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GEOLOGICAL SURVEY OF WESTERN AUSTRALIA

RECORD 1989/9

RESULTS OF AQUIFER TESTING YARRAGIL NORTH CATCHMENT DWELLINGUP

by
M.W. Martin

DEPARTMENT OF MINES
WESTERN AUSTRALIA

GEOLOGICAL SURVEY OF WESTERN AUSTRALIA

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RESULTS OF AQUIFER TESTING AT THE YARRAGIL NORTH CATCHMENT, DWELLINGUP

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DWELLINGUP

by

M.W. MARTIN

ABSTRACT

The hydraulic characteristics of saprolite derived from weathering of igneous basement rocks typical of the area east of Dwellingup, Western Australia have been evaluated from the results of a 7 day constant-rate pumping test and from air-compression slug tests.

The aquifer within the saprolite is unconfined and responds to pumping as a double-porosity medium that consists of transmissive fissures and porous blocks. Fissures occur as the result of weathering of the coarse-grained quartz-rich basement and the removal of material by groundwater flow. The porous blocks are derived from the weathering of fine-grained basement rock which contains minerals that weather to clay.

Although the aquifer responded to pumping as a double-porosity medium, the observation bores were further than half the saturated thickness of the aquifer from the pumping bore. This enabled analysis using porous-media methods. The heterogeneity of the aquifer resulted in a fissure-flow dominated response at one observation-bore site.

The best estimates of hydraulic parameters from the pumping test are 8.0 m^2/d for the transmissivity of the fissures, and 0.002 and 0.03 for S_2 and S_3 respectively. Values of hydraulic conductivity were calculated by assuming porous media flow. This provides an estimate of 0.4 m/d for horizontal hydraulic conductivity and 0.1 m/d for vertical hydraulic conductivity. Estimates of horizontal hydraulic conductivity determined from air-compression slug tests were 50 - 100% less than the average values calculated from the pumping test.

Keywords: Western Australia; Dwellingup; hydrogeology; unconfined aquifer; porosity; pumping test; slug test

INTRODUCTION

PURPOSE AND SCOPE

Research into the effects of bauxite mining on the water resources of the Darling Range has been in progress since early 1970. It involves multi-disciplinary groups from Government agencies and private industry.

This research has shown that priority should be given to determining the effects of an eastward extension of mining into the lower rainfall area (900 - 1 100 mm/a) of the region. This area is referred to as the intermediate rainfall zone, and represents a transition from high rainfall in the west to low rainfall in the east. The transition is also reflected by a west to east change in geomorphology and vegetation. It is proposed that investigations in the intermediate rainfall zone will involve detailed monitoring at a number of sites, and at one site, trial mining will be undertaken.

This report presents results from a drilling and pumping-test program carried out by the Geological Survey of Western Australia (GSWA) at the Yarragil North catchment during April, 1986. The values of hydraulic conductivity derived from the pumping test and from slug tests are compared.

LOCATION AND CLIMATE

The Yarragil North catchment is about 25 km east from Dwellingup (Fig. 1). It has an area of 223 ha, and is at the head of Yarragil Brook, which drains into the Murray River.

The test site is at the outlet of the catchment near

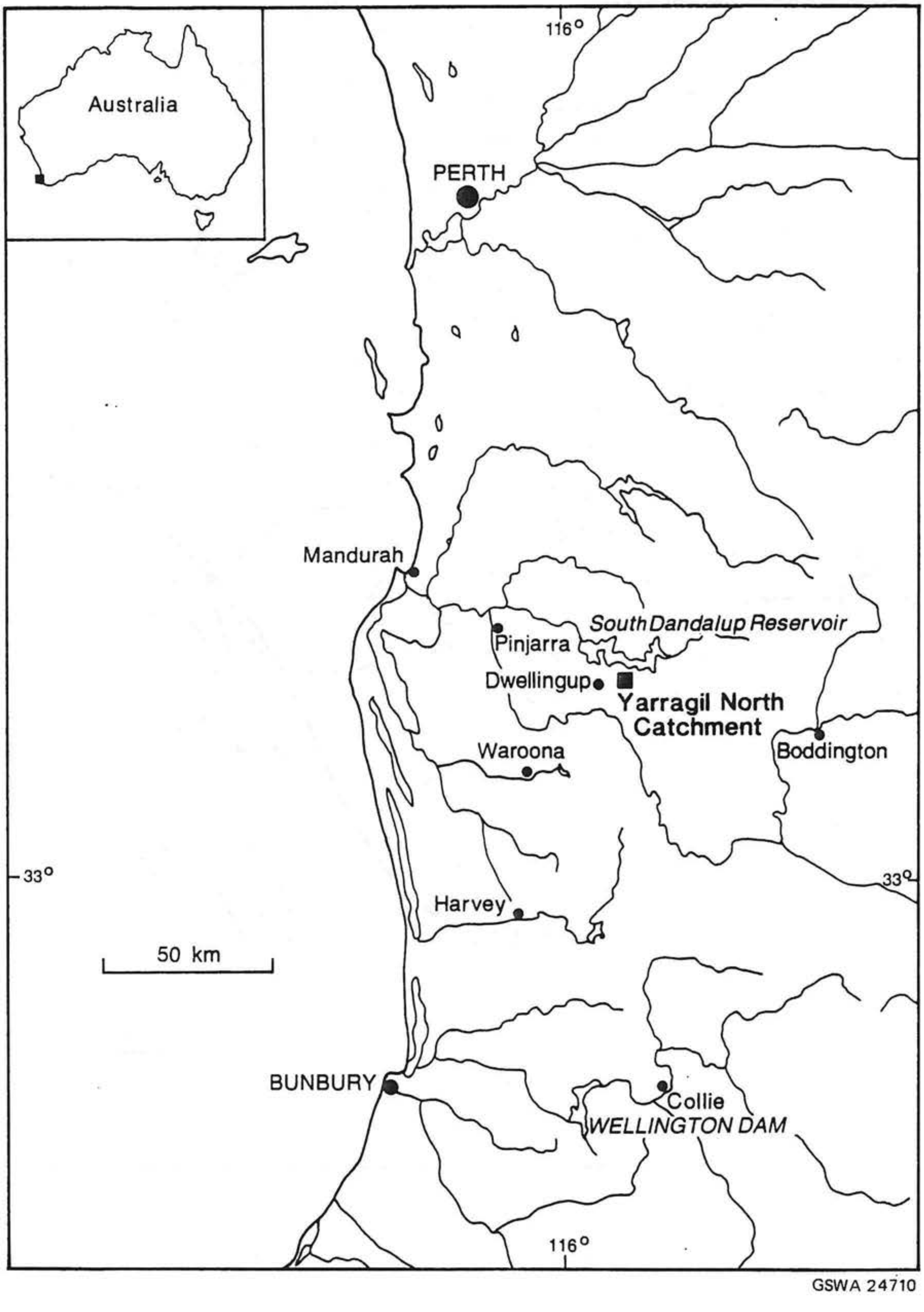

Figure 1 Location

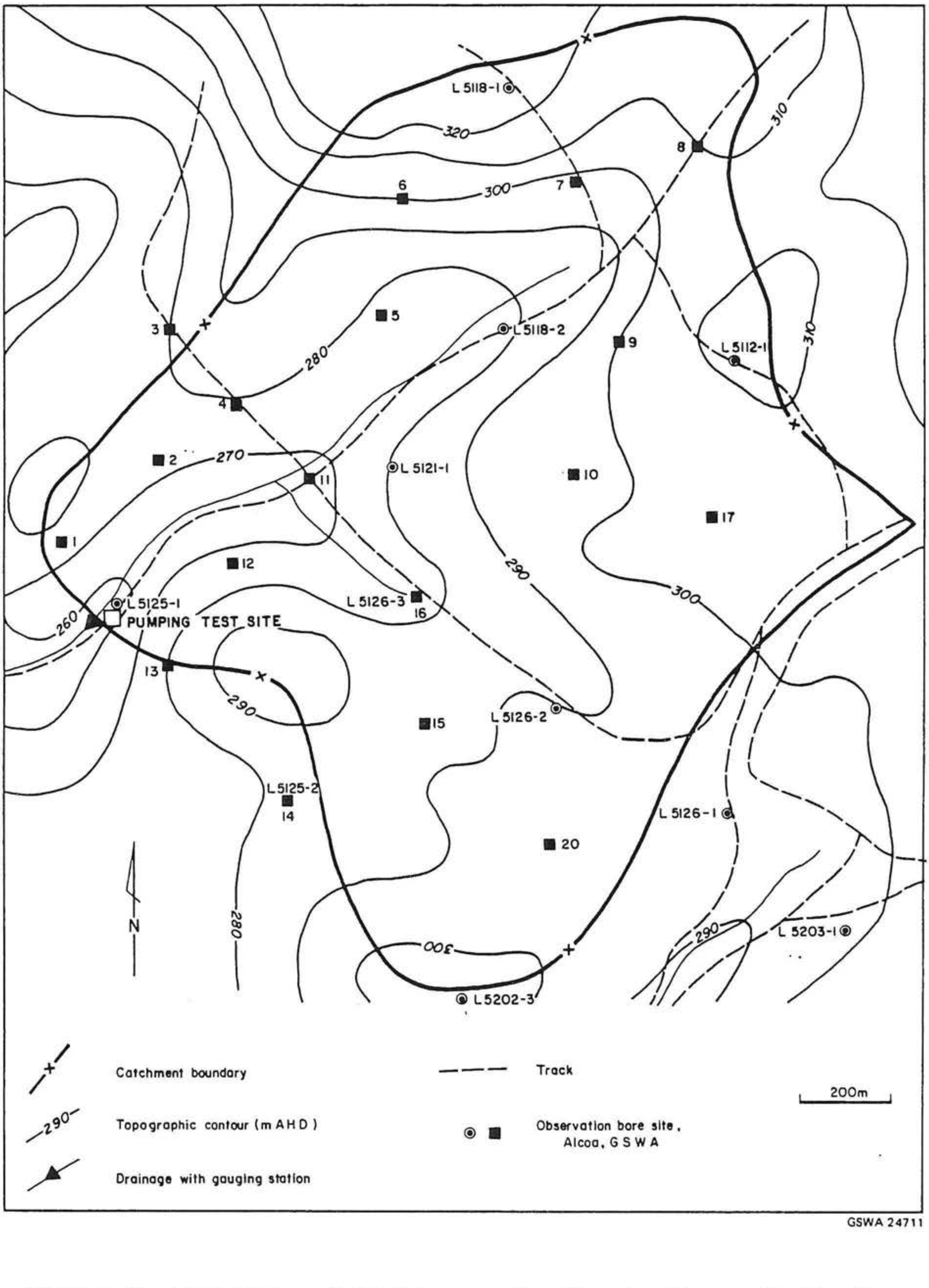

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Figure 2 Location of pumping-test site in Yarragil North Catchment the Water Authority of Western Australia gauging station (Station No. 614 046), which monitors rainfall and run-off from the catchment (Fig. 2).

The climate is Mediterranean: winters are cool and wet; summers, warm and dry. The average annual rainfall is 1 050 mm.

PREVIOUS INVESTIGATIONS

Two seismic refraction surveys of the underlying bedrock topography were conducted in the Yarragil North and adjoining 5D catchments during 1985 and 1986. In 1985, traverse lines totalling 7.6 km were surveyed (Street 1985), and in 1986, 19.4 km were surveyed (Wilson 1986).

Five cored holes were drilled by Alcoa of Australia in the Yarragil North catchment to determine the amount of salt stored in the soil. The holes were completed as bores to allow monitoring of groundwater levels. The network of monitoring bores was increased in 1987 when the GSWA completed 43 bores at 18 sites in the catchment (Thorpe and Martin 1988). These are shown on Figure 2.

METHODS

DRILLING AND BORE CONSTRUCTION

A test hole was drilled to a depth of 27 m using an air-rotary method. This proved sufficient water, and the hole was reamed to 152 mm diameter (dia) using a water-flush rotary method, and deepened until fresh bedrock was struck at 32 m depth.

The hole was completed as a production bore with 100 mm (dia) steel pipe from ground level to 3m, and 100 mm (dia) PVC casing (slotted between 8 m and 32 m) from 3 m to 32 m. The bore was demudded and the slotted section was packed with gravel. The annulus above the slotted section was cemented to the surface. The bore was then developed by air-lifting for about 20 hours.

Observation bores were drilled using a water-flush rotary method and completed with 50 mm diameter galvanized iron pipe from 0.5 m above ground level to 3 m below ground level, and with 50 mm diameter PVC from 3 m to the bottom of the holes. The bottom 3 m of the casing was machine slotted and, after demudding, the hole was packed with gravel. The annulus above the slots was cemented to the surface, and the bores were developed by air-lifting. Bore locations are shown on Figure 3 and bore completion details are contained in Table 1.

PUMPING TEST

A pumping test, at a constant rate of 20 m^3/d, commenced on 30 April 1986 and continued for seven days. The flow rate was monitored using an orifice plate and piezometer tube, and water was discharged into a stream bed about 400 m downstream from the test area.

Water levels in the production and observation bores were monitored using pressure transducers and chart recorders, or manual electronic water-level indicators. Water levels in bores with transducers were measured manually at four-hourly intervals to calibrate the measurements obtained by the transducers.

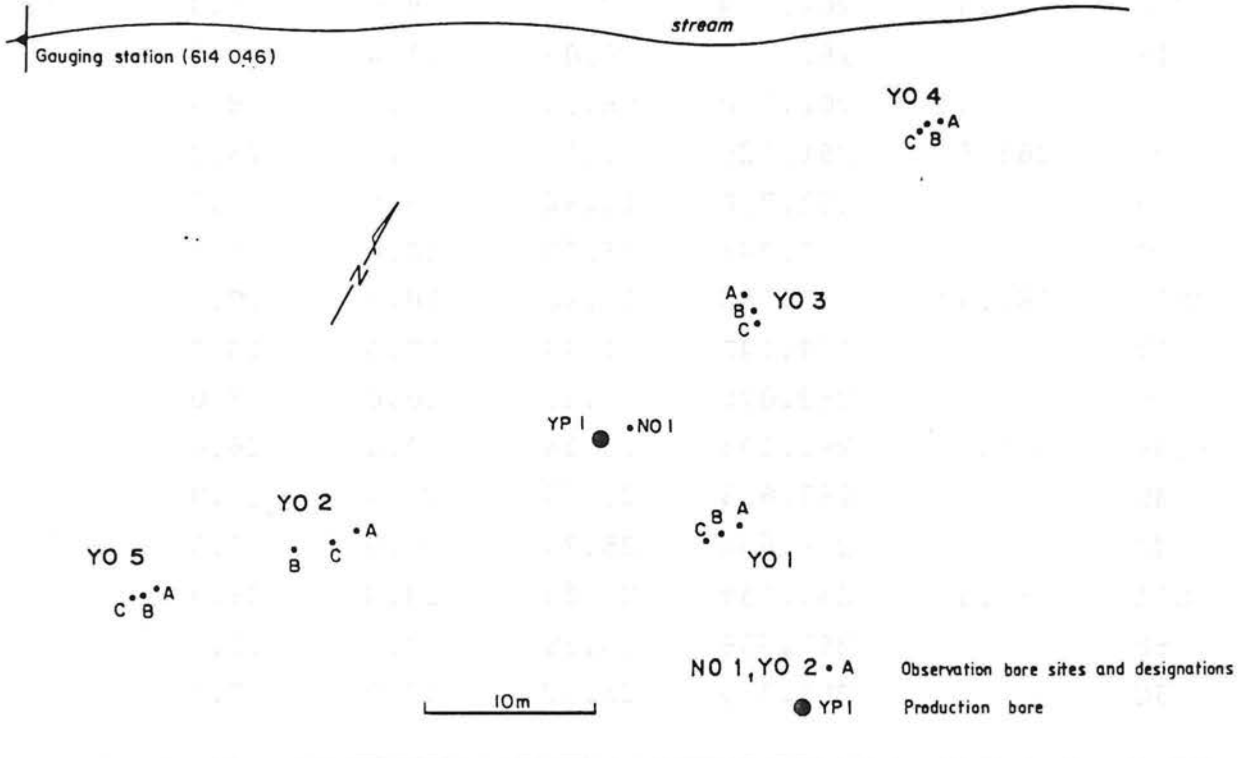

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Figure 3 Bore locations at pumping-test site

TABLE 1. BORE-COMPLETION DETAILS

Bore No.	Ground level (m)	Top of casing (m)	Distance from YP1 (m)	Depth	
				Total (m)	Top of Slots (m)
YP1	261.70	262.201	-	32.0	8.0
NO1	261.81	262.223	1.85	14.8	8.0
YO1A	262.50	262.814	9.57	29.0	26.0
1B		262.800	9.00	21.0	18.0
1C		262.790	8.56	11.0	8.0
YO2A	261.50	261.725	15.17	26.0	23.0
2B		261.750	18.86	19.0	16.0
2C		262.041	16.63	10.0	7.0
YO3A	261.60	262.064	11.80	30.5	27.5
3B		262.145	11.44	17.0	14.0
3C		262.070	11.22	10.0	7.0
YO4A	261.30	261.596	28.86	29.0	26.0
4B		261.695	26.35	20.0	17.0
4C		261.644	25.70	10.0	7.0
YO5A	261.30	261.559	27.68	24.4	21.4
5B		261.636	28.38	18.0	15.0
5C		261.710	28.92	10.0	7.0

Note: Ground level (G.L.) and top of casing (T.O.C.) are relative to Australian Height Datum (AHD).

SLUG TESTING

Air-compression slug tests were conducted in March and April 1987. The method, described by Thorpe and Martin (1988), involved pressurizing the casing with air to displace a column of water. The air pressure was kept constant using a regulator, until the water pressure reached equilibrium. The air pressure was then released and the recovery of water levels was monitored using a pressure transducer and chart recorder.

GEOLOGY

REGIONAL SETTING

The area is underlain by weathered and lateritized Precambrian granitic rocks -- and a few mafic dykes -- of the Yilgarn Block. The complete weathered profile consists of saprolite and overlying massive to nodular laterite or duricrust. The saprolite is a multicoloured clayey-silty sandy to silty-sandy clayey material, and three divisions can be distinguished within it. These are, in ascending order: a basal weathered zone, which overlies fresh to slightly weathered basement rock; a pallid zone; and a mottled zone, which is not present at the test site. Laterite occurs on the ridges and valley flanks; and colluvium, which is generally associated with dissection of the laterite surface, occurs on the lower slopes and valleys. Thin alluvial deposits may also occur in the valleys.

GEOLOGY OF THE PUMPING-TEST AREA

The basement at the test site is slightly weathered to fresh granitic rock. Although samples of fresh rock were not obtained by drilling, drill cuttings from the basal few metres of the saprolite are similar to those in the remainder of the catchment. The predominant rock type in the catchment is a fine- to coarse-grained, porphyritic, foliated granite (Thorpe and Martin 1988). Pegmatite bands, consisting of quartz and feldspar phenocrysts and occasional hornblende phenocrysts, are common at most sites. The mineral foliation is weak to prominent, and dips range from horizontal to 80°. Thin mafic bands or micaceous layers were seen in some cored samples.

The basement is overlain by 25 - 30 m of saprolite which contains relic structures and textures of the parent rock. The weathered zone is about 15 m thick and consists of white-and-brown to brown clayey sand and clayey gravel. The variations in lithology are characteristic of a weathered, fine- to coarse-grained porphyritic granite containing pegmatite bands. The weathered zone grades up into the pallid zone, the composition of which is similar to the weathered zone, but which is characterized by its pale to white colouration, a result of leaching. Some ferruginization and red staining occurs within the pallid zone.

The mottled zone and overlying duricrust are not present at the test site. They may have been eroded and the pallid zone overlain by sand and laterite pebbles of colluvial or alluvial origin. The uppermost layer is about 2 m thick at the site, but reaches a maximum of 4 m at YO5 (Fig. 4).

HYDROGEOLOGY

The hydrogeology of the Yarragil North catchment has been described by Thorpe and Martin (1988). Groundwater occurs in the saprolite and within fractures and joints of the fresh bedrock; but because fractures and joints are rare, the base of the groundwater flow system is considered to be the top of fresh bedrock. The upper surface of the groundwater flow system is a water table which occurs at a depth of about 7 - 8 m at the test site. The average saturated thickness of the saprolite is about 20 m.

The water-table contours at the test site and before pumping are shown on Figure 5. Groundwater flow is to the west-southwest, away from the stream, and suggests local recharge during streamflow. The hydraulic gradient on the water table ranges from 0.017 to 0.027.

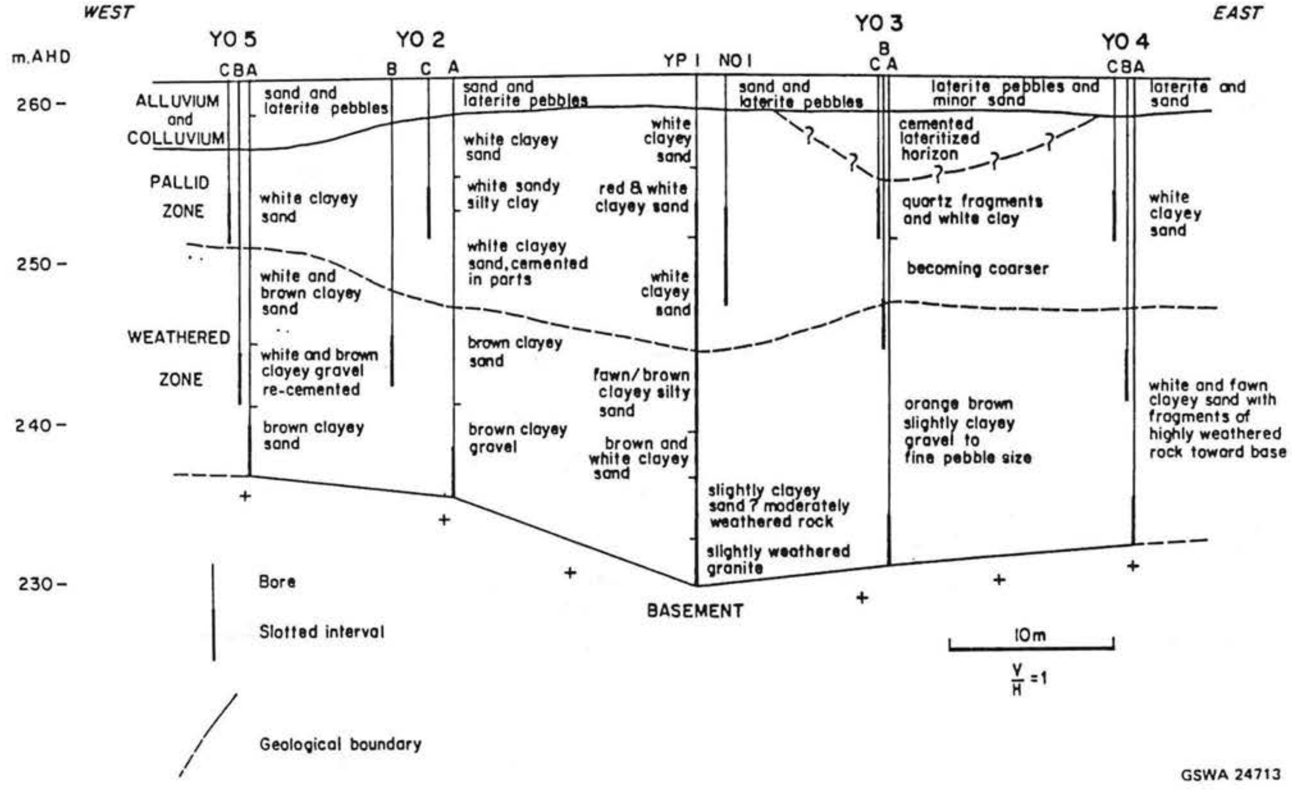

Figure 4 Geological section at pumping-test site

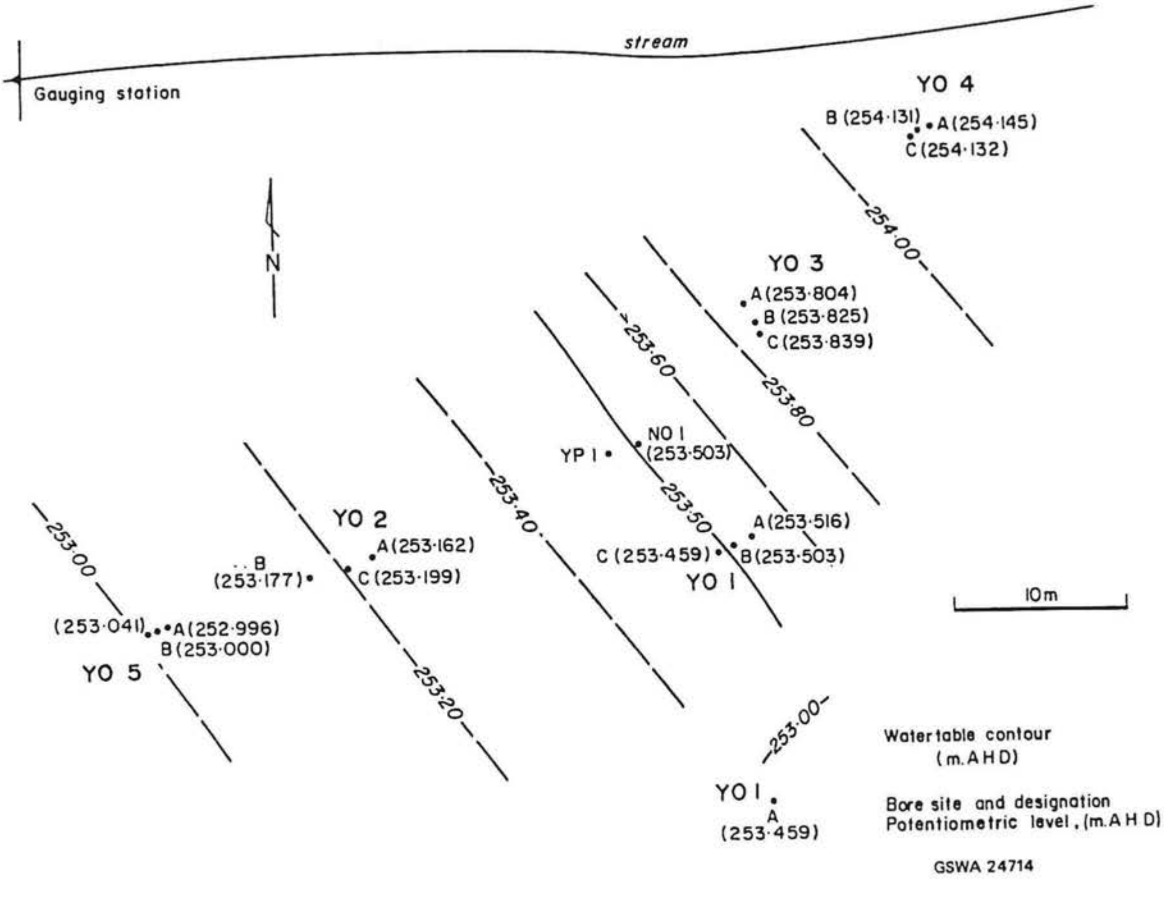

Figure 5 Water table contours before pumping

In section, the isopotentials (Fig. 6) suggest that groundwater flow is horizontal but with a slight downward component because of recharge.

CONSTANT-RATE TEST

ISOPOTENTIAL PATTERN

The pattern of the isopotentials after 1 000 and 10 000 minutes pumping are shown on Figures 7 and 8 respectively. The isopotentials at 1 000 minutes indicate a groundwater-flow divide between sites 2 and 5. At this time, the drawdown at site 5 was about 0.06 m, and this indicates that the isopotentials are affected by the pre-pumping groundwater gradient.

At 10 000 minutes, the flow pattern between sites 2 and 5 suggests that the aquifer is semi-confined. However, flow equations for drawdowns in an unconfined sloping aquifer are analogous to those for a semi-confined aquifer (Kruseman and de Ridder 1976), and the flow pattern at the end of pumping is partly modified by the pre-pumping water-table gradient.

The pattern of the isopotentials between site 4 and the production bore (YP1) is indicative of flow in an unconfined aquifer, with a downward component of flow. The regional inflow of groundwater has resulted in a steep gradient over this portion of the section.

TIME-DRAWDOWN RESPONSE

Log-log response

The log-log plot for the production bore (YP1 Fig.9) has a unit slope for the first 6 minutes of pumping, indicating bore storage. The curve then falls below the

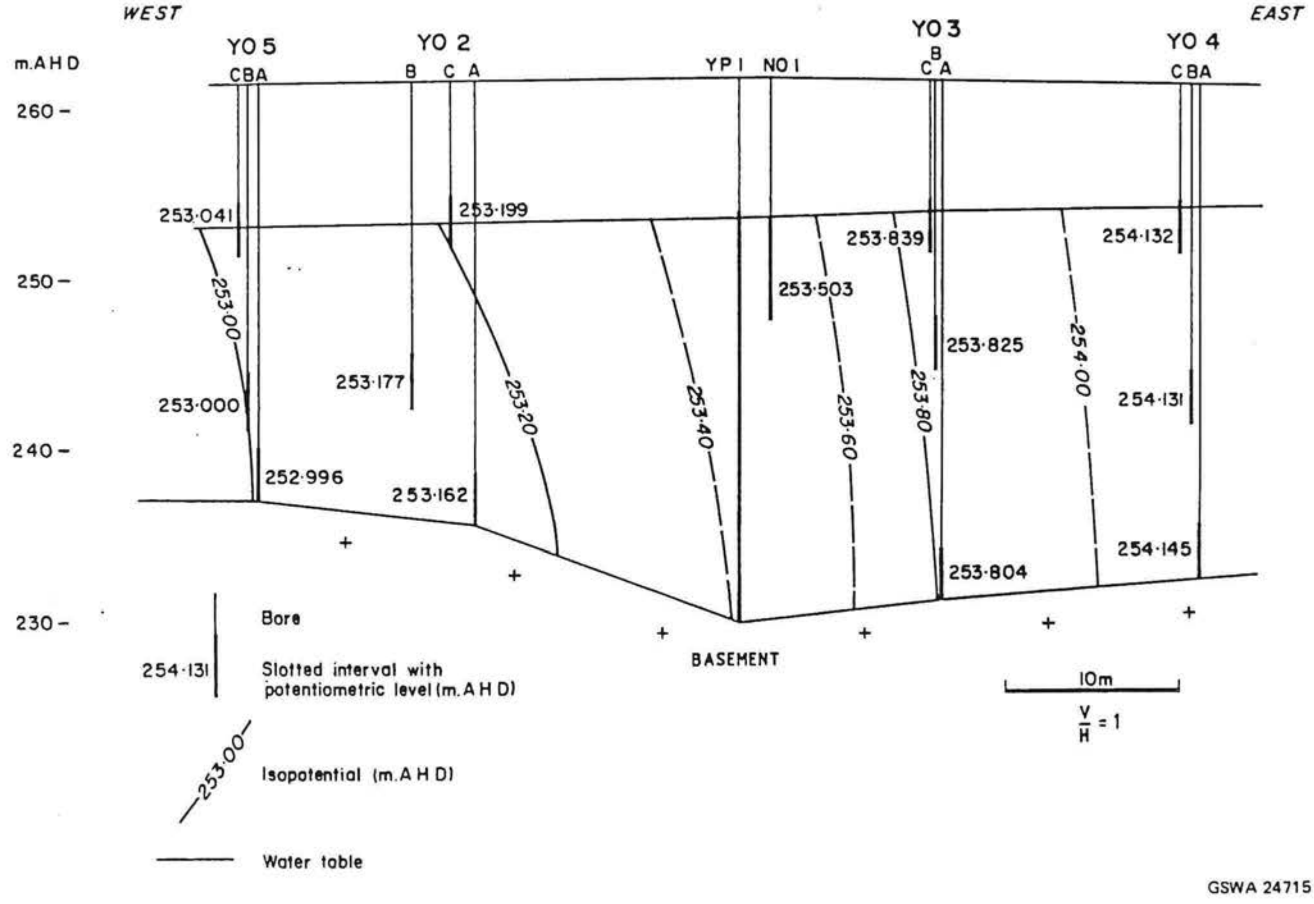

Figure 6 Isopotential pattern before pumping

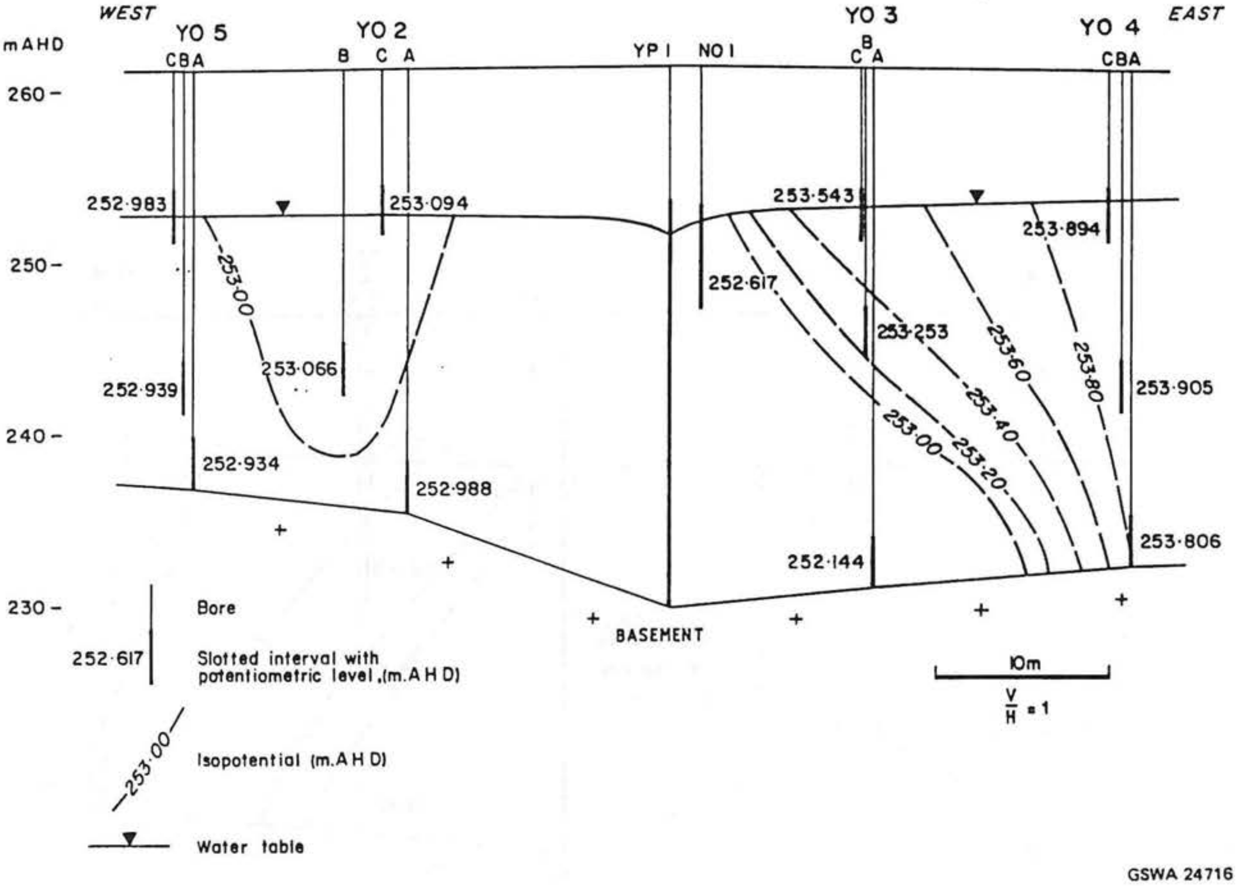

Figure 7 Isopotential pattern after 1,000 minutes of pumping

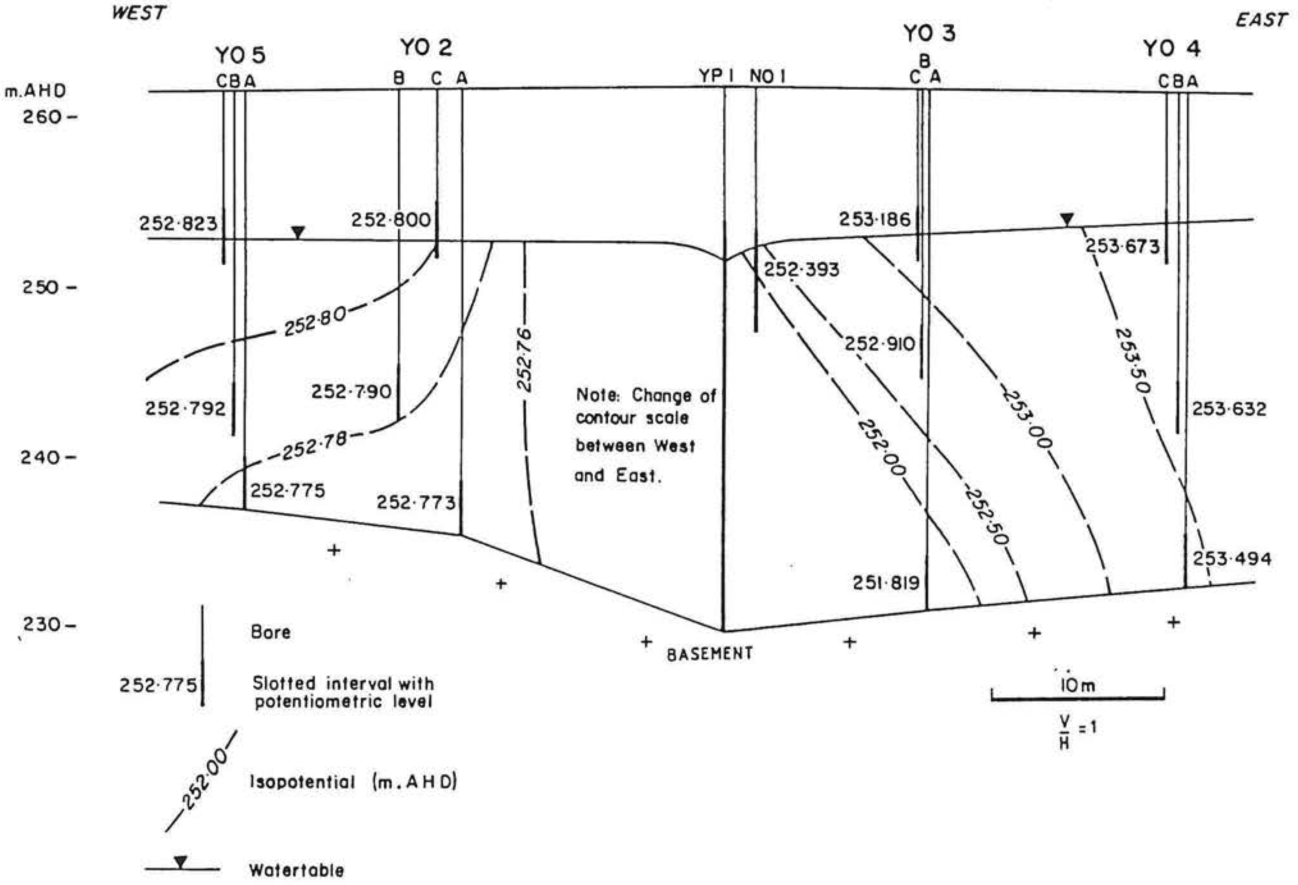

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Figure 8 Isopotential pattern after 10,000 minutes of pumping straight line, and flattens until about 20 minutes, when the curve steepens and drawdown continues until the end of pumping. This response was not obtained from drawdowns at the closest observation site, YO1, (about 9 m from YP1), but it was observed at site YO3 (about 11.5 m from YP1). At site YO3, the response occurs first and is greatest in the deep observation bore (YO3A), and is smallest and later in the shallowest observation bore (YO3C) (Fig. 9). The response probably indicates the presence of a zone of higher hydraulic conductivity between the production bore and site YO3. In the initial stages of pumping, water is drawn from this zone, then the rate of drawdown flattens as water leaks from the surrounding saprolite. The limited extent of this zone is indicated by the steepening of the time-drawdown response after 20 minutes pumping.

The time-drawdown plots of data from site 5 fall on a straight line. This could be due to merging of steep, early and late portions of the delayed yield curves of Boulton (1963), with no flat intermediate section. It could also be due to the presence of a major fissure within the saprolite. According to Jenkins and Prentice (1982), the drawdown responses from a number of observation bores in an aquifer containing a major fissure should fall on parallel straight lines when plotted against the square-root of time. However, the drawdown versus square-root time curves from bores 2A and 4B (Fig. 10) do not fall on straight lines which are parallel to that from site 5. This suggests that the flow is not controlled by a major fissure.

Drawdown data from the remaining bores form curved lines when plotted on log-log scale, and the drawdowns in the deepest observation bores are greater than in the shallowest bores. This is illustrated with data from bores at site YO1 (Fig. 11). These responses are characteristic of flow to a pumping bore in an unconfined aquifer.

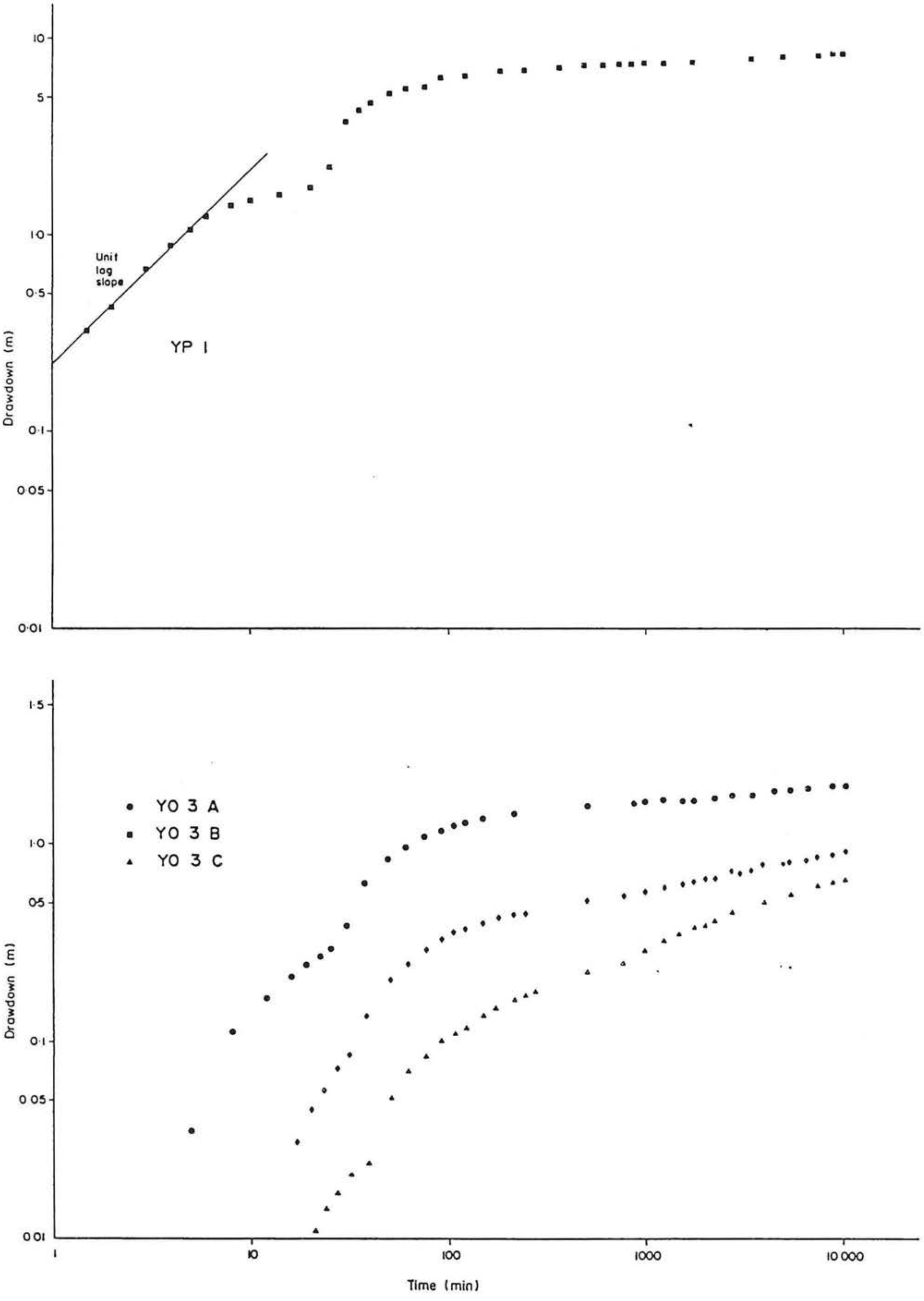

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Figure 9 Time-drawdown data from bores YP1, Y03A, Y03B, and Y03C

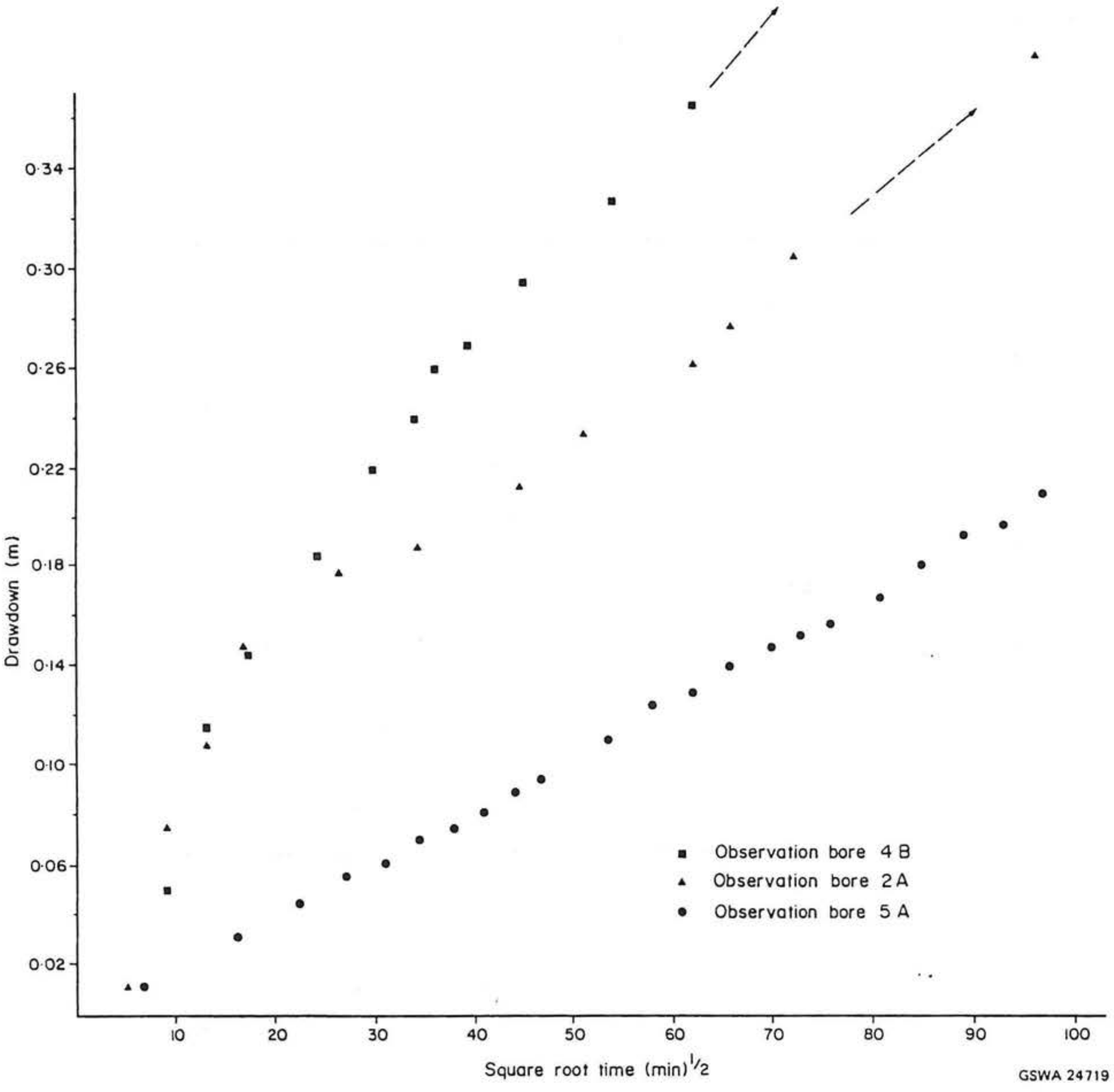

Figure 10 Plot of drawdown versus square root of time, bores 5A, 2A, and 4B

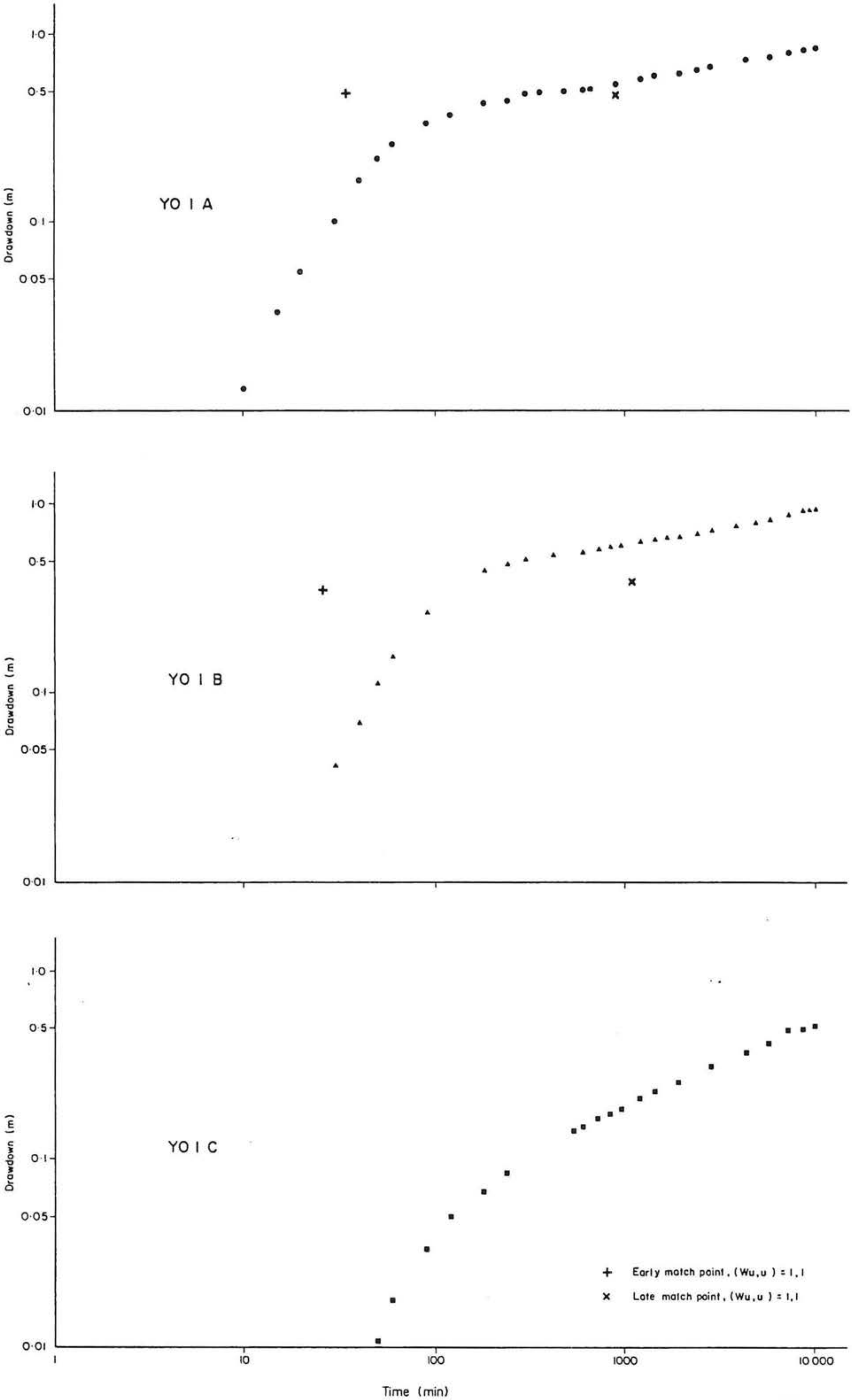

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Figure 11 Time-drawdown data from bores Y01A, Y01B and Y01C

Log-normal response

Two categories of the log-normal drawdown plots occur: in the first there are two parallel straight lines through early and late data with a connecting intermediate flatter section indicating leakage; and in the second, a straight line can only be plotted through the late data (Fig.12). The first straight line may not be observed because the leakage response occurs before the start time of the semi-log straight-line approximation of the Theis curve.

ANALYSIS

The aquifer within the saprolite is unconfined and responds to pumping as a double-porosity medium. The double-porosity model assumes that there is a uniform distribution of porous blocks and fissures throughout the aquifer (Gringarten 1982). In this geological environment, the fissures are probably coarse-grained, quartz-rich sections of the weathered basement, for example, relic quartz veins, pegmatitic bands, and coarse-grained granite. The permeability of these fissures has been increased by the dissolution and removal in suspension of weathering products by groundwater. The porous blocks are probably derived from weathering of fine-grained rock which contained an abundance of minerals that weathered to clay, for example feldspar and mica.

Boulton and Streltsova-Adams (1978) have derived equations for flow in an unconfined double-porosity aquifer. The resultant type-curves consist of an initial Theis curve that is due to the elastic storage response of the fissures followed by a deviation below the curve as the porous blocks contribute to flow. The curve then merges with a second Theis curve, which represents the storage properties of the fissures plus blocks. A further

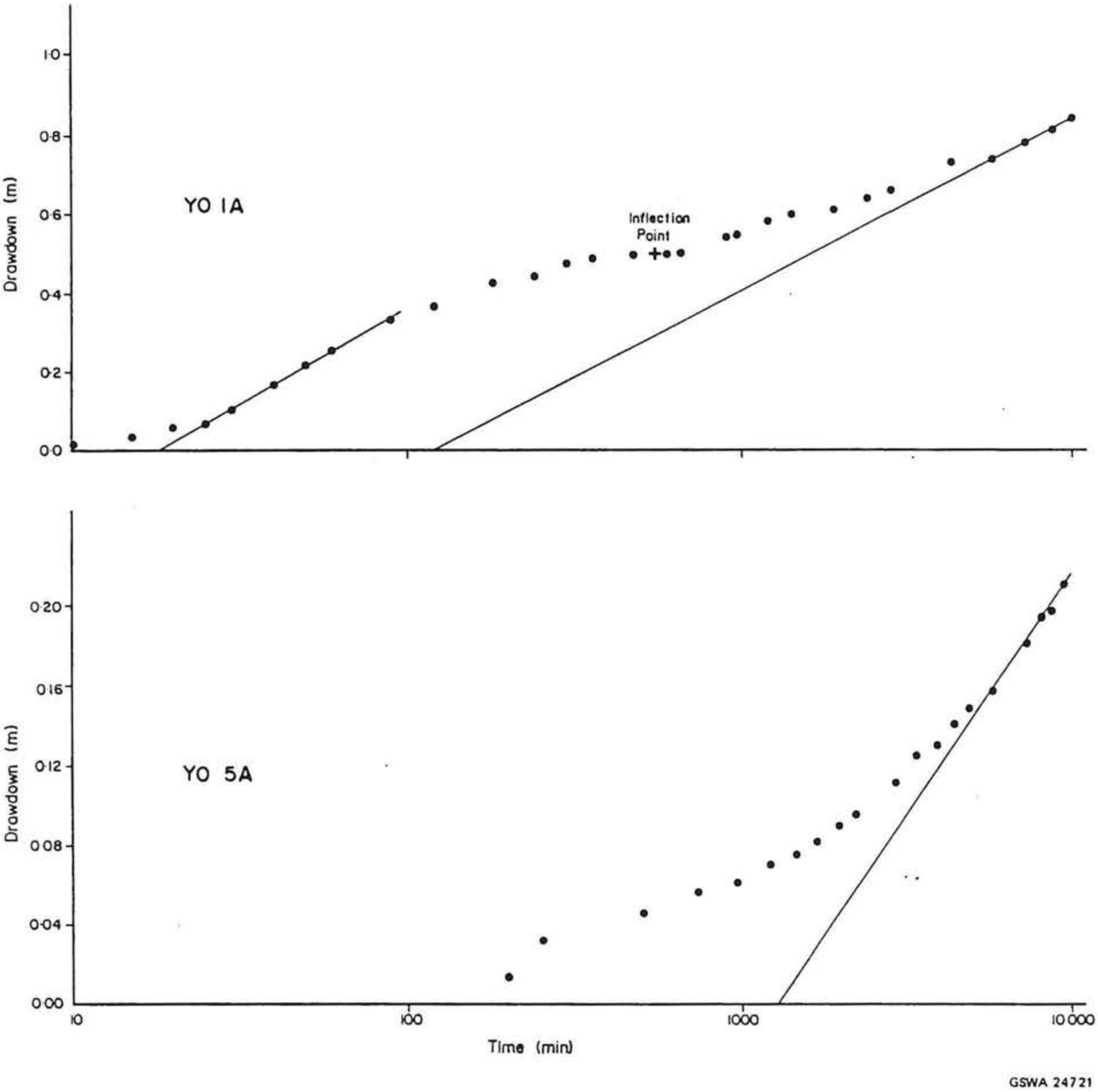

Figure 12 Time-drawdown data from bores YO5A and Y01A

deviation below this Theis curve occurs as a result of the vertical flow components which occur in an unconfined aquifer, and the final segments of the type curves merge with a third Theis curve which represents the storage properties of fissures plus blocks plus specific yield.

The three Theis curves were not observed in the time-drawdown data from this test. However, examples of type curves given by Boulton and Streltsova-Adams (1978) for observation bores at different distances from the production bore indicate that the fissure storage response becomes negligible as the distance from the production bore increases. The drawdown data then falls on type curves given by Boulton (1963).

The log-log time-drawdown data have been analyzed using the model of Boulton (1963). The method has been extended for calculation of vertical hydraulic conductivity, and straight-line analysis of the log-normal response, as described by Neuman (1975). The values of transmissivity are for the fissures, which transmit water to the production bore from storage within the fissures and blocks. As the dimensions of the fissures and blocks are unknown, the values of horizontal hydraulic conductivity have been calculated by assuming a porous medium and dividing the fissure transmissivity by the saturated thickness before pumping. Vertical hydraulic conductivities were calculated using this value.

Parameters derived using the curve-matching method are shown in Table 2, and results from the straight-line analyses are in Table 3. The variation between early and late estimates of transmissivity from each bore was less than 10%, and average values are shown in Tables 2 and 3.

TABLE 2. HYDRAULIC PARAMETERS BY CURVE MATCHING

Bore	T (m^2/d)	S_2	S_3	r/B	β	Kx (m/d)	Kz (m/d)
YO1A	4.4	.003	0.15	0.6	0.10	0.22	0.10
1B	3.3	.004	0.10	0.8	0.18	0.17	0.15
YO2A	8.6	.005	0.08	1.0	0.30	0.43	0.22
2B	8.6	.006	0.06	1.5	0.72	0.43	0.35
2C	7.2	.001	0.05	2.0	1.30	0.36	0.68
YO4A	5.7	.001	0.012	0.8	0.18	0.29	0.03
4B	8.2	.002	0.014	0.8	0.18	0.41	0.04
4C	8.8	.002	0.014	0.8	0.18	0.44	0.05
YO5(A-C)(a)	9.5	-	0.05	2.0	1.30	0.48	0.31

(a) Curves for YO5A-5C are essentially identical, only one set of parameters have been calculated.

T - transmissivity of fissures. S_2 - storage of fissures plus blocks. S_3 - S_2 plus specific yield. r/B - parameter of Boulton curves. β - parameter of Neuman curves, derived from r/B. Kx - horizontal hydraulic conductivity. Kz - vertical hydraulic conductivity.

TABLE 3. HYDRAULIC PARAMETERS BY STRAIGHT LINE METHOD

Bore	T (m^3/d)	S_2	S_3	Kx (m/d)	Kz (m/d)
NO1	14.4	-	0.005	0.72	-
YO1A	7.8	0.002	0.017	0.39	0.05
1B	6.9	0.004	0.016	0.35	0.003
1C	8.5	-	0.094	0.43	-
YO2A	12.4	0.007	0.041	0.62	0.17
2B	12.3	-	0.044	0.61	-
2C	11.7	-	0.053	0.58	-
YO3A	8.9	-	-	0.45	-
3B	9.1	0.002	0.006	0.46	0.001
3C	9.0	-	0.03	0.45	-
YO4A	10.1	0.001	0.005	0.51	0.02
4B	10.4	0.002	0.009	0.52	0.04
4C	10.6	0.002	0.007	0.53	0.07
YO5(A-C)	15.0	-	0.04	0.75	0.36

T - transmissivity of fissures. S_2 - storage of fissures plus blocks. S_3 - S_2 plus specific yield.
Kx - horizontal hydraulic conductivity. Kz - vertical hydraulic conductivity.

Because of the absence of a flat, intermediate section on the time-drawdown curves, care must be taken when matching early and late data to type curves and when fitting a horizontal line to the inflection point of the intermediate section of the log-normal plots. When the first straight line does not occur on the log-normal plots, estimates of parameters from early and intermediate data cannot be made using the straight line method.

The methods of analysis for unconfined aquifers are applicable to observation bores which fully penetrate the aquifer. The observation bores used in this test partially penetrate the aquifer; however, the small variation in values of transmissivity for bores at each site suggest that errors due to partial penetration are small.

The effect of the pre-pumping slope of the water table on drawdowns has not been evaluated. This is because the method requires an estimation of the maximum drawdown (Kruseman and de Ridder 1976) which was not possible from the test data.

Drawdown data from the production bore have not been analyzed because of the unknown effects of well losses. Analysis of data from bores at site YO3 and bore NO1 gave unreliable estimates of transmissivity using the curve-matching method because it was not possible to match early and late data to give a reasonable agreement between estimates of transmissivity. Because of the rapid fissure-flow response, a late-time storage estimate of about 10^{-5} for bore YO3A is incorrect.

EVALUATION OF RESULTS

The range in hydraulic parameters derived from this pumping test, although quite small, reflect the heterogeneity of the system and the uncertainties in the methods of analysis. However, the values shown in Tables 2 and 3 are considered to be representative of the aquifer. The arithmetic and geometric means of hydraulic parameters are shown in Table 4. For each analysis method, the difference between arithmetic and geometric means is small, and the greatest range occurs in values of vertical hydraulic conductivity.

TABLE 4. ARITHMETIC AND GEOMETRIC MEAN·VALUES OF HYDRAULIC PARAMETERS FROM PUMPING TEST

Matching method	T (m^2/d)	S_2	S_3	Kx (m/d)	Kz (m/d)
Curve:					
Arithmetic mean	7.6	0.003	0.057	0.38	0.23
Geometric mean	7.2	0.002	0.044	0.36	0.16
Straight line:					
Arithmetic mean	11.1	0.003	0.030	0.56	0.14
Geometric mean	10.8	0.002	0.020	0.54	0.05
Best estimate	8.0	0.002	0.03	0.4	0.1

T - transmissivity of fissures. S_2 - storage of fissures plus blocks. S_3 - S_2 plus specific yield. Kx - horizontal hydraulic conductivity. Kz - vertical hydraulic conductivity.

The mean values of S_2 from the curve-matching and straight-line methods are similar. For the straight-line method, the mean values of transmissivity are greater than, and mean values of S_3 and vertical hydraulic conductivity smaller than, for the curve-matching method. By using the curve-matching method, an underestimate of transmissivity and overestimate of S_3 may occur if the intermediate data are incorrectly matched to a r/B curve which has a value that is too high. This would also result in an overestimate of β and consequently of vertical hydraulic conductivity. For the straight line method, the intermediate portion of the time-drawdown data gradually merges with the late, straight-line approximation of the Theis curve. It is possible to fit a straight line through this section of the intermediate portion of the curves, particularly where observation bores are located at a large distance from the production bore. The effect of this would be to overestimate transmissivity and underestimate S_3. Because of these factors, both methods should be used to evaluate the data from pumping tests which are analyzed using the unconfined aquifer models. Also, the use of both methods may increase the number of parameters which can be evaluated.

SLUG TESTING

The values of hydraulic conductivity derived from air-compression slug tests are shown in Table 5. They have been calculated using the method of Hvorslev (1951). In general, the values from the slug tests are less than those from the pumping-test. This may be due to:

(a) small volume of aquifer which is slug-tested

(b) number of bores too small to give a representative average of hydraulic conductivity,

(c) observation bores not fully developed

The smaller values derived from the slug-testing method are probably due to insufficient bore development. In general, bores in material of higher hydraulic conductivity were more readily developed than bores in material of lower hydraulic conductivity.

TABLE 5. VALUES OF HYDRAULIC CONDUCTIVITY FROM PUMPING TEST AND SLUG TESTS

Bore	Hydraulic Conductivity		
	Curve match (m/d)	Straight line (m/d)	Slug test (m/d)
YO1A	0.22	0.39	0.10
1B	0.17	0.35	0.01
YO2A	0.43	0.62	0.11
2B	0.43	0.61	0.10
YO3A	-	0.45	0.26
3B	-	0.46	0.19
YO5A	0.48	0.75	0.61
5B	0.48	0.75	0.61

The arithmetic and geometric means of hydraulic conductivity from slug tests on 27 bores in the Yarragil North catchment (including the pumping-test site), were 0.21 and 0.14 m/d, respectively (Thorpe and Martin 1988). This is similar to the means of 0.25 and 0.15 m/d from slug tests at the pumping test site, and may indicate that the slug tests provide a reasonable estimate of hydraulic conductivity but underestimate the catchment average by 50% to 100%.

CONCLUSIONS

1. The hydraulic responses observed during the pumping test indicate that the saprolite responds to pumping as an unconfined aquifer with a double porosity medium. Location of observation bores at distances greater than about one half the saturated thickness (10 m) minimized the effect resulting from the elastic storage of the fissures. This facilitated evaluation using unconfined aquifer methods.

2. The analysis of the pumping test has provided estimates of the hydraulic parameters of the aquifer. The best estimates from two methods of analysis are:

Transmissivity (T)	8.0	m^2/d
Storage of fissures plus blocks (S_2)	0.002	
Storage of fissures plus blocks plus specific yield (S_3)	0.03	
Horizontal hydraulic conductivity (Kx)	0.4	m/d
Vertical hydraulic conductivity (Ky)	0.1	m/d

3. Air-compression slug-test analyses provided reasonable estimates of hydraulic conductivity. The average values from bores at the test site were 50% to 100% less than the average values calculated from the pumping test.

4. For slug-test results to be satisfactory, bores need to be adequately developed, and this can be determined by conducting slug test at different stages of development.

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NOTATION

R.L.	reduced level	m
G.L.	ground level	m
T.O.C.	top of casing	m
A.H.D.	Australian Height Datum	m
T	transmissivity of fissures	m^2/d
S_2	Storage of fissures plus blocks	
S_3	Storage of fissures plus blocks plus specific yield	
r/B	parameter of Boulton curves	
β	parameter of Neuman curves, derived from r/B	
Kx	Horizontal hydraulic conductivity	m/d
Kz	Vertical hydraulic conductivity	m/d
C	Values derived using curve matching method	
S	Values derived using straight line method	

Subscripts

A	arithmetic mean
G	geometric mean

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