both Jacob's and Boulton's methods. Boulton's method was used to compare the analytical techniques for confined and unconfined aquifer responses and is discussed later.

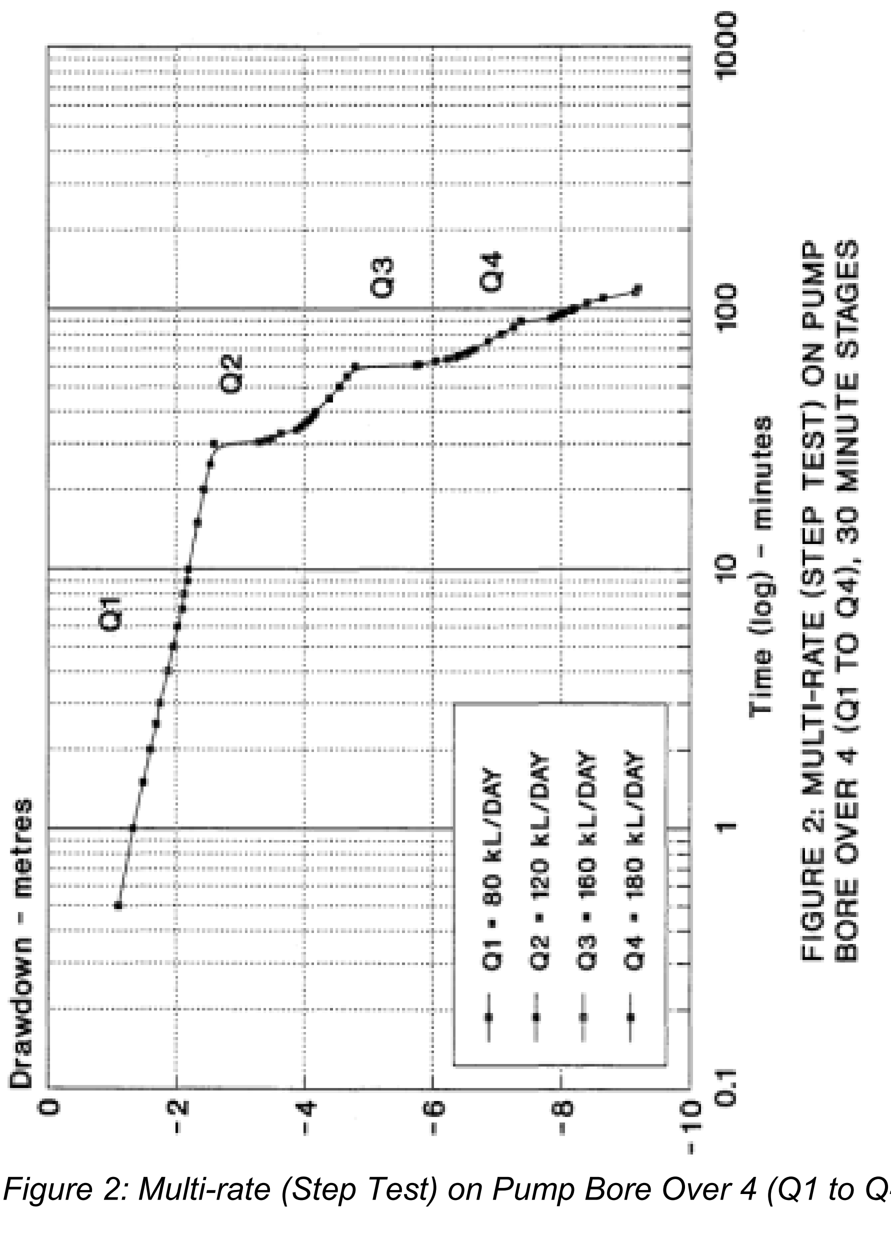



*Figure 2: Multi-rate (Step Test) on Pump Bore Over 4 (Q1 to Q4), 30 Minute Stages*

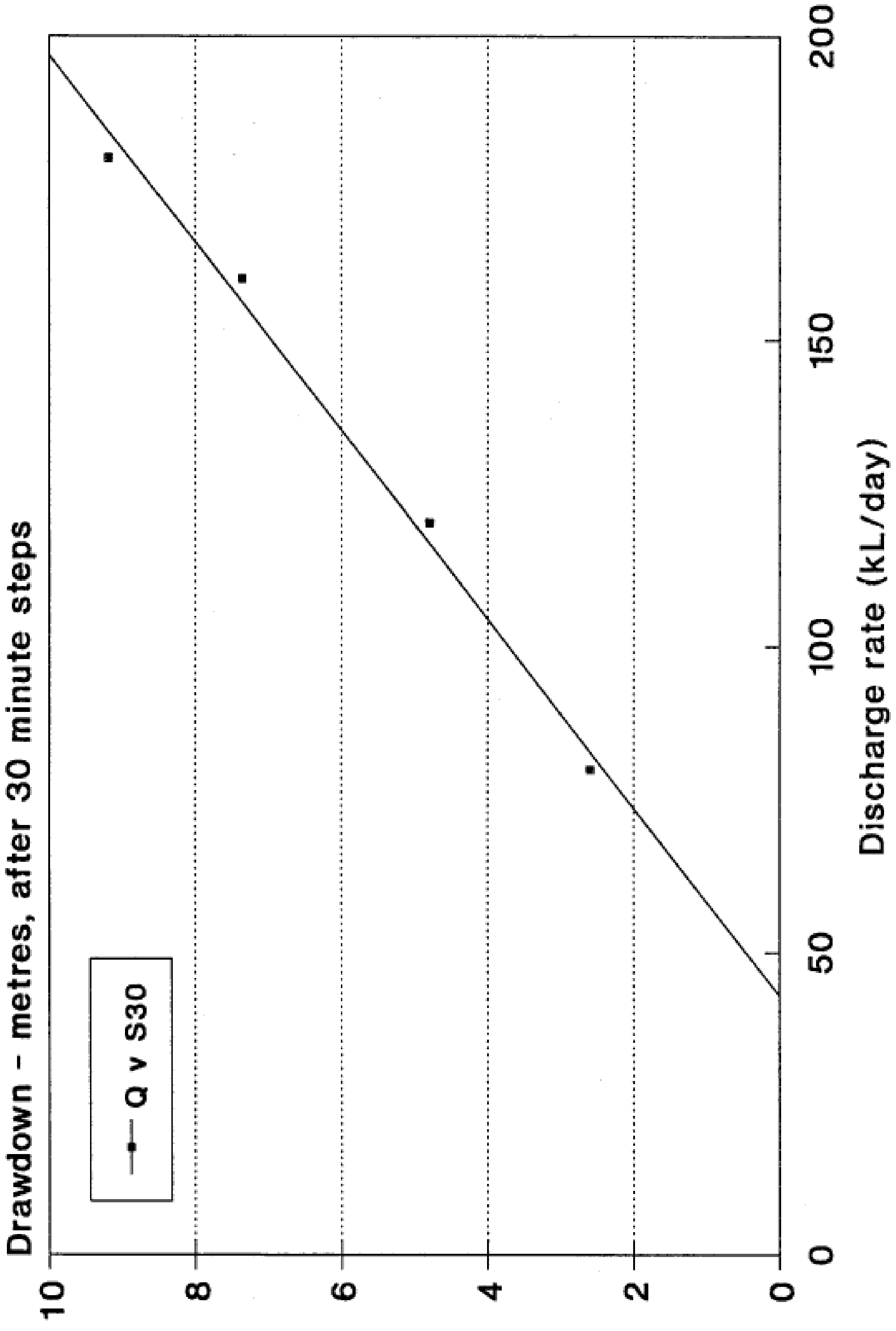



FIGURE 3: PLOT OF DISCHARGE (Q) VERSES DRAWDOWN (S) AFTER EACH 30 MINUTE STEP.

*FIGURE 3*

Flow rates were held constant throughout the 1,400 minute test using a manometer and regular (10 to 100 minute ) discharge tests. A submersible pump was used for the short test (1,440 mins) while a 3HP diesel centrifugal pump was used for the long-term test. Discharge rates were checked hourly during the initial stages and then daily following establishment of steady drawdown conditions in the longer pump test. Flow measurements from the syphon were taken daily. Tests were conducted during a period when local groundwater levels were not changing significantly as a result of “external” effects (eg. recharge).

## *4.6 Evaluation*

The results of the pumping tests and farm economics data (courtesy of M. & P. Harvey) were used an input information to run PUMPS (George, 1990b). The model determines the cost-benefits of groundwater pumping used to control salinity. The area predicted to be reclaimed by the pumping programme was generated from values of aquifer yield, transmissivity and storage coefficient derived from the pump tests. Data was analysed using a model (GWPLOW) developed by Van der Heijde (1985).

## *4.7 Slug Tests*

Estimates of the saturated hydraulic conductivity of bores drilled in the hillslope were obtained by inserting a sealed 2 m aluminium tube below the water-table, allowing it to equilibrate, then rapidly withdrawing the tube and measuring the recovery. The methods outlined by Bouwer and Rice (1976) and later updated by (Bouwer, 1989) were used to analyse the recovery data.

# 5. Results And Comments

## *5.1 Lithology*

Groundwater on the hillslope is contained within weathered Archaean basement rocks which comprises a coarse textured or saprolite (aquifer) and an overlying deeply-weathered, “pallid zone” (aquitard). Some groundwaters occur within the colluvial soils near the discharge area (Figure 4). Details from samples obtained at each of the bores describing the lithology are presented in Appendix 1.

The saprolite grit aquifer is present in all of the drill holes on the catchment. However, its thickness varies markedly from site to site. In the vicinity of the production well the saprolite grit zone is approximately 9 m thick (H2P) while at H2S (17 m E) it is only 5 m thick. At H2B and H2A, 200 m and 160 m away respectively the grits thin to approximately 2 to 3 m. At H3C, 300 m downslope only 1 m of poorly developed grits occur above bedrock and are overlain by deeply-weathered, pallid sandy clays.

The saprolite aquifer is characterized by limited weathering of feldspar and biotite. Primary grain cements have been broken leaving a coarse sand. The chemical and physical properties of weathered zone aquifers have been reviewed by George (1990c). The saprolite grades upwards gradually over 1 to 2 m into the pallid and mottled zones. The pallid zone is comprised of kaolin and quartz, although nearer the surface the profile is often enriched with iron and siliceous cements. The cements comprise quartz-anatase-zircon materials (QAZ silcretes). At H2S the pallid zone is approximately 3 m thick, while in parts of the discharge area (for example, 100 m downhill) the zone is thin and exposures of the saprolite aquifer occur in erosion gullies. Before the drilling and seismic surveys were carried out, these materials were thought to be exposed bedrock. However, both survey techniques showed this not to be the case.

The texture of the colluvial zone above the saprolite and pallid zone material is a clayey sand to sandy clay. In the vicinity of H2S the soils can be referred to as the Booraan depositional soil association (after Bettany and Hingston, 1961), while upslope soils of the lateritic Ulva soil association (yellow gravels to sands) are dominant (Table 1).

The depth to bedrock is highly variable ranging from less than 1 m adjacent to the quartz vein to about 15 m at H1C. The cross-section shown in Figure 4 (located on Figure 12) shows a more uniform depth in the direction of groundwater flow. The distribution of the saprolite, pallid and colluvial zones are also shown.

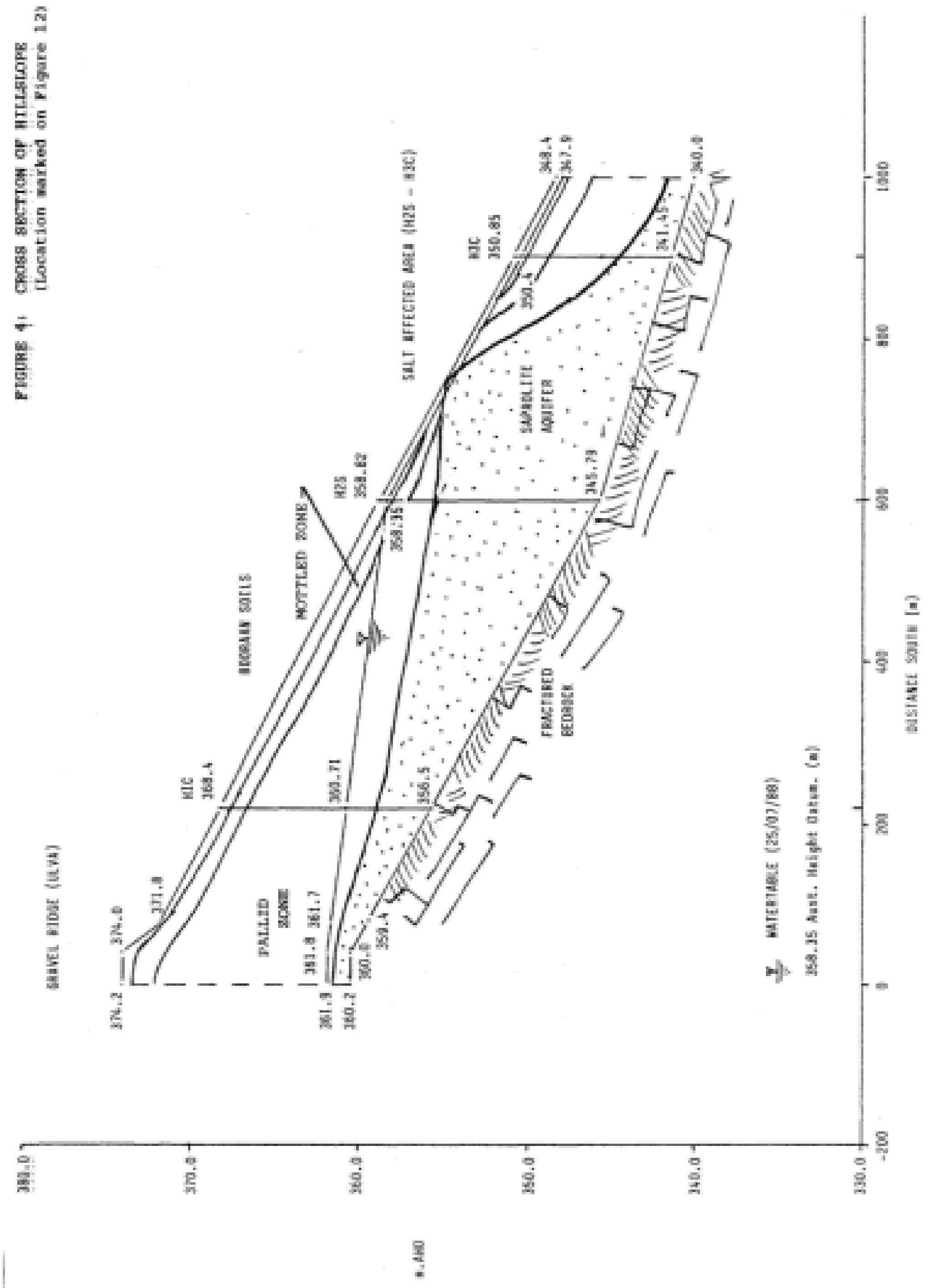


FIGURE 4: CROSS SECTION OF HILLSLOPE
(Location marked on Figure 12)
SALT AFFECTED AREA
SAPROLITE AQUIFER
FRACTURED BEDROCK
MOTTLED ZONE
PALLID ZONE
WATERTABLE (25/07/88)
DISTANCE SOUTH (m)
m AHD

*FIGURE 4*

## *5.2 Slug Tests*

The results of the slug tests and bore construction details are given in Table 2. The results show that the hydraulic conductivity of the saprolite grits ranges from 0.15 to 0.52 m/day (mean 0.33 m/day). The pallid zone has a much lower hydraulic conductivity (0.03 and 0.006 m/day).

**Table 2 • Slug Test Results and Bore Construction Details**

| Bore No. | Hydraulic Conductivity (m/Day) | (Zone) | Bore Depth (M) | Screened Depth (M) | SWL* (M) |
|---|---|---|---|---|---|
| H1C | 0.29 | Saprolite | 11.90** | 9.9 - 11.9 | 7.69 |
| H2A | 0.15 | Saprolite | 12.50 | 10.5 - 12.5 | 3.27 |
| H2B | 0.33 | Saprolite | 3.00 | 1.0 - 3.0 | 0.78 |
| H2S | 0.52 | Saprolite | 13.60 | 11.6 - 13.6 | 0.94 |
| H2SB | 0.006 | Pallid | 210 | 1.1 - 2.1 | 0.94 |
| H2 Pump | 0.38 | Saprolite | 11.90 | 11.9 - 2.9 | 0.95 |
| H3C | 0.03 | Pallid | 9.40 | 7.4 - 9.4 | 0.50 |

* SWL = static water-level.

** Total depth drilled 13.7 (1.9 m lost in saprolite grits zone).

## *5.3 Pumping Tests*

### 5.3.1 One Day Test

The time-drawdown, semi-logarithmic plots of the observation and pumping bores are shown in Figure 5. Early time data suggests a straight-line approximation (Jacob's method) is valid over the period between 5-50 minutes for the pump bore. After this time the line was interrupted by a pumping rate change. Refitting the data to account for the change, increased the period over which the straight line approximation is valid until 140 minutes. Between 120 to 140 minutes and the end of the test, poorly defined boundaries are indicated by the breaks of slope (slight) which in turn result in a rapidly increasing drawdown over time.

The log-log plot of the time-drawdown data for piezometer H2S (Figure 6), located 17 m east, falls accurately on the Theis curve (not shown), suggesting that the system behaves as a confined aquifer. When the effect of observed boundaries are accounted for, and only the early-time (< 50 mine) data is used, the plot suggests that some (minimal) delayed-yield may have occurred after about 300 minutes of pumping. However, observations in the shallow bore at site H2S show a response to pumping after 800 minutes. This suggests that if delayed-yield was occurring, it had occurred for 500 minutes before the effects began showing in H2SB. The minor deviation from the Theis curve of the data (indicating minimal delayed-yield) reflects the thin nature and low conductivity of the aquitard.

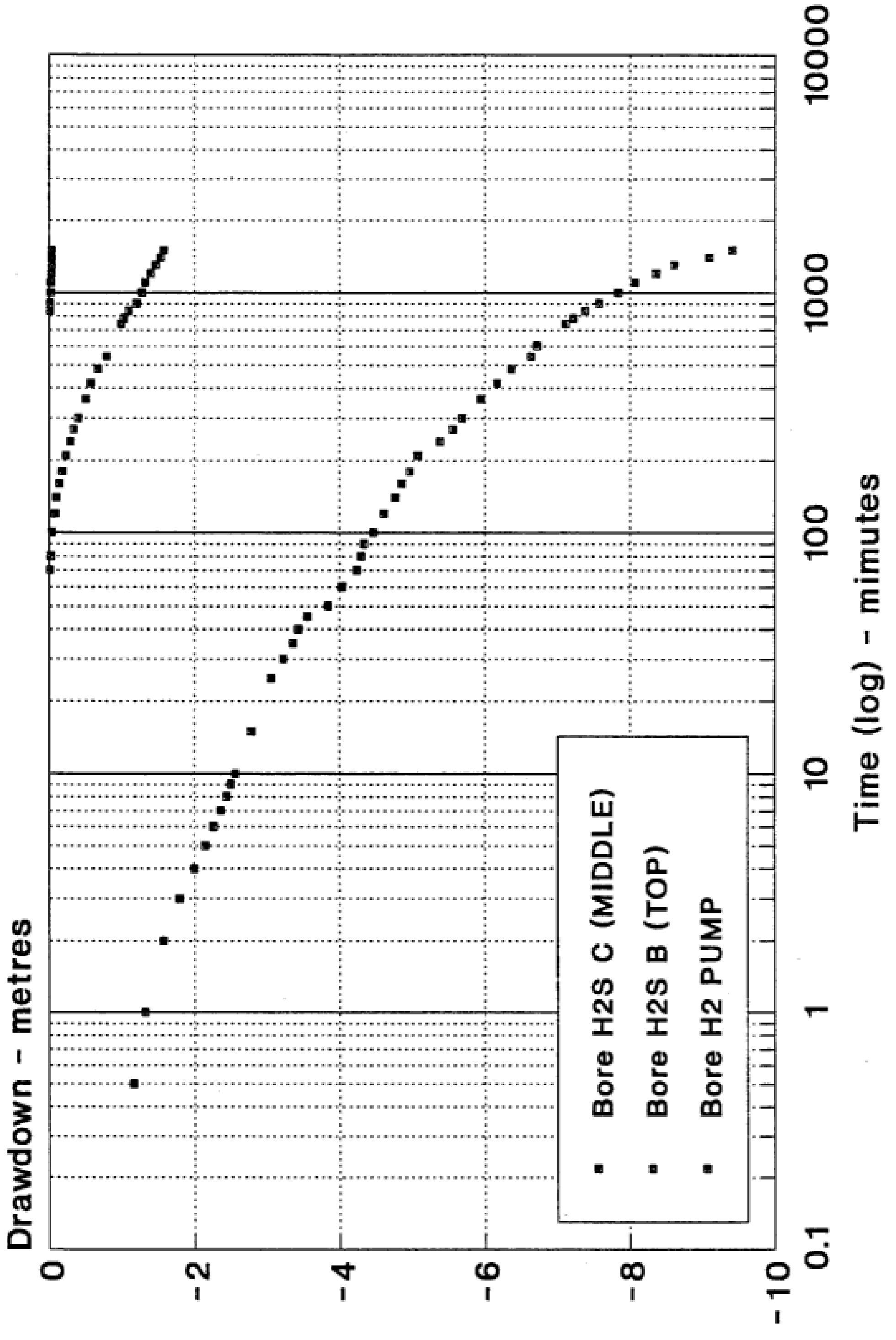



FIGURE 5: TIME-DRAWDOWN PLOT OF THE PUMP BORE AND NEARBY PIEZOMETERS (1 DAY TEST)

*FIGURE 5*

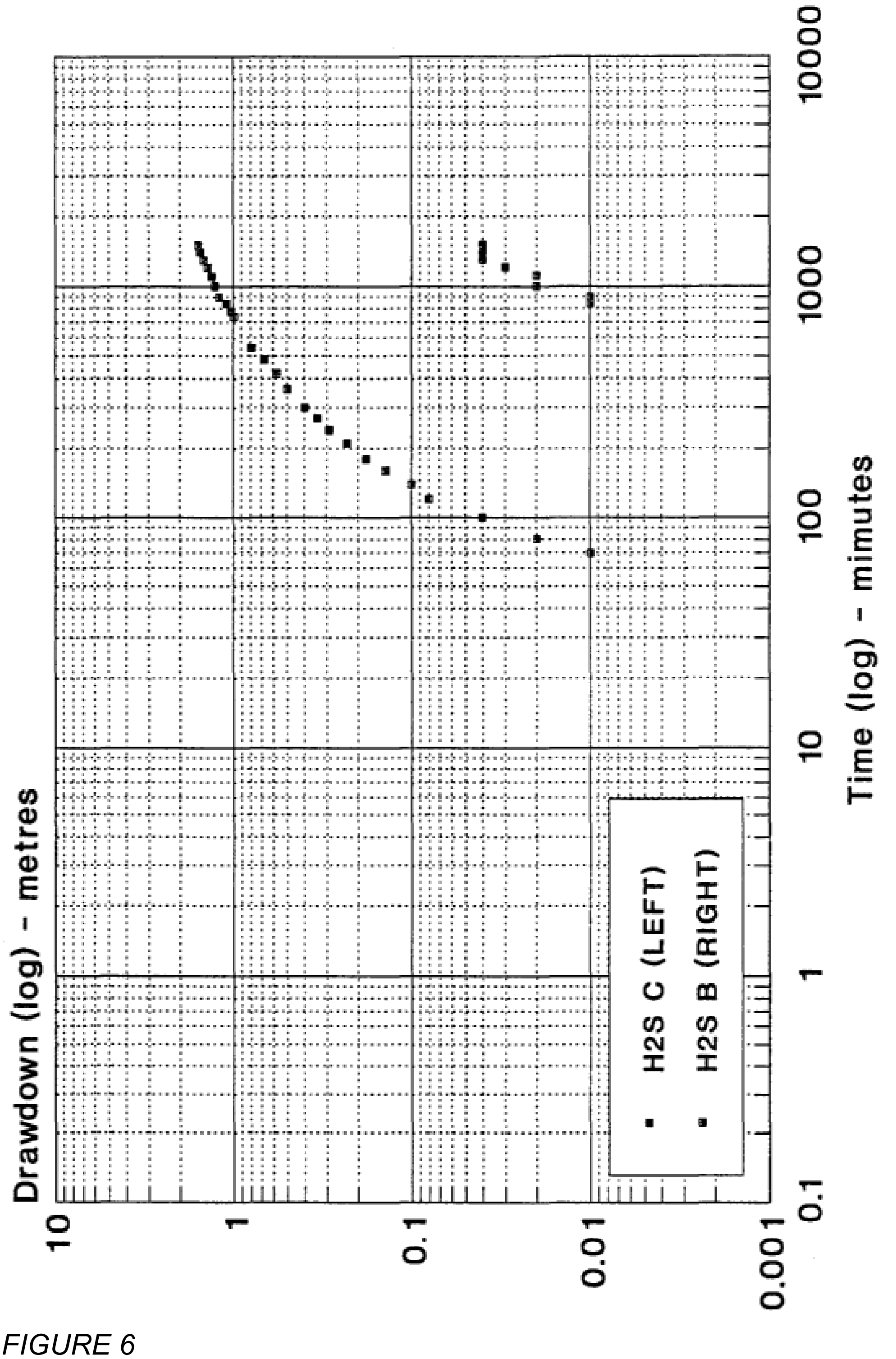



FIGURE 6: TIME-DRAWDOWN PLOT OF NEARBY PIEZOMETERS (Q=80 kL/DAY, 1 DAY TEST)

*FIGURE 6*

**Table 3 • Hydraulic Properties from the 1,440 Minute Pump Test***

| | Boulton | Theis |
|---|---|---|
| Transmissivity ($m^2$/day) | 5.4 $m^2$/day | 6.4 $rn^2$/day |
| Storage Coefficient | 0.01 | 0.012 |

* Observations of H2SC and B only.

The preliminary results obtained from the 1,440 minute pumping test for the hydraulic properties of the site are given in Table 3. They are presented for both the unconfined, unsteady state analysis (Boulton's method) and confined, unsteady state analysis, the Theis method (Kruseman and de Ridder, 1983).

### 5.3.2 Twenty-Two Day Test

Results of observations on bores during the 22 day (31,680 mine) test are shown in Figure 7. The semi-logarithmic plot of pump-bore and nearest observation bore shows the maintenance of an initial straight line until approximately 120 to 140 minutes, when a pump rate fluctuation or boundary affect appears.

Pump rate fluctuations were controlled after two days. Evidence of the rapidly increasing drawdown at about 3,600 minutes therefore suggests a major barrier was encountered. Drawdown in H2SB began slowly (after 600 minutes) then rapidly approached a straight line after 2,000 minutes. Drawdown in H2SC shows an initial rapid drawdown at 1,500-4,000 minutes, then a slow increase to 20,000 minutes, with an increasing drawdown toward the end of the test.

The log-log plot (Figure 8) shows the effect of rate changes on the observation bores next to the pumping well (H2SB, C). However, at H2SB the log-log response appears to show a more significant delayed yield affect than that which occurred in the short test. Results of analyses of the aquifer using the observation bores of H2SC and H2B are presented in Table 4.

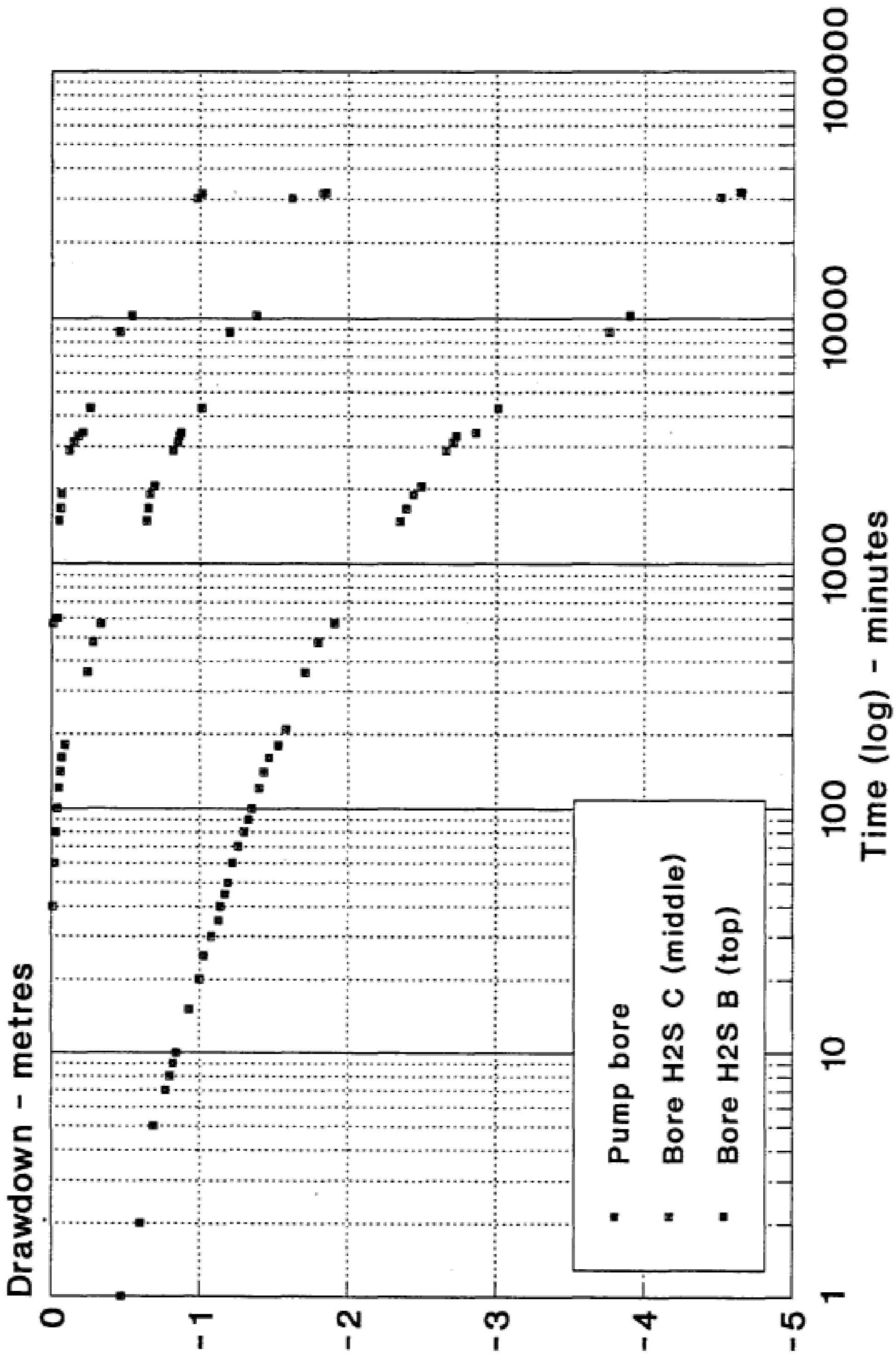



FIGURE 7: TIME-DRAWDOWN PLOT - PUMP BORE AND PIEZOMETERS (Q=32 kL/DAY, 22 DAYS)

*FIGURE 7*

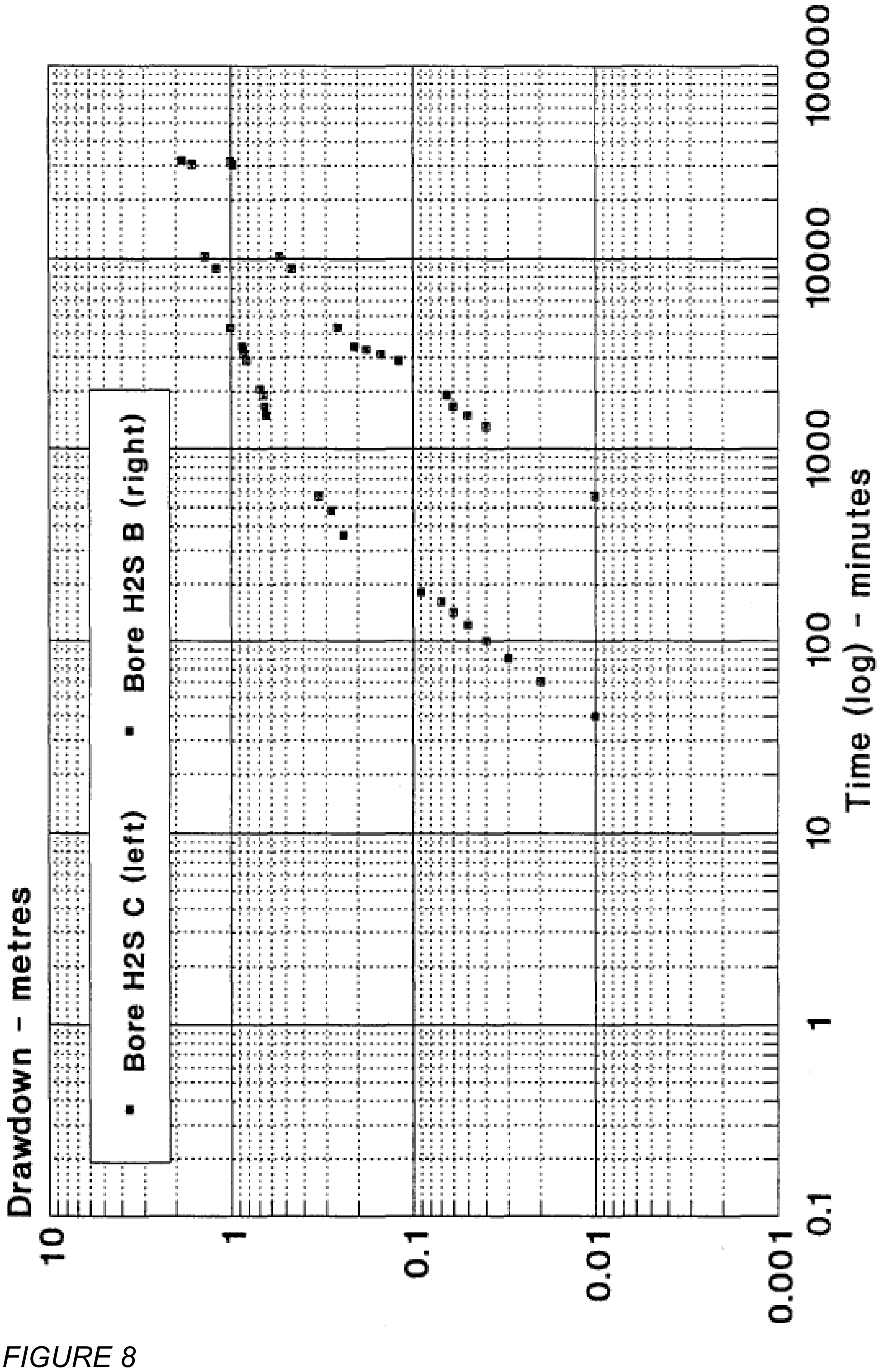



FIGURE 8: LOG-LOG PLOT OF TIME-DRAWDOWN AT H2S (Q=32 kL/DAY, 22 DAY TEST)

*FIGURE 8*

**Table 4 • 22 Day Pump-Test Results**

| | H2SC | H2B |
|---|---|---|
| Transmissivity ($m^2$/day) | 3.86 - 6.54 | 1.7 |
| Storage Coefficient | 0.046 - | 0.001 |

Combining data from the short duration pumping test and long test, it can be estimated that the transmissivity of the aquifer near the production well is of the order 4-6 $m^2$/day, while the storage coefficient is approximately 0.01. Further away the transmissivity decreases to be approximately 2 $m^2$/day in response to barrier effects encountered by the cone of influence of the long-term test. The estimated hydraulic conductivities from the production well area, derived from the transmissivity estimates are therefore 0.38-0.65 m/day. However, a regional or hillslope value based on the 22 day test of only 0.20 m/day may be more appropriate. The results compare favourably with the slug test data presented in Table 2.

## *5.4 Geophysics*

Figures 9, 10 and 11 show the results of the magnetic, EM31 and EM34(3) surveys. The magnetic surveys show a large amount of variation in the magnetic intensity recorded which is not consistent with initial traverses conducted prior to conducting the grid survey. It is likely that an instrument error or geomagnetic storms were responsible, although none were predicted. Preliminary surveys did not locate any magnetic anomalies north of H3C, however, a minor anomaly was located 400 m south of this bore. The EM31 and EM34(3) contour maps show the variability in the distribution of stored salt, especially low in the landscape. Terrain conductivities increase rapidly from the lateritic breakaway to the Booraan association soils below. High terrain conductivities occur in the salt-affected areas above the quartz vein, indicating that discharge is occurring as a result of the flow restriction created by the vein.

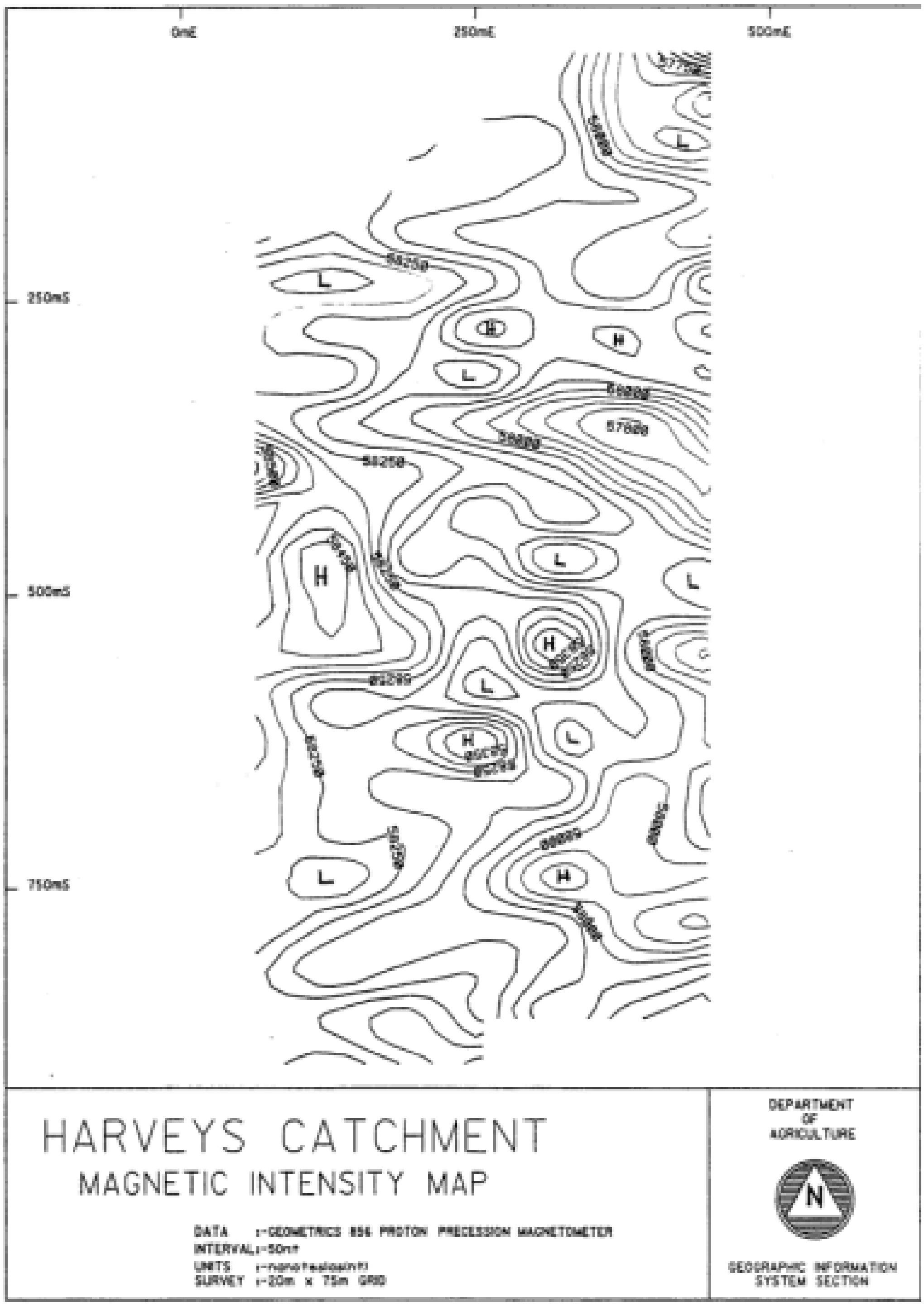

0mE
250mE
500mE
250mS
500mS
750mS
HARVEYS CATCHMENT
MAGNETIC INTENSITY MAP
DATA :-GEOMETRICS 856 PROTON PRECESSION MAGNETOMETER
INTERVAL:-50nT
SURVEY :-20m x 75m GRID
DEPARTMENT OF AGRICULTURE
N
GEOGRAPHIC INFORMATION SYSTEM SECTION

*FIGURE 9*

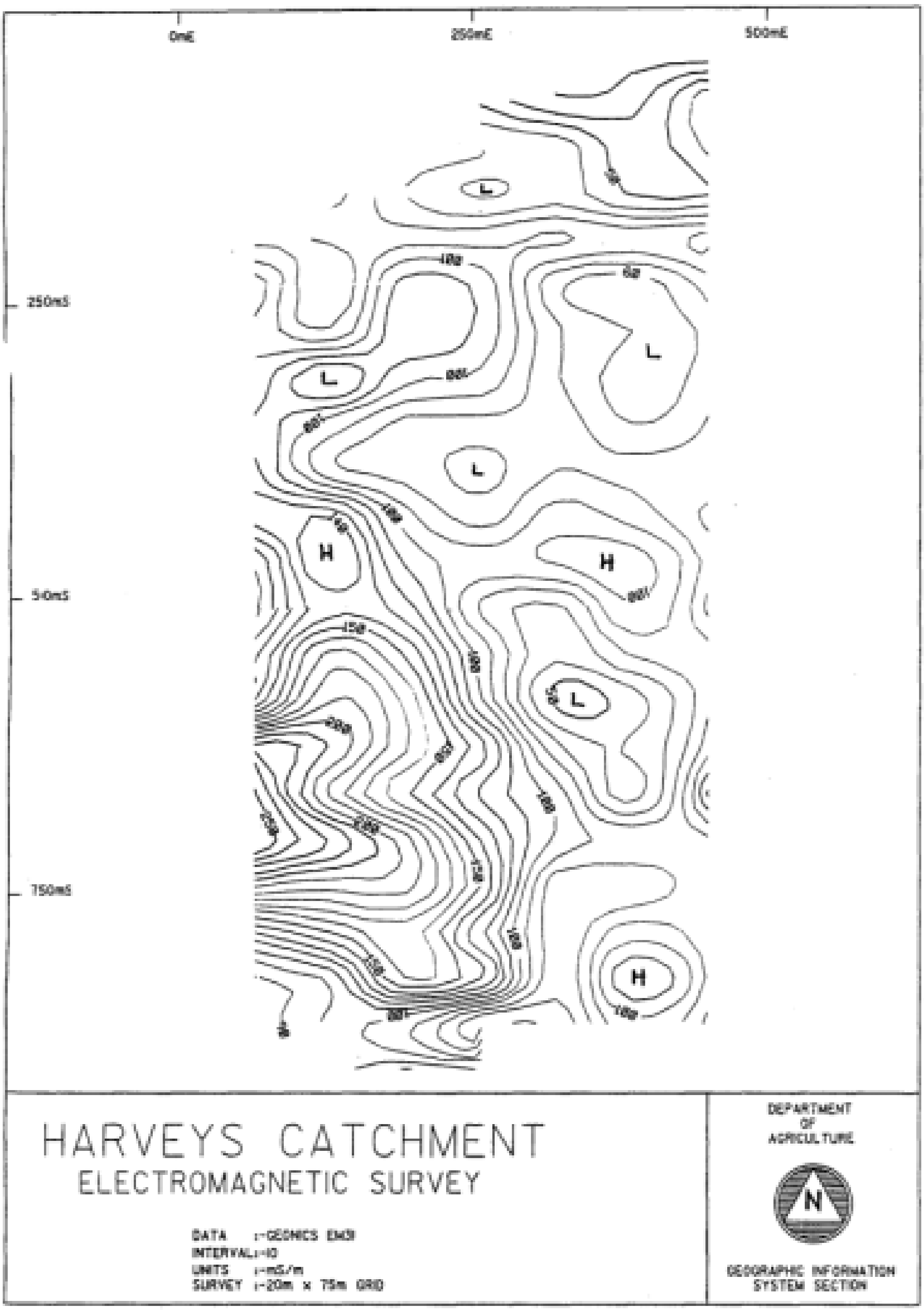
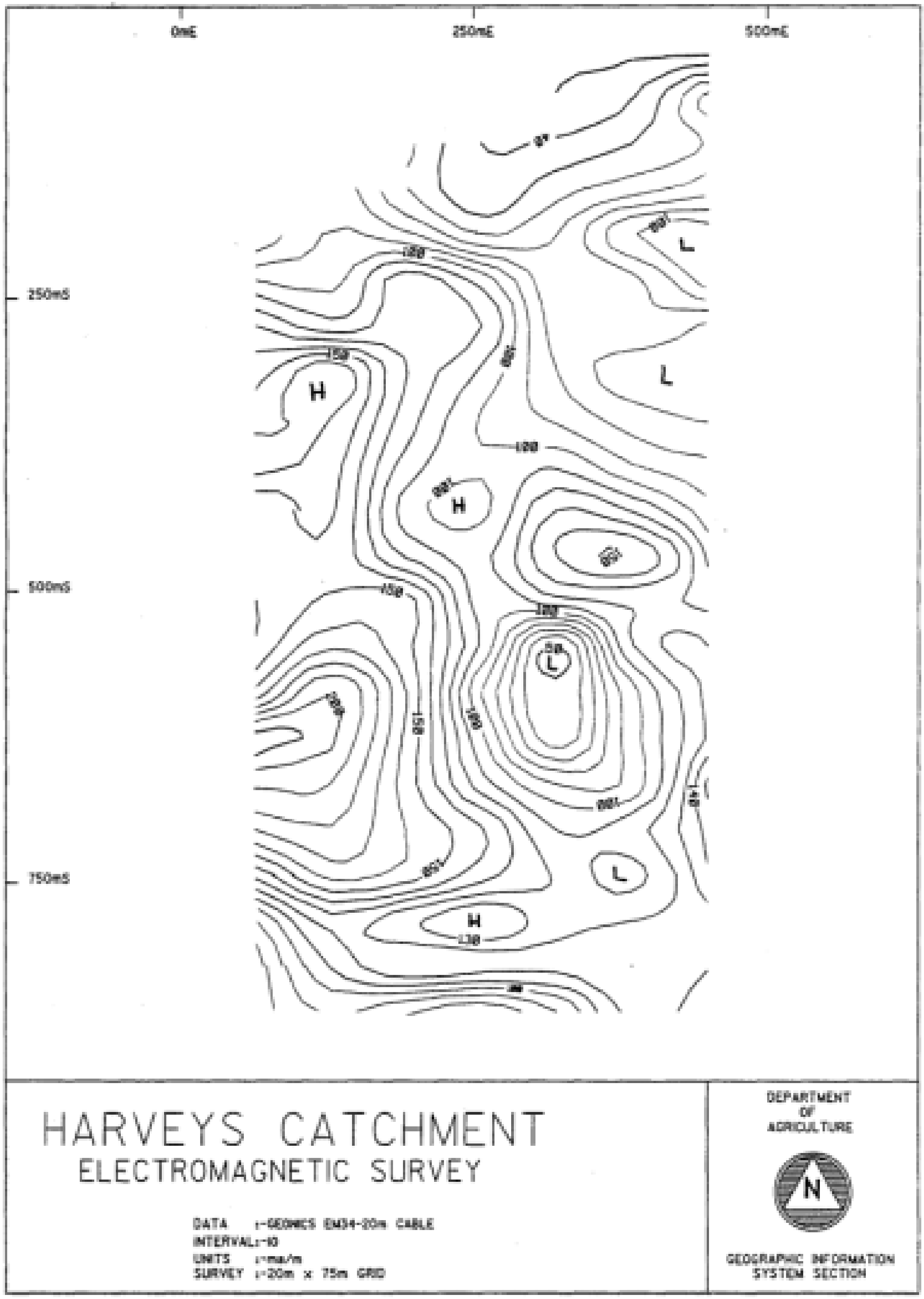

0mE
250mE
500mE
250mS
500mS
750mS
HARVEYS CATCHMENT
ELECTROMAGNETIC SURVEY
DATA :-GEONICS EM31
INTERVAL:-10
UNITS :-mS/m
SURVEY :-20m x 75m GRID
DEPARTMENT OF AGRICULTURE
N
GEOGRAPHIC INFORMATION SYSTEM SECTION

*FIGURE 10*


0mE
250mE
500mE
250mS
500mS
750mS
H
L
HARVEYS CATCHMENT
ELECTROMAGNETIC SURVEY
DATA :-GEONICS EM34-20m CABLE
INTERVAL:-10
UNITS :-ms/m
SURVEY :-20m x 75m GRID
DEPARTMENT
OF
AGRICULTURE
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GEOGRAPHIC INFORMATION
SYSTEM SECTION

*FIGURE 11*

The relationships between actual salt storage (EC 1:5) and measured terrain conductivities (ECa) are described by Equation 1 and should be referred to when evaluating these diagrammes:-

$$EC\ 1{:}5 = 0.88\ ECa - 11.39\ (r^2 = 0.76) \qquad (1).$$

Analysis of 62 bores in the eastern wheatbelt (R. George, unpublished data) suggests that the observed terrain conductivity explains 76% of the variability of soil samples obtained from the upper 6 m of the profile.

## *5.5 Soil Chemistry*

Two boreholes were sampled to determine the variability of stored salt in the recharge area (H1C) and discharge area (H2S). The results are given in Table 5. The distribution of the physical properties (% clay, % sand, etc.) of the weathered materials is reflected by the saturation index column also shown in Table 5. High saturation percentages indicate sandy clay materials of the pallid zone (30-40%), while lower values (< 30%) represent the saprolite grits zone. Salinities in the saprolite grits are lower than that in the pallid zone, and similar (H2S) or higher (H1C) to those in the near-surface materials.

At H1C the total estimated chloride storage is 510 tonnes/ha, while at H2S it increases to 910 tonnes/ha. The majority of salt is stored below the water-table (H1C), although it is shown to decrease slightly with depth into the saprolite (aquifer). The saprolite grits can be recognized from the distribution of the saturation index. At H1C the grits begin at 9.5 m. At H2S they commence between 8 and 9 m. The saprolite grits occur from 3 m below ground to bedrock in the production well, only 17 m west of H2S.

## *5.6 Groundwater Chemistry*

Groundwater samples were taken in December 1988 and analysed (Table 6). The waters are extremely saline ranging from 1,000 mS/m at H2SB to 4,600 mS/m at H1C. Waters have high levels of chloride and sodium reflecting their cyclic origin (Hingston and Gailitis, 1976). High levels of bicarbonate were found in bores H2SB and H3C while most bores had high to moderate concentrations of silica. Waters in the pump bore had a mean salinity of 4,490 mS/m and a silica content, near saturation levels for amorphous silica (Mimes and Twidale, 1983), of 101 mg/L. Waters are very acidic, except for those at H2SB. The high pH and low salinity are uncharacteristic of the other sites. Local recharge from a contour bank next to the bore (1 m) is suggested as the cause. The high bicarbonate levels also imply a local source of recharge.

## Table 5 • Distribution of Chemical Properties

| Bore No. | Depth (m) | PH - | EC mS/m | Chloride % | Saturation Index % | ECe mS/m | Zone |
|---|---|---|---|---|---|---|---|
| WC30H1C | 1 | 4.6 | 40 | 0.05 | 35 | 491 | HZ |
| (SWL = 7.69) | 2 | 5.2 | 11 | 0.01 | 30 | 138 | PZ |
| | 3 | 4.6 | 34 | 0.05 | 34 | 425 | PZ |
| | 4 | 4.6 | 42 | 0.05 | 36 | 471 | PZ |
| | 5 | 4.6 | 54 | 0.06 | 34 | 550 | PZ |
| | 6 | 45 | 68 | 0.09 | 32 | 764 | PZ |
| | 7 | 4.4 | 236 | 0.34 | 28 | 2,450 | PZ |
| | 8 | 4.2 | 305 | 0.47 | 34 | 3,770 | PZ |
| | 9 | 4.2 | 351 | 0.56 | 36 | 3,940 | PZ |
| | 10 | 4.5 | 214 | 0.26 | 25 | 2,710 | SG |
| | 11 | 4.6 | 194 | 0.30 | 24 | 2,550 | SG |
| | 12 | 4.6 | 212 | 0.28 | 24 | 2,750 | SG |
| | 13.7 | 4.6 | 174 | 0.25 | 26 | 2,220 | SG |
| WC33 H2S | 1 | 8.9 | 217 | 0.29 | 38 | 2,170 | HZ |
| (SWL = 0.95) | 2 | 5.2 | 193 | 0.27 | 31 | 2,440 | HZ |
| | 3 | 4.5 | 218 | 0.31 | 30 | 2,290 | SG |
| | 4 | 4.2 | 291 | 0.43 | 30 | 3,350 | SG |
| | 5 | 4.2 | 333 | 0.49 | 31 | 3,900 | SG |
| | 6 | 4.3 | 319 | 0.49 | `31 | 3,900 | Sc |
| | 7 | 4.5 | 218 | 0.31 | 34 | 2,400 | Sc |
| | 8 | 4.2 | 378 | 0.57 | 28 | 4,780 | SG |
| | 9 | 4.1 | 504 | 0.79 | 30 | 5,340 | SG |
| | 10 | 4.0 | 410 | 0.64 | 30 | 4,450 | SG |
| | 11 | 4.6 | 195 | 0.29 | 25 | 2,500 | SG |
| | 12 | 4.9 | 195 | 0.29 | 23 | 2,540 | Sc |
| | 13 | 5.2 | 217 | 0.31 | 23 | 2,990 | SG |
| | 13.6 | 5.2 | 241 | 0.35 | 26 | 2,650 | Sc |

* SWL = Static water-level in piezometer at the site.

MZ = Mottled Zone

PZ - Pallid Zone

SG = Saprolite Grits

**Table 6 • Chemistry of Catchment Waters**

| Bore No. | PH | EC[1] | Na | K | Ca | Mg | Sr | Fe | $HCO_3$ | Br | Cl | SO | NO | $Si0_2$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| WC31 H1C* | 3.1 | 4,620 | 11,210 | 282 | 52 | 1,035 | 2.3 | 10.3 | 0 | 49 | 18,589 | 3,279 | 0 | 36.8 |
| WC3O H2A* | 3.8 | 2,160 | 4,681 | 179 | 15 | 288 | 0.8 | 3.7 | 0 | 21 | 7,783 | 1,212 | 0 | 37 |
| WC33 H2S | 7.8 | 1,010 | 1,989 | 19 | 44 | 258 | 5.4 | 0.1 | 139 | 16 | 3,371 | 375 | 0 | 9 |
| | 3.3 | 4,170 | 9,617 | 216 | 78 | 989 | 3.3 | 0.7 | 0 | 49 | 16,570 | 2,380 | 0 | 36 |
| WC32 H2B* | 3.7 | 1,190 | 2,448 | 59 | 23 | 243 | 1.4 | 10.2 | 0 | 14 | 4,277 | 516 | 0 | 12 |
| WC34 H2P** | 3.1 | 4,490 | 9,870 | 185 | 72 | 1,010 | - | - | 0 | 48 | 17,400 | 2,300 | 0 | 10l*** |
| WC35 H3C* | 6.7 | 2,990 | 5,967 | 213 | 31 | 849 | 7.3 | 0.1 | 25 | 35 | 11,521 | 1,372 | 0 | 34 |

* Analysis by Chemical Centre of Western Australia (pH samples analysed two weeks after sampling -ferrolysis may have occurred).

** CSIRO data.

*** $Si0_2$ analysis.

1. EC = mS/m All other data are mg/L.

# 6. Discussion

## *6.1 Groundwater Balance*

A flow-net for the hillslope was constructed from the information obtained from piezometers located across the hillslope. A preliminary groundwater balance was then carried out on the basis of calculations made across each flow cell. The flow cells containing the hillslope were considered to be bounded to the west by a flow-line and to the east by a large quartz vein. The vein was thought to act as an hydraulic boundary as saline groundwater discharge had not developed on the lower side. The top of the groundwater catchment is assumed to coincide with the topographic divide (Figure 12).

Above the 358 m equipotential (Figure 12) non-saline soils with groundwaters from 1 to 8 m below the surface were defined as the recharge area to the seep. The salt-affected area is considered to reflect the discharge area, although some flow within the aquifer also occurs down-gradient from this area. The four cells have depths of saprolite defined from the drilling and hydraulic properties related to the pump-tests. Transmissivities were calculated according to the change in aquifer thickness and the results of the pumping and slug tests. Gradients were obtained from topographic surveys. The results were presented in Table 7.

**Table 7 • Calculations of Flow in each Cell***

| Cell # | Transmissivity (m2/day) | Width Of Cell (m | Gradient - | Time (days) | Discharge (kL/year) |
|---|---|---|---|---|---|
| 1 | 4.50 | 90 | 0.0068 | 365 | 1,000 |
| 2 | 3.80 | 105 | 0.0072 | 365 | 1,050 |
| 3 | 2.60 | 115 | 0.0077 | 365 | 840 |
| 4 | 1.50 | 95 | 0.0081 | 365 | 410 |
| | | | | **TOTAL** | 3,300 |

* Calculations are based on Darcy's Law (Q = Twi) using Dupuit-Forchheimer assumptions.

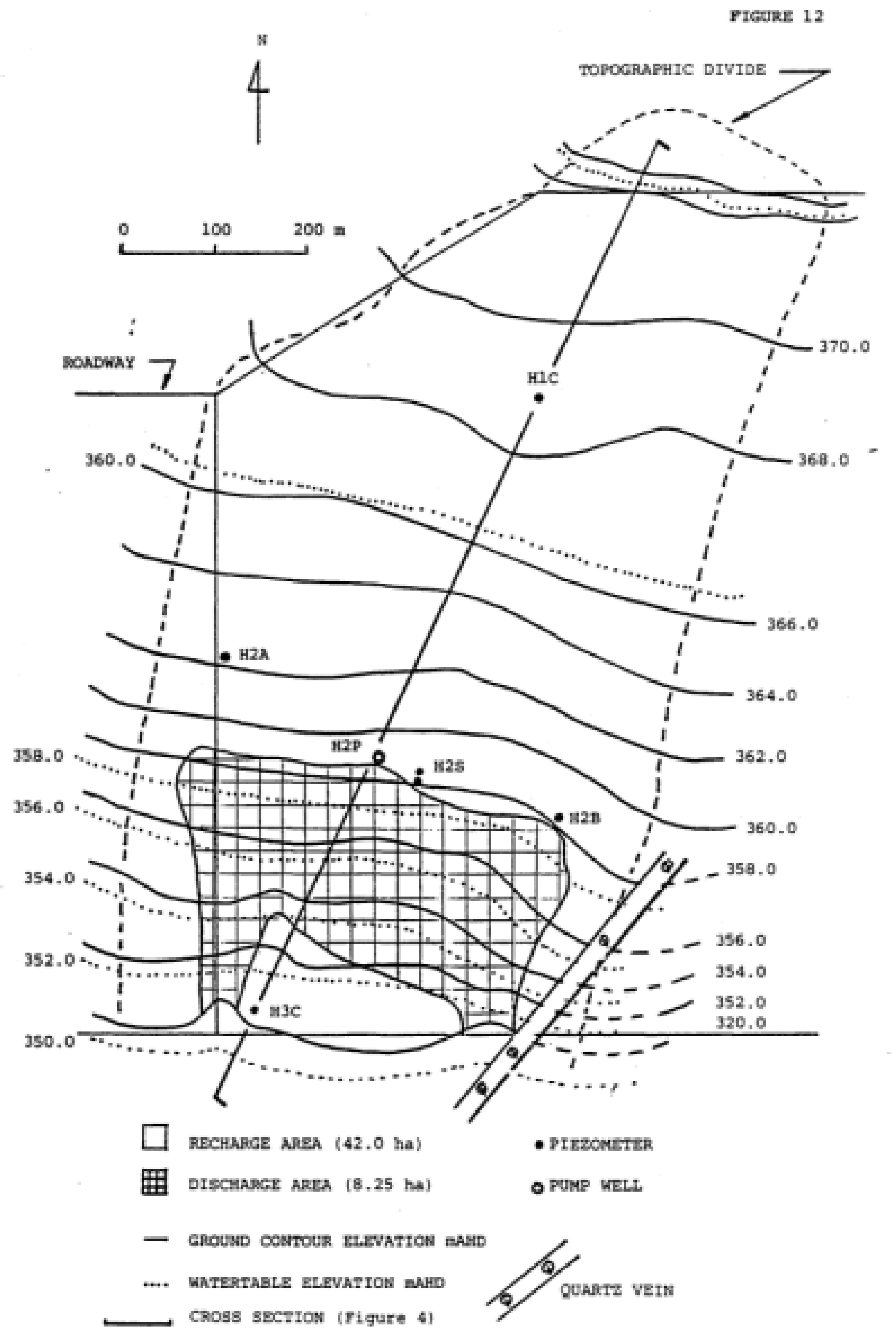
FIGURE 12
N
TOPOGRAPHIC DIVIDE
0 100 200 m
ROADWAY
H1C
370.0
368.0
360.0
366.0
H2A
364.0
H2P
362.0
358.0
H2S
356.0
H2B
360.0
354.0
358.0
356.0
352.0
354.0
352.0
H3C
320.0
350.0
RECHARGE AREA (42.0 ha)
PIEZOMETER
DISCHARGE AREA (8.25 ha)
PUMP WELL
GROUND CONTOUR ELEVATION mAHD
WATERTABLE ELEVATION mAHD
QUARTZ VEIN
CROSS SECTION (Figure 4)

*FIGURE 12*

The estimate is based on the assumption that an annual balance exists between groundwater recharge and discharge. Although it is unlikely that this will be the case over longer periods of time (decades) it is considered that on an annual basis the catchment is in a state of dynamic equilibrium. Observations of water-levels during 1987 validate the assumption, as bores showed a rise of up to 30 cm during winter and a similar fall during summer. No nett increase or decrease has been observed over the three year monitoring period (1986-1989). Hydrographs of six bores at the site are given in Figures 13 and 14.

If the annual flux of water across the recharge-discharge hinge line is approximately 3,300 kL/year, and it is all derived from the recharge area (42 ha), a recharge rate of about 8 mm year is obtained. Given the difficulties establishing an accurate and representative transmissivity, and catchment area value, it is likely that the recharge would be of the order of 5 to 10 mm year.

Groundwater discharge rates were also estimated from the same technique. Before this could be carried out, deep aquifer flow beneath the seep had to be accounted for. It can be noted from Figure 4, that flow occurs beyond the hillslope towards the valley floor. Using estimates of hydraulic conductivity derived from the slug test at H3C and surveyed levels nearby, an approximate maximum flow of 500 kL/year is obtained. Groundwater discharge (2,800 = 3,300-500 kL/yr) takes place across an area of 8.25 ha. Therefore, the discharge rate would be about 35 mm/year. Discharge rates of this magnitude (20-60 mm/year) are probably reasonable when the ratio of the recharge to discharge areas are considered. At Harvey's hillslope this is approximately 1:5. Recharge is of the order of 2 to 4% of rainfall while discharge is only about 2% of the potential evaporation rate from the seep. The low discharge rates may account for the observation that the salt-affected area is large in comparison to the size of the catchment ups lope.

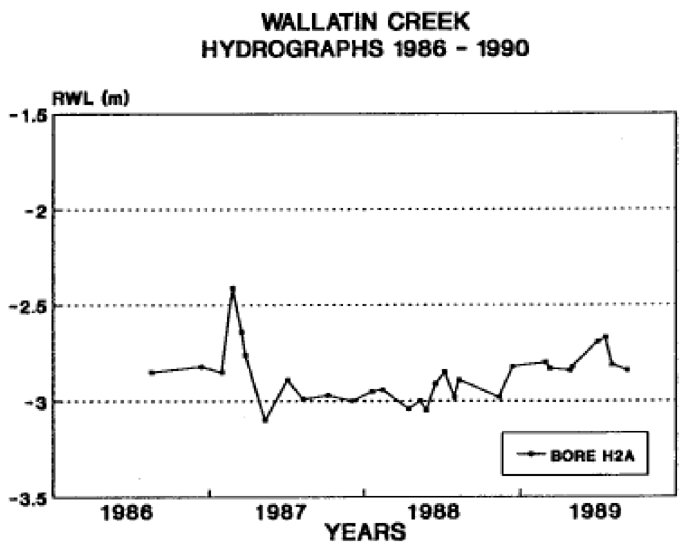


*FIGURE 13*

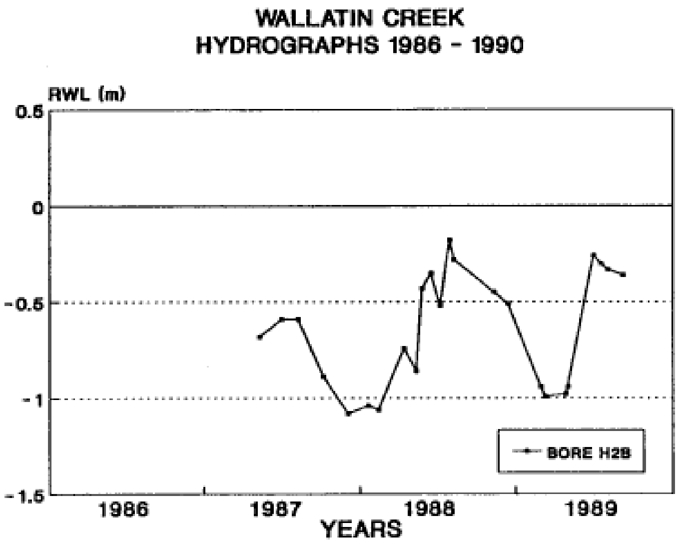
WALLATIN CREEK
HYDROGRAPHS 1986 - 1990
RWL (m)
0.5
0
-0.5
-1
-1.5
BORE H2B
1986
1987
1988
1989
YEARS

*FIGURE 13*

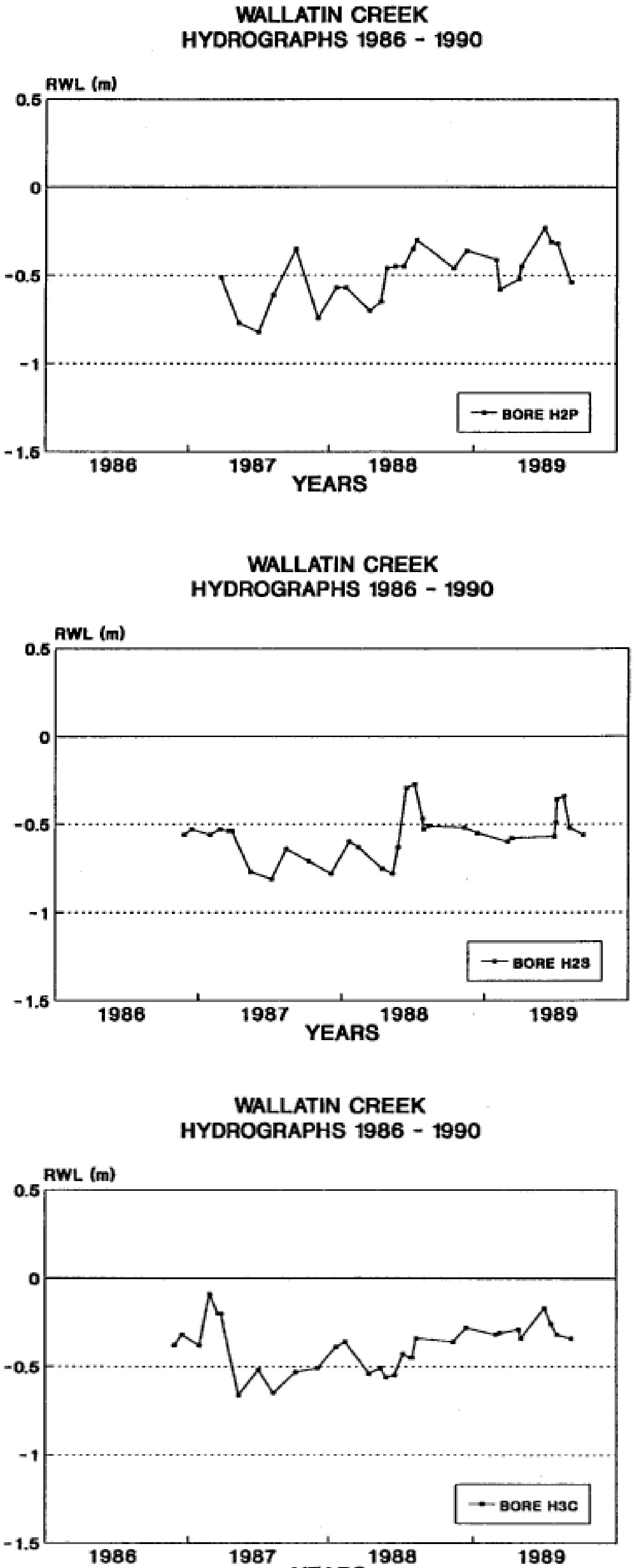
WALLATIN CREEK
HYDROGRAPHS 1986 - 1990
RWL (m)
0.5
0
-0.5
-1
-1.5
BORE H2P
1986
1987
1988
1989
YEARS
WALLATIN CREEK
HYDROGRAPHS 1986 - 1990
RWL (m)
0.5
0
-0.5
-1
-1.5
BORE H2S
1986
1987
1988
1989
YEARS
WALLATIN CREEK
HYDROGRAPHS 1986 - 1990
RWL (m)
0.5
0
-0.5
-1
-1.5
BORE H3C
1986
1987
1988
1989
YEARS

*FIGURE 14*

The long-term effect of pumping groundwater at 32 kL/day for a period of 365 days, suggests that water-table control is likely across the hillslope. At this discharge rate, approximately 3.5 times the annual recharge (or 11,680 kL/year) could be removed from the hillslope. Even given the long-term pumping rate decreases to, say, 20 kL/year, the volume discharged remains over twice the annual recharge estimated from Table 7.

The off-site effects of removing 20 to 32 kL/year of saline groundwater (31,000 mg/L - Table 6) are unknown. However, as a result, between 226 and 362 tonnes of salt would be moved downstream annually. No comparison has been made with the annual volume of salt leaving the catchment under the present salt-affected state. Such a comparison is valid and should be considered before a groundwater pumping option is considered for the site.

## *6.2 Salt Balance*

A preliminary salt balance can also be conducted from the results of the groundwater balance and knowledge of salt storage and saltfall on the hillsope. The chloride ion is used as a conservative tracer (Peck and Hurle, 1976).

Saltfall on the hillslope was estimated from the results presented by Hingston and Gailitis (1976) to be about 6 mg/L of chloride per year. Chloride storage was estimated from bores H1C and H2S to be 510 and 910 tonnes/ha. Chloride concentrations at the recharge-discharge hinge line were obtained from bores H2S and H2P. They were 16,570 and 17,400 mg/L Cl respectively. Using the estimates of groundwater flux from Table 5, a mean chloride flux of 56 tonnes/yr can be calculated.

If salt storage at H1C is representative of the 42 ha of recharge area (which appears likely from the conductivity distribution presented by the EM31 and EM34(3) (Figure 8), then approximately 21,000 tonnes of chloride are stored in the hillslope. If the mean annual flux is 56 tonnes/year then it is likely to take a minimum of 200 years to leach out 50% of the stored chloride (half-life of chloride for the catchment). Additional salt input in rainfall of about 20 kg Cl /ha/yr (ie. 6 mg/L x 330 mm) must also be accounted for. Therefore, during the 200 year period an additional 160 tonnes (or three years discharge) will be deposited.

Although the salt balance does not take into account the changing rate of chloride loss over time, the data suggests that total salt removal (as about 50% of the total stored salts is chloride) will only be achieved after about 800 years of groundwater discharge and salinisation under present flow conditions.

## *6.3 Aquifer Type*

The saprolite grit aquifer on the hillslope appears to be a heterogeneous, an isotrophic material, which changes its characteristics in all directions depending on the nature of the underlying bedrock and weathering history. However, analysis of aquifers using conventional, theoretical methods (Kruseman and de Ridder, 1983) assumes homogeneous and isotrophic conditions. While it can be argued that the scale of all the variability may not be significant enough to cause problems for the analysis of transmissivity and storage coefficient, it should be recognized that the mathematical assumptions may not be valid.

As a result of this the hydraulic properties were assessed using methods of analysis for both confined and unconfined conditions. The unconfined analysis was performed as the thickness of the aquitard was small and soon after pumping commenced, the piezometric surface was lowered into the aquifer; while a confined analytical technique was used owing to the large differences in hydraulic conductivity of the aquitard and aquifer (see Table 2). The results of this comparison (Table 3) indicate that there is little difference. However, the physical characteristics and lithology hillslope favour the use of the confined method of analysis.

The variability in thickness of the aquifer is suggested to be a result of changes in the composition of the bedrock and weathering history. A quick analysis of the magnetics data, from this and other sites, does not reveal any obvious patterns. The need to remotely estimate the aquifer thickness, if pumping of groundwaters is to become an important management method, requires additional research, beyond the scope of this project. Similarly, continuing analysis of the hydraulic properties of the saprolite aquifer and a review of appropriate analytical methods is required.

## *6.4 A real Influence of Pumping*

The results of the constant-rate pumping tests described above can be used to estimate the area in which pumping might effectively lower groundwater levels. At the conclusion of the 22 day test, water-levels were lowered by less than 0.5 m between 160 to 200 m away from the pumping bore. Effective salinity control requires the groundwater level to be kept at a minimum of 1.8 m below the ground surface (Nulsen, 1981).

A groundwater model developed by Van de Heijde (1985) called “GWFLOW” was used to evaluate the effect of pumping the aquifer at approximately 32 kL/day, over a 365 day period. This method was used for comparison with the groundwater balance approach discussed previously (Section 6.1). The hydraulic properties derived in Sections 5.2 and 5.3 were used as input data. To validate the approach, the model was first run with relevant hydraulic properties and water-level responses obtained from the pumping tests (Table 5). The model was used to determine the drawdown of H2S and H2B C after one day and 22 days respectively (Table 8).

**Table 8 • Validation of "Gwflow"**

| | 1,440 Minute Data | 22 Day Data | |
|---|---|---|---|
| | Run1 | Run2 | Run3 |
| Transmissivity ($m^2$/day) | 5.4 | 4.5 | 1.7 |
| Storage coefficient ($m^3/m^3$) | 0.012 | 0.01 | 0.01 |
| Discharge rate (kL/day) | 80 | 32 | 32 |
| Test duration (days[s]) | 1 | 22.1 | 22.1 |
| Distance to observation bore (m) | 17 | 17 | 17 |
| Estimated drawdown (m) | 1.67 | 2.46 | 5.08 |
| Actual drawdown (m) | 1.85 | 4.64 | 4.64 |

The discrepancy shown between the estimated and actual drawdown of the 22 day test, from the close agreement of the shorter test, suggests the estimated regional aquifer transmissivity (4-6 $m^2$/day) is lower than initially suggested. The value obtained from H2B C (of 1.7 to 2.0 $m^2$day) may be a more realistic indication of the actual transmissivity of the hillslope and shows a closer agreement between the actual and estimated drawdowns. A value of 2 $m^2$/day was chosen for further analysis.

Other runs of the model aimed to solve for the condition of pumping over the longer term. A period of 365 days was used so that the catchment could be considered as being in a steady-state condition (recharge and discharge neglected). The estimated drawdown at various distances are presented in Table 9.

**Table 9 • Estimated Drawdown at Steady-State away from the Pumped Well**

| | Run 4 | Run 5 | Run 6 | Run 7 | Run 8 |
|---|---|---|---|---|---|
| Transmissivity ($m^2$/day) | 2.0 | 2.0 | 2.0 | 2.0 | 2.0 |
| Storage coefficient ($m^3/m^3$) | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 |
| Discharge rate (kL/day) | 32 | 32 | 32 | 32 | 32 |
| Test duration (day(s]) | 365 | 365 | 365 | 365 | 365 |
| Distance to observation bore (m) | 17 | 100 | 200 | 300 | 400 |
| Estimated drawdown (m) | 8.07 | 3.60 | 1.96 | 1.12 | 0.64 |

If salinity can be controlled by pumping at 32 kL/day, the maximum potential area within the cone of influence, with a drawdown of greater than 1.8 m, would be approximately 12 ha. On the hillslope all of the currently salt-affected area (8.25 ha) could therefore be reclaimed. In fact, an additional 3.75 ha may be prevented. However, it is unknown whether the 12 ha potential suggested from the model could be realized, as several major barrier-boundaries (in the form of a quartz vein, variable aquifer dimensions and a changing transmissivity) would:-

(i) prevent pumping at 32 kL/day;

(ii) increase drawdown near the pumpsite; and

(iii) increase drawdown away from the barriers.

In the case of Harvey's sub-catchment a barrier-boundary would also be produced by the change of gradient of the piezometric surface in the steeply sloping, salt-affected area (Figure 4). Without the benefit of a 365 day pumping test, it is suggested as a first approximation, that a maximum area of 12 ha could be reclaimed. Sensitivity analyses were conducted in the economics model, PUMPS, described below (Section 5.4).

## *6.5 Economic Analysis of Pumping*

Groundwater pumping is a technically feasible option to control soil salinity on the hillslope. In Section 6.4 it was estimated that the potential area which could be reclaimed was approximately 12 ha. An economic evaluation using a modified borefield and observation network was carried out using economic data provided by the landholder.

A summary of the economic analyses and the final evaluations and input data are given in Table 10. The input data is "economically" optimistic as low costs have been attributed to drilling, consultants' fees and no costs are given for groundwater disposal. Disposal was only considered to be legal for the purpose of this demonstration. Five runs are presented with different values of variables in the evaluation section. Runs 1 and 2 are considered to most closely represent reality. The reader is referred to George (l990b) for a detailed discussion of the operation and limitations of PUMPS.

**Table 10 • Summary of Data and Results from Pumps**

| *** Input Data** | **Cost (5)** |
|---|---|
| 1. Drilling costs (1 production well and 6 observations wells) | 2,025 |
| 2. Power supply costs (SEC .. 1,000 m, transformer and connection) | 4,200 |
| 3. Annual running costs (0.75 kW/hr pump @ 8,760 hr/yr) | 1,090 |
| 4. Capital costs of pumps (and 5% repairs) | 1,000 |
| 5. Reclamation time (fully reclaimed in 10 years - sliding scale) | - |
| 6. Site and disposal costs (for effluent and fencing) | 2,000 |
| 7. Consultants fee (for services not offered by Department of Agric.) | 5,000 |

| *** Evaluation** | **Run 1** | **Run 2** | **Run 3** | **Run 4** | **Run 5** |
|---|---|---|---|---|---|
| Area reclaimed (ha) | 8.25 | 12 | 24 | 24 | 12 |
| Real discount rate (%) | 5 | 5 | 5 | 5 | 5 |
| Nett income (S/ha) | 60 | 60 | 60 | 80 | 120 |
| Marginal tax rate (5) | 0.49 | 0.49 | 0.49 | 0.49 | 0.49 |
| Land value (S/ha) | 300 | 300 | 300 | 300 | 300 |
| Break Even Year | > 75 | > 75 | > 75 | 28 | 35 |
| Profit (loss) at 75 yrs | (-32,000) | (-24,000) | (-3,000) | +9,900 | +6,800 |
| Trend * | Negative | Negative | Negative | Positive | Positive |

NB: The model calculates over a maximum period of 75 years.

* The trend suggests whether the loss is increasing over time (negative) or decreasing (positive).

The results suggest that groundwater pumping, although technically feasible, is uneconomic given the current costs associated with pumping and farm economics. In another economic analysis on the hillslope, McFarlane et al. (1988) found that recharge area management was also uneconomic. It should be remembered that the data used in the current analyses probably understate the actual costs (ie. if consultants are used). The site costs and disposal estimates of $2,000 first assumes that the disposal of water is legal and environmentally acceptable. A review of salinities described in Table 6 suggest this is probably not the case as groundwaters are of the order of 31,000 mg/L. Although the waters could be pumped along an already saline drainage line (Figure 1), it is not considered to be a long-term option, as in other catchments in the eastern wheatbelt, George (1990d) has noted that creek flows have resulted in additional recharge and associated increases in groundwater levels.

At Harvey's hillslope the nett income per hectare is high in comparison with the district average ($20 to 40 ha - S. Hossen, personal communication, 1988). The high marginal taxation rate (maximum possible under current legislation) is also an advantage which other farmers may not enjoy. In all cases it is assumed that conservation earthworks have been deducted against taxation in the first year of expenditure.

## *6.6 Alternatives to Conventional Pumps*

Apart from the conventional submersible, petrol or diesel centrifugal pumps, alternative “Airwell” and solar systems could also be used. Analysis of the economics of conventional, solar and Airwell systems suggest that none are suitable at this location. In all cases the costs associated with power generation (conventional and Airwell) and storage (solar) make continuous pumping, at constant rates, prohibitive.

An alternative to the pumping systems noted above are syphons. Syphons are theoretically capable of withdrawing water up to one atmosphere pressure (or an equivalent drawdown of 10.35 m). However, mechanical inefficiencies mean that the limit is usually between 7 and 8 m. Several experiments were conducted at Harvey’s hillslope to determine the application of syphons. Pump-test data was used to determine the maximum flow rate available (0.37 L/s or 32 kL/day) and the syphons set accordingly.

The syphon initially operated successfully (for between one to three days) at rates which ranged from 0.2 to 0.5 L/s. However, on each occasion the syphon was broken by gas buildup at the head of the pipe. To overcome the problem, attributed to vapourization along the lines and gas bubbling from the bore, a 200 L pressurized, gas-exchange tank was constructed and installed.

The tank was filled with water and connected to the top of the syphon so that gas would enter the tank and be replaced by water. The header tank extended the operation of the syphon by up to seven days. Flow rates after this period were lower than expected as the total working head controlling the syphon had become high, due to the drawdown in the well.

In conclusion it is suggested that syphons are capable of maintaining flow rates of between 0.3 and 0.5 L/sec. for periods up to seven days before header tanks needed refilling. However, vapourization of water in the syphon, low land-surface gradients (2.6%) and gas emanating from the borehole may make the use of syphons impractical in many cases for salinity control.

## *6.7 Other Management Options*

Unless economic and environmental problems can be overcome, a pumping option in its current form appears inappropriate. It is suggested that at this site, where continuous cropping and high productivity pastures are well established, that recharge area management using annuals is unlikely to be sufficient to prevent or control recharge enough to reduce the area of saltland.

Perennials such as tagasaste could be established on the gravels of the Ulva association, although this accounts for only 10% of the recharge area. Similarly, eucalypts could be planted in rows across the contour to intercept water in the saturated and unsaturated zones and provide shelterbelt effects. However, discharge area management using halophytes appears to have the greatest economic and conservation value to the landholder. Saltbush should be established through the salt-affected area, while salt tolerant eucalypts, acacias and melaleucas, have been planted in a small trial plot. Small plots of saltbush and salt tolerant trees (E.camaldulensis var saltdown) show potential for wider use. The eucalypts in particular are now two years old and are growing on groundwaters of between 30,000 and 50,000 mg/L. Saltbush seedlings also established and grew well. Saltbush would appear to be the most cost-effective management approach available for this site.

# 7. Conclusions

A hillslope was analysed to determine the nature and distribution of groundwaters responsible for salinisation and the feasibility and economics of using pumps and syphons for reclamation.

A transmissive and extensive saprolite aquifer was discovered in the saprolite grits above bedrock which could be successfully pumped at up to 32 kL/day for long periods of time. However, even though reclamation may have been possible over an area of 12 ha, it was not economic. The high salinity of the groundwaters suggested that disposal was likely to be a major problem.

The initial transmissivity estimated from the short-term pumping test of 5.4 to 6.4 m/day over-estimated the actual or regional transmissivity (of < 2 m/day - from long-term test) by about 30%. The pump tests revealed that the transmissivity of the saprolite aquifer is highly variable. A storage coefficient of 0.01 appears appropriate for use in saprolite aquifer conditions. Slug tests accurately indicate the hydraulic conductivity of a bore site, but are overestimates over the aquifer in general. The ability to remotely (magnetics) assess the location and thickness of the saprolite grits is a priority for future research. Electromagnetics appeared to describe the distribution of salt storage and can be used to broadly assess groundwater quality.

Recharge at the site is of the order of 5 to 10 mm/yr (average over the recharge area) while discharge rates from the salt-affected area are only about 30 to 40 mm/yr. Groundwaters are extremely saline (“4,500 mS/m). The estimate of time required to leach the catchment of its salt suggests that secondary salinity could be maintained for a period of up to 800 years. Management systems using saltlarid agronomy and salt tolerant trees should be investigated further. Recharge area plantings of tagasaste, shelter belts and high water-use (profitable) pastures and crops should be encouraged.

# 8. Acknowledgements

The authors would like to thank Dr D.J. McFarlane and Mr A.T. Ryder for help drilling some of the observation wells. Dr R. Salama is kindly thanked for the data (excluding H2 Pump) in Table 6. Special thanks is given to Mark and Helen Harvey for their assistance, and especially for help in monitoring the 22 day test and for providing information on their farms economics.

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**Well Log Reports - Drilling Results**

| | | | |
|---|---|---|---|
| Project Bore No: | 30 Hic | Rig Type: | RAB |
| Catchment: | Wallatin Ck | Casing Depth: | 11.90 (m) |
| Date Drilling: | Nov 1986 | Depth Drilling: | 12.00 (m) |
| Location: | Harveys | Quality: | 5020 mS/m |
| Grid Reference: | 31°26’16”N 117°44’05”E | Yield: | < 5 kL/day |
| Land Unit: | Booraan | Depth To Bedrock: | 12.00 (m) |
| | | Slotted Length: | 2 (m) |
| Watertable Depth: | 7.94 (m) | Samples: | Few |

## Results

| Depth (m) From | To | Description of Bore | Zone |
|---|---|---|---|
| 0 | 0.5 | Grey sandy clay. | Surficial |
| 0.5 | 1.0 | Light orange/brown sandy clay. | Mottled |
| 1.0 | - | Mottled sandy clay, granite - granite gneiss. | (Pallid) |
| | | Goethite, haematite and kaolin minerals with fine grained qtz. (moist throughout). | |
| - | 8.5 | Wet sample, foam and water added. | |
| 9.5 | - | Coarse grits, qtz., feldspar, mica - granitic. | Saprolite |
| | | Small supply coming from this coarse zone. | |
| 12.0 | - | Bedrock. | Bedrock |
| | | Drilling record says unsaturated zone was remarkably moist throughout. Due to ponding in contour bank or paddock recharge. | |

**Comments :** Flow < 5 kL/day - saline.

RJG

**Well Log Reports - Drilling Results**

| | | | |
|---|---|---|---|
| Project Bore No: | 31 H2A C | Rig Type: | RAB |
| Catchment: | Wallatin Ck | Casing Depth: | 12.50 (m) |
| Date Drilling: | Mark 1987 | Depth Drilling: | 12.60 (m) |
| Location: | Harveys | Quality: | 2350 Ms/M |
| Grid Reference: | 31°26'16"N 117°44'05"E | Yield: | 30 - 50 kL/day |
| Land Unit: | Booraan | Depth To Bedrock: | 12.60 (m) |
| | | Slotted Length: | 2 (m) |
| Watertable Depth: 3.04 (m) | | Samples: | Nil |

## Results

| Depth (m) From | To | Description of Bore | Zone |
|---|---|---|---|
| 0 | 0.1 | Surficial sands | Sands |
| 0.1 | 1.5 | Mottled coarse sandy clay. Fresh feldspar and qtz. by 1.5 m | Mottled |
| 1.5 | | Saprolite zone encountered. | Saprolite |
| | | Medium to fine grained granitic - gneiss minor epidote and haematite common | |
| | (6.0) | Bands of coarser material. Flow only beginning to appear. | |
| | (9.0) | Coarser saprolite, large feldspar, qtz and large amounts of micaceous minerals. | |
| | | Increasing grain size. Flow increasing rapidly from 10m – 12m. | |
| 12.6 | | Bedrock | Bedrock |

**Comments :** Flow 30 – 50 kL/day - saline.

RJG

**Well Log Reports - Drilling Results**

| | | | |
|---|---|---|---|
| Project Bore No: | 32 H2 C | Rig Type: | RAB |
| Catchment: | Wallatin Ck | Casing Depth: | 3.00 (m) |
| Date Drilling: | Nov 1986 | Depth Drilling: | 3.15 (m) |
| Location: | Harveys . | Quality: | 340 mS/m |
| Grid Reference: | 31$^{0}$26'16"N 117$^{0}$44'05"E | Yield: | < 5 kL/day |
| Land Unit: | Danberrin. | Depth To Bedrock: | 3.15 (m) |
| | | Slotted Length: | 2 (m) |
| Watertable Depth: | 0.83 (m) | Samples: | Few |

## Results

| Depth (m) From | To | Description of Bore | Zone |
|---|---|---|---|
| 0 | 0.5 | Orange/brown sands derived from alluvial deposits in contour bank. | Sands |
| 0.5 | 1.5 | Orange/brown coarse - gritty sandy clay. | Mottled |
| 1.5 | 1.8 | Moist, from saprolite zone. | Saprolite |
| | (2.1) | Small flow (1 - 2 L./min) granitic grit. | |
| 3.15 | - | Bedrock. | Bedrock |

**Comments :** < 5 kL/day flow - brackish.

RJG

**Well Log Reports - Drilling Results**

| | | | |
|---|---|---|---|
| Project Bore No: | 33 H2 Syphon | Rig Type: | RAB |
| Catchment: | Wallatin Ck | Casing Depth: | 13.00 (m) |
| Date Drilling: | Nov 1986 | Depth Drilling: | 13.03 (m) |
| Location: | Harveys | Quality: | 4100 Ms/In |
| Grid Reference: | 31°26'16"N 117°44'05"E | Yield: | 30 - 50 kL/day |
| Land Unit: | Booraan | Depth To Bedrock: | 13.03 (m) |
| | | Slotted Length: | 2 (m) |
| Watertable Depth: | 1.01 (m) | Samples: | EC, PH, C1, ECe, Sat% |

## Results

| Depth (m) From | To | Description of Bore | Zone |
|---|---|---|---|
| 0 | 0.3 | Brown clay sands. | Surficial |
| 0.3 | 2.5 | Mottled brown/red sandy clay to medium sandy clay. Haematite rich zones. | Mottled |
| 2.5 | - | Grits, medium textured with noticeable amount of clay minerals. Medium sized feldspars and quartz, little mica. | Saprolite |
| | (7.5) | Finer grained material, gneissic- granite remnants. | |
| 11.00 | - | Extremely coarse grained, 1 - 15 mm, twinning on feldspars with porphyritic texture. Epidote noticed. | |
| 13.00 | - | Bedrock. | Bedrock |
| | | Intermediate bore 1.8. m (0.8 - 1.8). | |

**Comments :** Flow rate 30 – 50 kL/day, however noticed decreasing after 2 hours developing.

RJG

**Well Log Reports - Drilling Results**

| | | | |
|---|---|---|---|
| Project Bore No: | 34 H2 Pump | Rig Type: | RAB 175 mm |
| Catchment: | Wallatin Ck | Casing Depth: | 11.90 (m) |
| Date Drilling: | Mark 1987 | Depth Drilling: | 11.90 (m) |
| Location: | Harveys | Quality: | 4590 mS/m |
| Grid Reference: | 3l°26'16"N 117°44'05"E | Yield: | 190 kL/day |
| Land Unit: | Booraan | Depth To Bedrock: | 11.90 (m) |
| | | Slotted Length: | 11 (m) |
| Watertable Depth: | 0.95 (m) | Samples: | Few |

## Results

| Depth (m) From | To | Description of Bore | Zone |
|---|---|---|---|
| 0 | 0.3 | Brown clay sands. | Surficial |
| 0.3 | 2.9 | Red/brown mottled sandy clay, decreasing in clay content with depth. Haematite rich zones (1.0 - 1.8). Silicified material at (0.6), small pebbles. | Mottled |
| 2.9 | - | Rapid decrease in clay content 2.8 - 3.0 m fresh feldspars, medium grain site 1 - mm, with large amounts of qtz. Little mica. | Saprolite |
| | (6.0) | Flow rate increasing rapidly with depth, already 60 kL/day. Little clay in suspension. | |
| | (9.0) | Flow rate massive, derived from porphyritic feldspar and large qtz. Micas common. | |
| 11.90 | - | Bedrock. | Bedrock |
| | | Several pump tests conducted. | |
| | | July 1987<br>T = 3.2 - 6.5 kL/day<br>S = 0.04 (0.001 - 0.02). | |

**Comments :** Initial flow estimated at 2 litres/sec (190 kL/day) - saline. Pump test conducted at 32 kL/day and 90 kL/day.

RJG

**Well Log Reports - Drilling Results**

| | | | |
|---|---|---|---|
| Project Bore No: | 35 H3 C | Rig Type: | RAB |
| Catchment: | Wallatin Ck | Casing Depth: | 9.40 (m) |
| Date Drilling: | Nov 1986 | Depth Drilling: | 9.40 (m) |
| Location: | Harveys | Quality: | 3230 mS/m |
| Grid Reference: | 3l°26'16"N 117°44'05"E | Yield: | < 10 kL/day |
| Land Unit: | Booraan | Depth To Bedrock: | 9.40 (m) |
| | | Slotted Length: | 2 (m) |
| Watertable Depth: | 1.65 (m) | Samples: | Few |

## Results

| Depth (m) From | To | Description of Bore | Zone |
|---|---|---|---|
| 0 | 0.4 | Brown sands. | Sands |
| 0.4 | 2.0 | Mottled sandy clay, only just moist, colluvial zone? Due to layering and sorting of materials to 2.0 m | Mottled |
| | (3.0) | Paler, finer textured, kaolin and fine qtz. beginning of pallid zone? | Pallid Saprolite |
| 3.6 | - | Saprolite grits, coarse granitic fabric with large feldspars | |
| | | Little flow apparent until 8.5m. Rapidly increasing until bedrock encountered. | |
| 9.4 | - | Bedrock. | Bedrock |

**Comments :** Flow rate less than 10 kL/day - saline.

RJG

**Well Log Reports - Drilling Results**

| | | |
|---|---|---|
| Project Bore No: | 36 H4 C | Rig Type: RAB |
| Catchment: | Wallatin Ck | Casing Depth: 6.25 (m) |
| Date Drilling: | Nov 1987 | Depth Drilling: 6.70 (m) |
| Location: | Forsyth's | Quality: 3910 mS/m |
| Grid Reference: | 31$^{0}$26'51"N 117°44'10"E | Yield: < 5 kL/day |
| Land Unit: | Booraan | Depth To Bedrock: 6.70 (m) |
| | | Slotted Length: 2 (m) |
| Watertable Depth: | 1.63 (m) | Samples: Nil |

## Results

| Depth (m) From | To | Description of Bore | Zone |
|---|---|---|---|
| 0 | 0.1 | Pale brown sand | Surficial |
| 0.1 | 1.0 | Light brown, green sandy clay | Mottled |
| 1.0 | 3.0 | Red, haematite rich - green mottled sandy clay (moist at 2.5 m). | |
| 3.0 | 6.7 | Saprolite grits, granitic fabric, coarse | Saprolite |
| 6.7 | - | Bedrock | Bedrock |

**Comments :** Flow rate less than 10 kL/day

RJG