GEOLOGICAL SURVEY OF WESTERN AUSTRALIA

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HYDROGEOLOGY OF THE WESTERN FORTESCUE VALLEY PILBARA REGION WESTERN AUSTRALIA

DEPARTMENT OF MINES
WESTERN AUSTRALIA

Geological Survey Record 1986/8

HYDROGEOLOGY OF THE
WESTERN FORTESCUE VALLEY
PILBARA REGION
WESTERN AUSTRALIA

by

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Western Australia
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CONTENTS

PLATES

FIGURES

TABLES

APPENDICES

ABSTRACT

Exploratory drilling to prove groundwater reserves for the West Pilbara Water Supply has been carried out in the Fortescue Valley during the period 1968 to 1982. Exploratory bores have been drilled at 97 sites and a limited number of pumping tests were carried out.

In 1984 about 10 Mm^3 was pumped from twelve bores to supply Karratha, Dampier, and Wickham. However, from 1985 onwards conjunctive use of this bore water with the water supplies of the Harding Dam will substantially reduce groundwater abstraction.

The western Fortescue Valley contains a sequence of alluvial, colluvial, and lacustrine sediments which range in age from Cretaceous to Recent. These sediments were deposited in a broad valley that cut into Early Proterozoic bedrock.

The aquifers are unconsolidated alluvium, conglomerate, dolomite and pisolite, which are all interconnected to form a single complex flow system that is generally unconfined, although confined conditions are also locally present. Of these aquifers, the Millstream Dolomite is the most extensive and highly productive.

Recharge takes place by infiltration from flooding in the Fortescue River, from creeks into the piedmont slopes flanking the plain, and directly from rainfall. Flood recharge is the most important factor.

Natural discharge from the system is from springs at Millstream with an estimated mean natural discharge of about 15×10^6 m^3 a^{-1}. A small amount also discharges to the Fortescue and Robe Rivers through alluvium and fractured bedrock.

Total groundwater storage is estimated to be in the region of 1 700 x 10^6 m^3 with a salinity range of 300-1 500 mg L^{-1}. Areas of significantly lower salinity and hardness than the present water supply borefield have been identified by the drilling.

Spring flow at Millstream, which supports permanent pools and an extensive tract of vegetation, has been much reduced since abstraction for water supply began, and supplementation of spring flow from boreholes is now carried out.

INTRODUCTION

LOCATION AND LAND USE

The area of investigation occupies the westernmost 120 km of the broad Fortescue Valley, which extends for 450 km between the Hamersley and Chichester Ranges in the Pilbara region of Western Australia (Fig. 1).

Parts of the Millstream, Yalleen, and Coolawanyah pastoral leases lie within the area; land use is predominantly cattle grazing.

In 1982 the Millstream Lease was acquired by the State Government in order to obtain tenure of the land overlying the aquifer used for the West Pilbara Water Supply Scheme, and to enable expansion of the existing Millstream National Park so that the park would encompass the whole of the aquifer-fed pool system of the Fortescue River.

PURPOSE AND SCOPE

The area has been explored by drilling and test-pumping since 1968, in order to define the hydrogeology and potential yield of the flow-system which supplies the Millstream borefield.

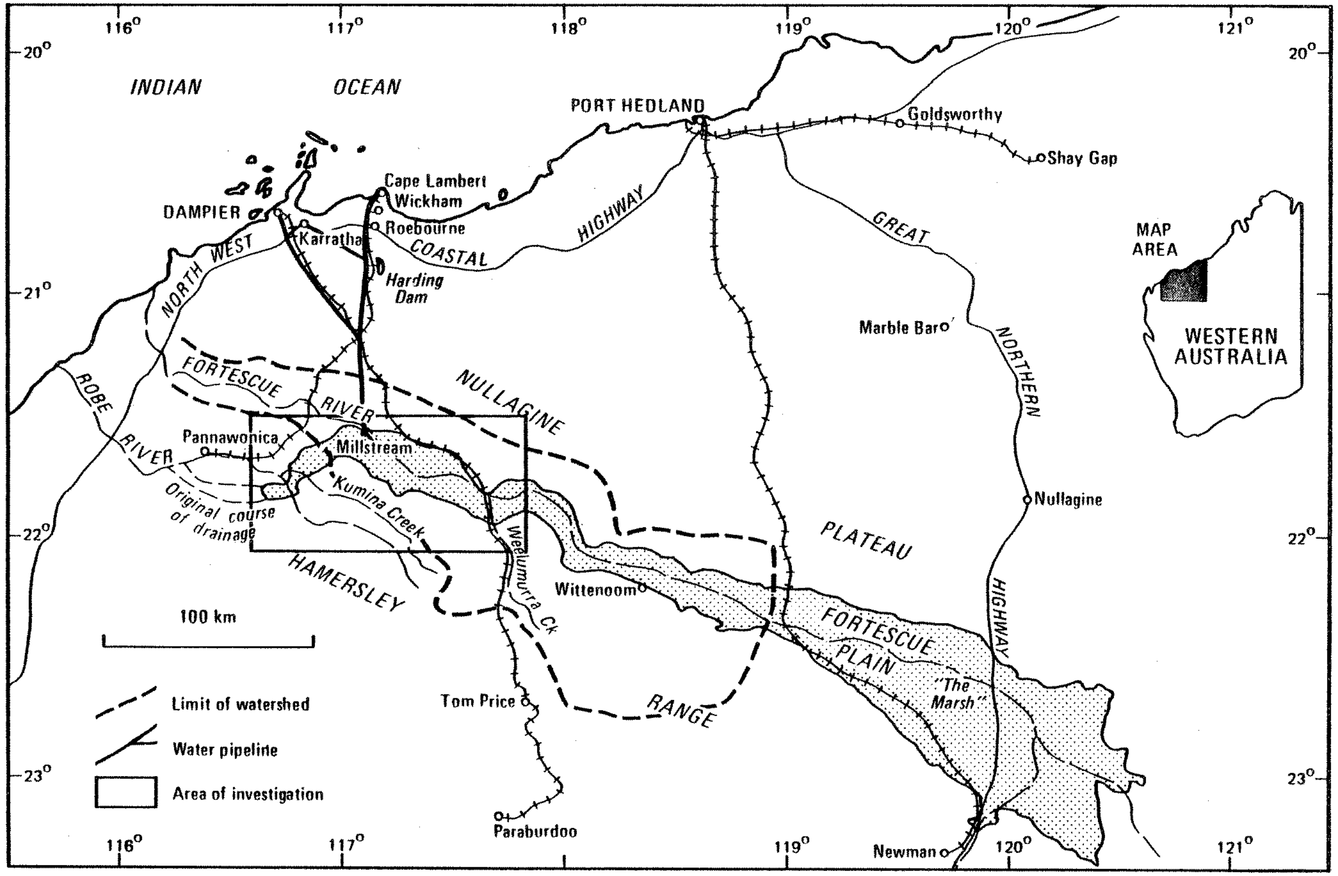

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Figure 1. Locality map.

In this report the work carried out by the Mines Department and the Public Works Department (PWD) between 1971 and 1982 is described, and a hydrogeological synthesis is presented for the entire area.

PREVIOUS WORK

Twenty-five exploratory bores were drilled in 1968 by the PWD, using rotary-percussion and cable-tool rigs, and fourteen bores test pumped (Davidson, 1969). In 1969 and 1971 twelve production bores were drilled and test pumped by the PWD for the West Pilbara Water Supply (Forth, 1971; Sadler and Parker, 1974).

Davidson (1972) outlined the possibilities of artificial recharge, and Balleau (1973) briefly described the groundwater in the Fortescue River Valley, including the Millstream area.

In 1975 five fully cored boreholes were drilled by the PWD in an investigation into specific yield of the Millstream Dolomite aquifer (Barnett and others 1977).

Barnett (1981) has described in detail the stratigraphy of the Cainozoic sediments in the Fortescue Valley, which is based on the drilling carried out up to 1980.

In order to relate the discharge at the springs near Millstream to observed variations in water table levels, computer models have been developed for the PWD (MacDonald, Wagner, and Priddle Pty Ltd, 1975; Snowy Mountains Engineering Corporation, 1982).

METHODS OF INVESTIGATION

Drilling

Details of bores drilled by the Mines Department are summarised in Appendix 1; two boreholes (Nos 1/76 and 2/76) that were drilled on contract for PWD by Weber Drilling are also included.

Drilling was carried out by conventional rotary methods and by downhole hammer. Bores 9, 10, and 11 were diamond drilled to take cores of bedrock. Air was the main circulatory medium used, sometimes with the addition of foam. Mud, mainly bentonite, was also used in later drilling to overcome collapsing surface gravels and loss of circulation in cavernous strata.

Most bores were completed with 105 mm i.d. steel casing, which were slotted over selected intervals. Some of the bores were screened. Boreheads were completed with cement blocks, and the bores left capped and locked.

Drilling progress was generally slow, partly because of collapsing strata and loss of circulation, but also because of equipment breakdowns.

Pumping Tests

Pumping tests were carried out on fourteen of the exploratory bores that were drilled into the Millstream Dolomite in 1968 (Davidson, 1969) and on the 12 production bores that were drilled subsequently in 1969 and 1971. The dolomite proved to be so transmissive that even at pumping rates of up to 5 545 m^3d^{-1} drawdowns were generally less than 0.5 m, and in some cases were too small to be measured. No estimate of specific yield could therefore be made; assessment of transmissivity was also impossible, apart from the relative observation that the dolomite is very highly transmissive.

Bores 9 and 10, which tap the Robe Pisolite and the Wittenoom Dolomite respectively, were pump tested in 1972.

Five bores in the Weelumurra Creek area were tested in 1975, with a further two in 1982. This testing indicated generally low transmissivities in the Kumina Conglomerate, despite reports of high yields from bores in the same area that were drilled during construction of the Tom Price to Dampier railway.

A programme of drilling and testing five bores into the Millstream Dolomite was carried out in 1975. These bores were fully cored, and specific yield was assessed by downhole steroscopic photography coupled with laboratory measurements. Reliable estimates of the distribution of specific yield with depth were obtained at each site (Barnet and others, 1977).

Attempts were also made to measure the transmissivity of the dolomite by pressure testing small intervals that were isolated by means of inflatable packers. However, this was unsuccessful, as even small intervals (0.3 m) were commonly too transmissive to permit any measurable pressure head changes to be induced at the maximum pump capacity available (720 m^3d^{-1}).

Bores 1/76 and 2/76, which are slotted over the lower part of the Millstream Dolomite and the Robe Pisolite, were pump tested in 1976.

All pumping tests undertaken up to and including 1976 were carried out using conventional equipment; water-levels were measured with air-gauge and electric probe, and discharge with orifice plate and piezometer tube.

In 1978 and 1979 all bores in the western part of the area were tested - except 4 bores (6C, 47A, 63A and 68A) that could not sustain a discharge rate of 1 L sec^{-1} (86 m^3 day^{-1}). Water levels, discharge rates and barometric pressure were measured using pressure transducers, and the results recorded continuously by means of electronic chart recorders. In 1978 a number of technical and procedural problems occurred with this novel equipment, and the quality of the results was often poor. Operational methods and equipment were modified in 1979, and the problems experienced in 1978 were largely overcome.

The general pumping-test programme used on each bore prior to 1978 was a step-drawdown test followed by a constant-rate test. No recovery period was allowed after each step of the step-drawdown test.

In 1978 the programme was modified to include a step-drawdown test before and after a constant-rate test. Step-drawdown tests comprised four 30-minute steps of pumping at about 15%, 30%, 45% and 60% of maximum bore yield or maximum pump yield, whichever was the lesser. Time for full recovery was allowed after each step. Constant-rate tests at 75% of maximum bore or pump capacity ranged in duration from 4 to 12 hours, and were followed by a recovery period of equivalent length. The first step-drawdown test on each bore was regarded as the final stage of development; the second was used to determine bore efficiency. Aquifer parameters were derived from constant rate test results.

All pumping test results have been analysed by standard curve-matching methods - using Boulton delayed-yield curves. When an early-time artesian response occurred, the Theis curve has been used. When results cannot be matched to type-curves, an estimate of transmissivity has been made using early-time specific capacity after Walton (1970). Corrections for partial penetration, anisotropy, barometric pressure, and dewatering have been made where appropriate and significant.

The results are tabulated in Appendix 2, and discussed in relation to individual formations later in this report.

Geophysics

Gamma ray logs have been run on all bores as an aid to stratigraphic correlation.

Seismic refraction surveys were carried out in three separate areas to assist in the interpretation of the bedrock configuration (Nowak, 1976;Rowston, 1978). Results were generally equivocal because of velocity inversion or energy attenuation in loose and dry superficial strata.

Monitoring

The PWD measure water levels in the exploratory-observation bores at two- to six-monthly intervals. Continuous water level recorders are installed on five bores with tipping-bucket rain gauges at 13A, 56A, and W4C. Rainfall is also measured at Fish Pool and Gregory Gorge (Fig. 2).

ENVIRONMENT

CLIMATE

The climate is arid, and daily summer temperatures usually exceed 35°C.

Rainfall is unreliable and mainly cyclonic, so that the monthly and annual totals vary widely. Most rain falls in summer from December to April. Mean annual rainfall is 356 mm, with a median value of 332 mm.

The average annual evaporation at Millstream is about 2 500 mm.

LANDFORMS

The Fortescue Plain (Fig. 2) is bounded to the south by the steep erosion scarp which forms the edge of the Hamersley Range and to the north by the gentle southern slopes of the Chichester Range.

The plain ranges in width from 10 to 25 km and slopes gently from an elevation of about 345 m at Weelumurra Creek to about 315 m at the Robe-Fortescue watershed, 90 km to the west. Coalescing alluvial fans form a 5 to 10 km wide piedmont slope which flanks the Hamersley Range. The western edge of the plain has been dissected by the Robe River and its tributaries, and incised by the present course of the Fortescue River with its narrow flood plain up to 1 km wide.

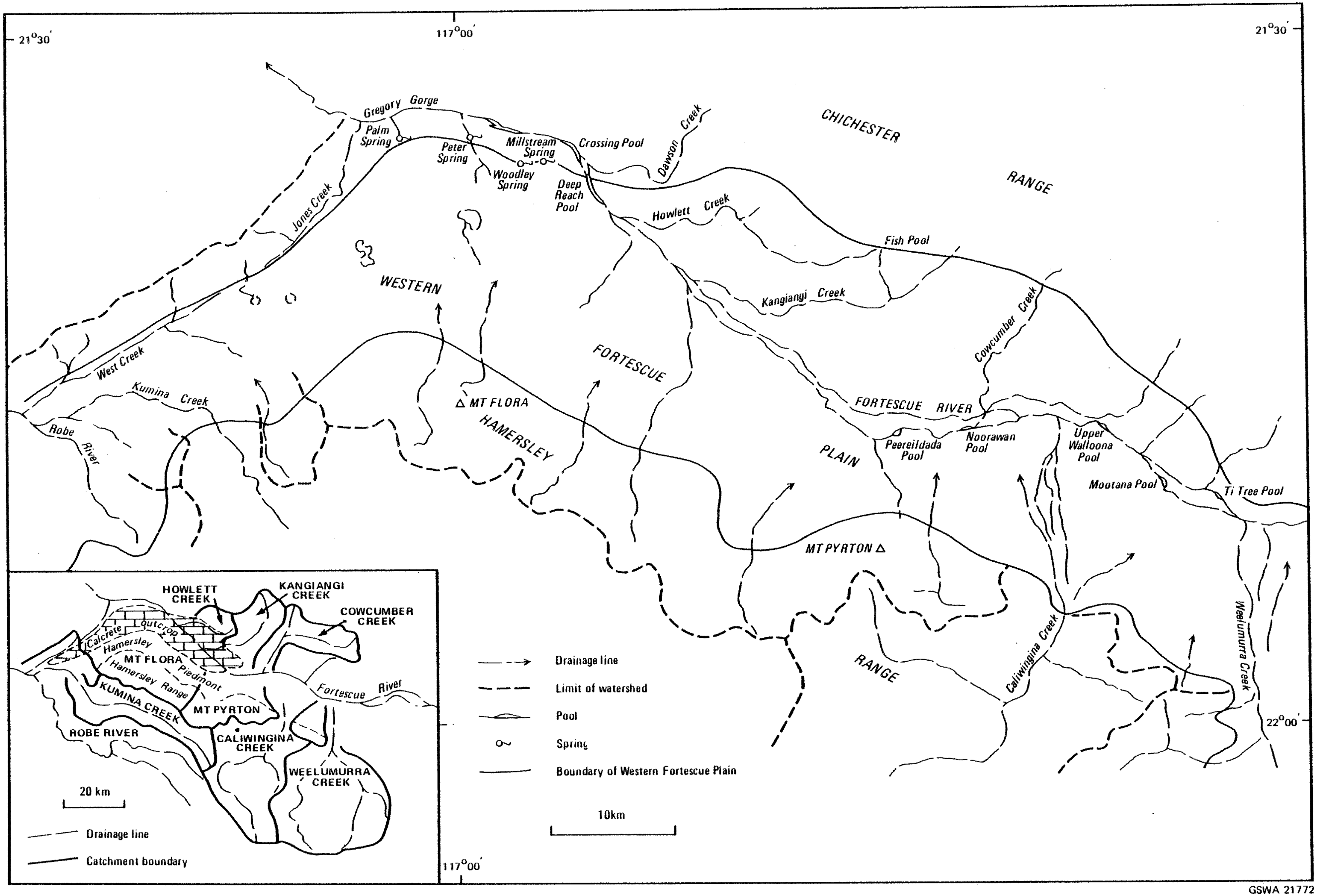

Figure 2. Physiography and drainage of the western Fortescue Valley.

DRAINAGE

The Fortescue River drains an area of approximately 13 00 km^2 upstream from Millstream, excluding the upper Fortescue which dissipates into "the Marsh" (Fig. 1). The river follows a braided course along the plain as far west as Millstream where the river diverts to the north-west into a series of gorges cut into Proterozoic bedrock.

Several pools, up to 14 m deep, have formed near Millstream where the river course has become constricted and infilled with alluvium. The pools are permanent and are maintained by springs from the dolomite aquifer beneath the plain. The continuing erosion and deposition between the pools, which are constantly changing the morphology, has been commented on by Dames and Moore (1977) and Barnett (1979).

Creeks that drain the Hamersley Ranges mainly dissipate into alluvial fans before reaching the Fortescue River, whereas the northern tributaries, which drain the Chichester Range, follow defined channels and join the Fortescue River (Fig. 2).

The plain just west of Millstream is an area of internal drainage that forms the watershed between the Robe and Fortescue Rivers. The Robe and its tributaries, and also the southern tributaries of the Fortescue are actively eroding the margin of the plain.

The areas of the major catchments are given on Table 1.

TABLE 1. CATCHMENT AREAS

Catchment	Area (km^2)
Dawson Creek	220
Howlett Creek	90
Kangiangi Creek	280
Cowcumber Creek	340
North eastern tributaries	280
Weelumurra Creek	1 120
Caliwingina Creek	990
Hamersley Range	470
Hamersley Piedmont	620
Calcrete outcrop	540
Kumina Creek	530

Runoff

Flow in the Fortescue River usually takes place in the December-March period as a result of cyclonic rainfall in the catchment. Localized runoff also occurs in summer due to thunderstorm activity.

Runoff in the Fortescue River has been gauged at Gregory Gorge since 1968 by the PWD. Annual flows between 1968 and 1980 ranged from a minimum of 2.8×10^6 m^3 in 1968-69 (September - August) to a maximum of $1\ 238 \times 10^6$ m^3 in 1975-76, which was due almost entirely to the flood that followed the passage of Cyclone Joan in December 1975. These large floods are infrequent; computer modelling (based on the eight years of flow record to 1975) indicates that only one flood larger than that caused by Cyclone Joan would have occurred in the previous 70 years for which rainfall records are available.

The salinity at Gregory Gorge between 1973 and 1980 ranged from a minimum of 93 mg L^{-1} to a maximum of 3 045 mg L^{-1} with a flow weighted average of 497 mg L^{-1} (PWD, unpublished data). The flow weighted average for the year 1975-76, dominated by the Cyclone Joan flood, was

136 mg L^{-1}; this demonstrates that the larger flows have the lowest salinity water. The higher salinities in years of no flooding are due to evaporation from aquifer derived water; the spring flow into Deep Reach Pool having a salinity of about 1 200 mg L^{-1}.

VEGETATION

The vegetation of the area has been described in detail by Dames and Moore (1975). The Fortescue Plain and the ranges either side are covered by spinifex and annual grasses with scattered eucalypt and acacia thickets. Woodland and low open forest occupy the Fortescue River channel and its narrow flood plain.

The vegetation along the Fortescue River between Deep Reach Pool and Gregory Gorge forms the largest area of woodland in the Pilbara. A number of ecosystems are unique to the area, including the sedgeland fed from Millstream spring and the woodland of Millstream Palms. All this vegetation is dependent on spring flow and, to a lesser extent, runoff. It is estimated (H. Ventriss, pers. comm.) that the potential annual water requirements of the vegetation is 11.9 x 10^6 m^3.

Although by the end of 1982 spring flow along the northern margin of the aquifer west of Millstream had ceased, palm communities are able to survive on shallow groundwater in the bedrock.

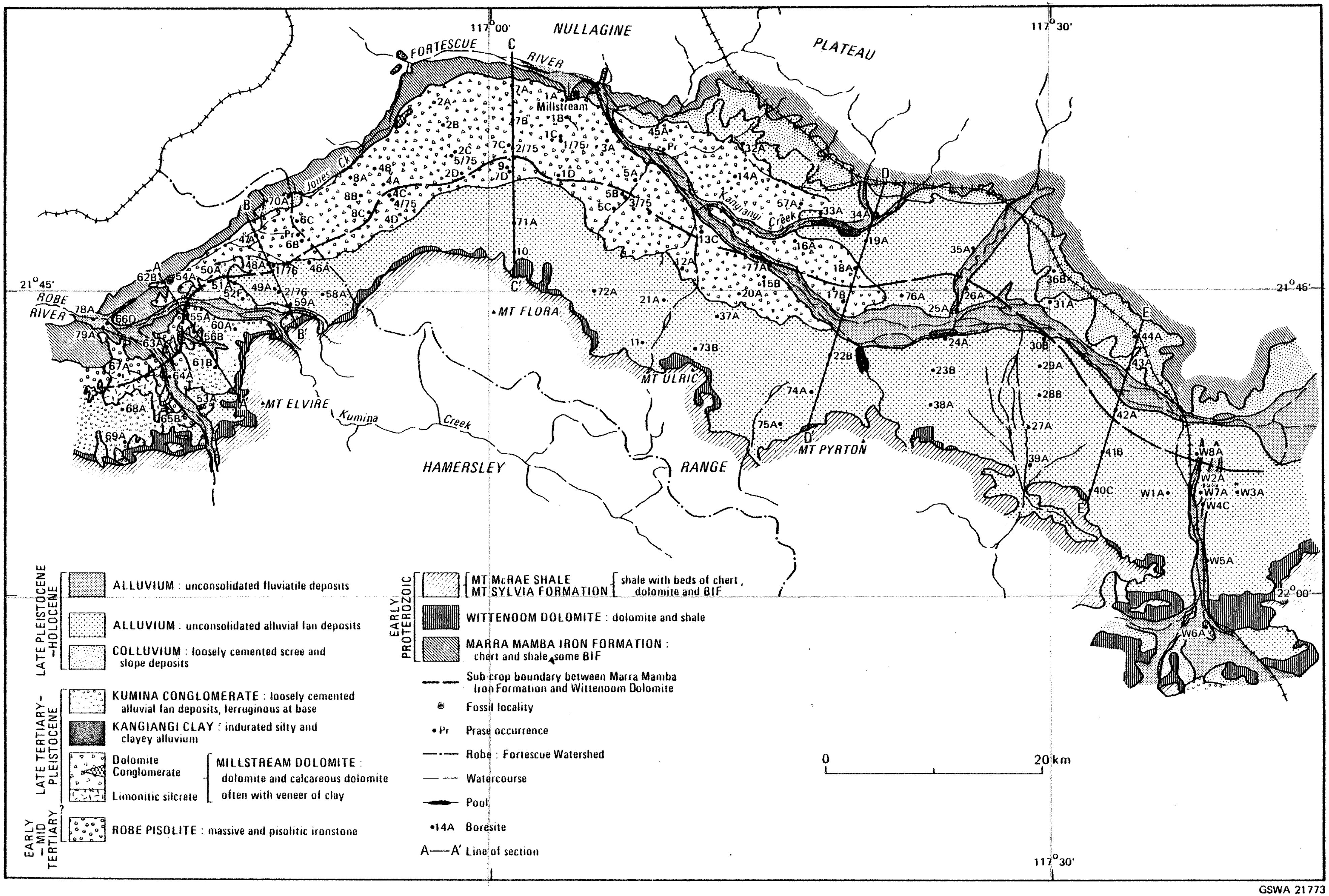

Figure 3. Surface geology and bore locations.

GEOLOGY

GENERAL

The western Fortescue Valley contains a complex sequence of alluvial, colluvial and lacustrine sediments, that range in age from Cretaceous to Holocene. These sediments have been deposited in a valley incised into rocks of the Early Proterozoic Hamersley Basin, which form the bedrock for the later units. The valley follows the strike of the less resistant Wittenoom Dolomite.

The geology and geological history of the post-Proterozoic sediments have been discussed in detail by Barnett (1981). The geology is described in this report only in sufficient detail to outline the geological framework in which the groundwater occurs. There are some differences in interpretation due to information from more recent drilling. The surface geology of the area was mapped by Kriewalt and Ryan (1967), and Williams (1968).

The stratigraphic sequence is given in Table 2. Surface geology is shown on Figure 3, and structure contours on the bedrock and Cainozoic formations are shown on Figure 4. Diagrammatic cross-sections showing the relationships of the formations are given in Figures 5 and 6, and Plate 1.

TABLE 2: STRATIGRAPHIC SEQUENCE IN THE WESTERN FORTESCUE VALLEY

Age	Stratigraphic Unit	Maximum recorded thickness (m)	Lithology and remarks
Late Pleistocene to Holocene	Alluvium	15	Alluvium along present water-courses
	Calcareous silt	5	Grey calcareous silt with tufa
	Residual clay	3	Residual clay overlaying Millstream Dolomite
	Alluvium	3	Alluvial fan deposits, unconsolidated
	Colluvium	5	Colluvium
Middle Tertiary to Pleistocene	Kumina Conglomerate	90	Boulders, cobbles, gravel and sand in matrix of silty clay. Commonly ferruginous at base. Consolidated.
	Kangiangi Clay	47	Indurated well-bedded silty clay with sand and gravel beds. Ferruginous at base.
	Millstream Dolomite	50	Dolomite and calcareous dolomite with layers of silcrete, clay and gravel.
Early-Middle Tertiary	Weelumurra Beds (a)	34	Dark grey pyritic shale
	Robe Pisolite (a)	33	Massive and pisolitic ironstone, with clayey layers
Tertiary or Cretaceous?	Undifferentiated	75	Conglomerate and clay
Early Cretaceous	Yarraloola Conglomerate	36	Fluviatile conglomerate
Proterozoic	Hamersley Group:		
	Wittenoom Dolomite	150	Grey calcitic crystalline dolomite.
	Marra Mamba Iron Formation	20	Interbedded shale and chert, minor BIF
	Fortescue Group:		
	Roy Hill Shale Member	35	Black carbonaceous shale with bands and nodules of marcasite and pyrite.

(a) The relative age of these two units is uncertain.

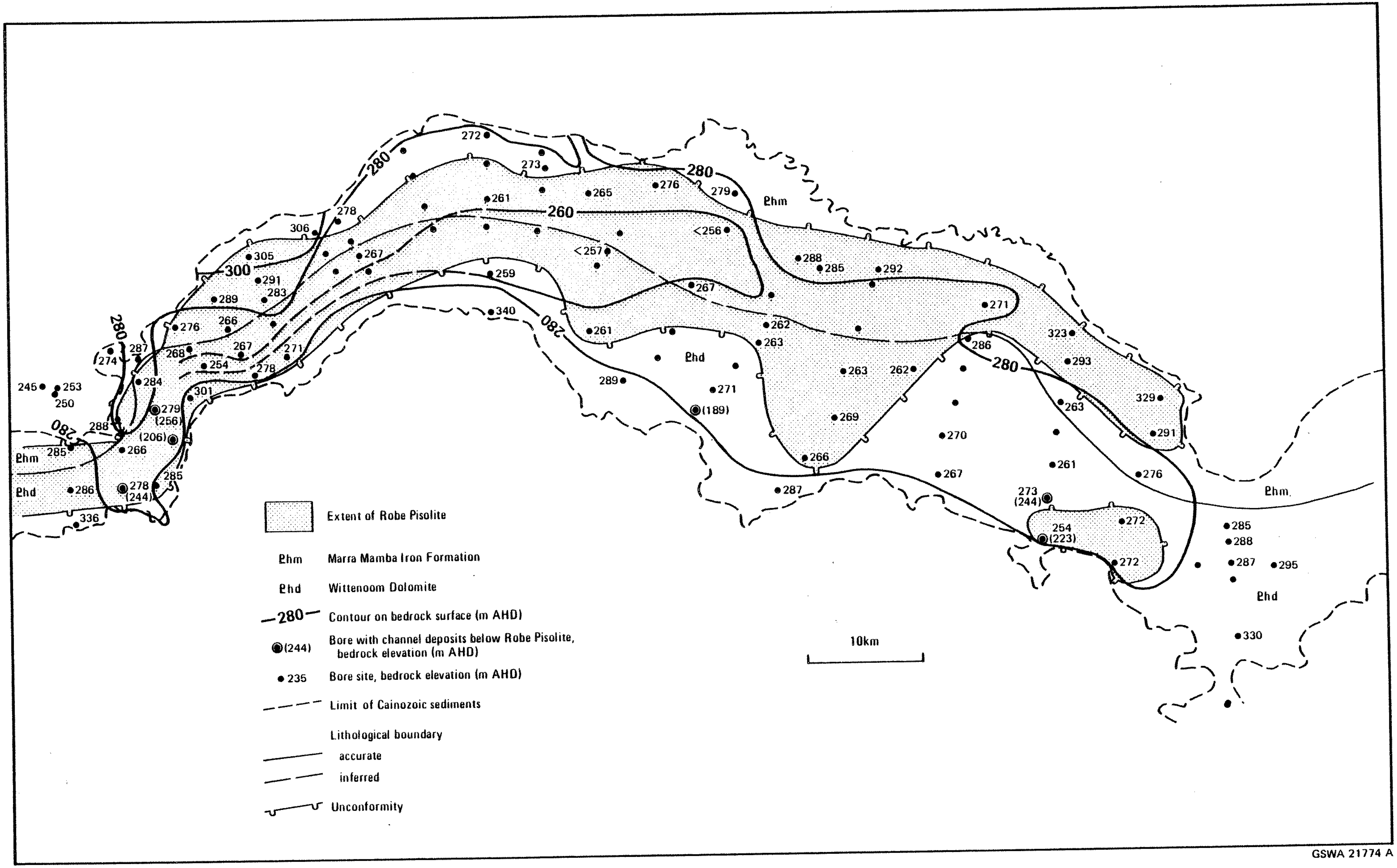

Figure 4A Extent of Robe Pisolite, and contours on Precambrian block.

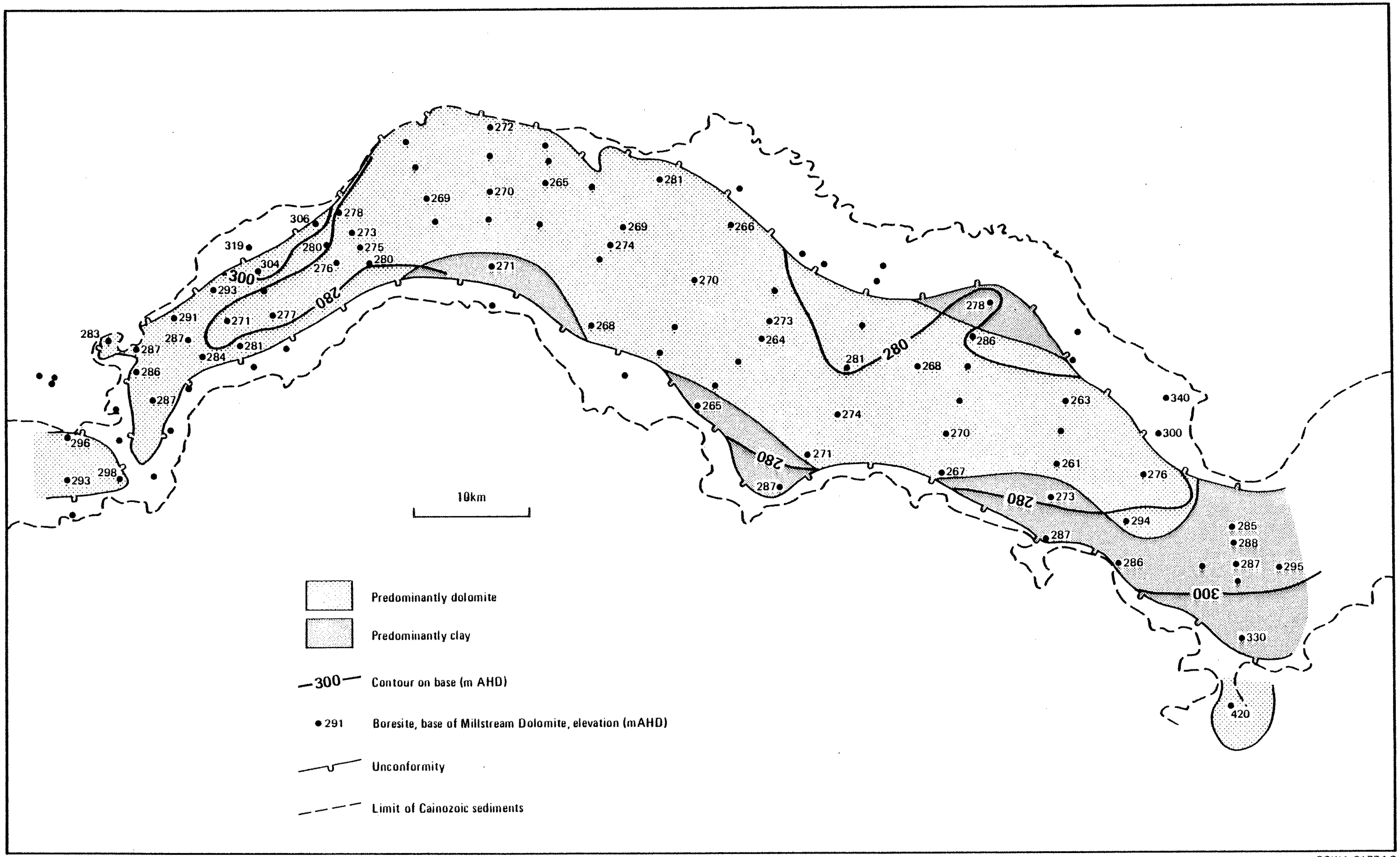

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Figure 4B Extent of Millstream Dolomite, and contours on base.

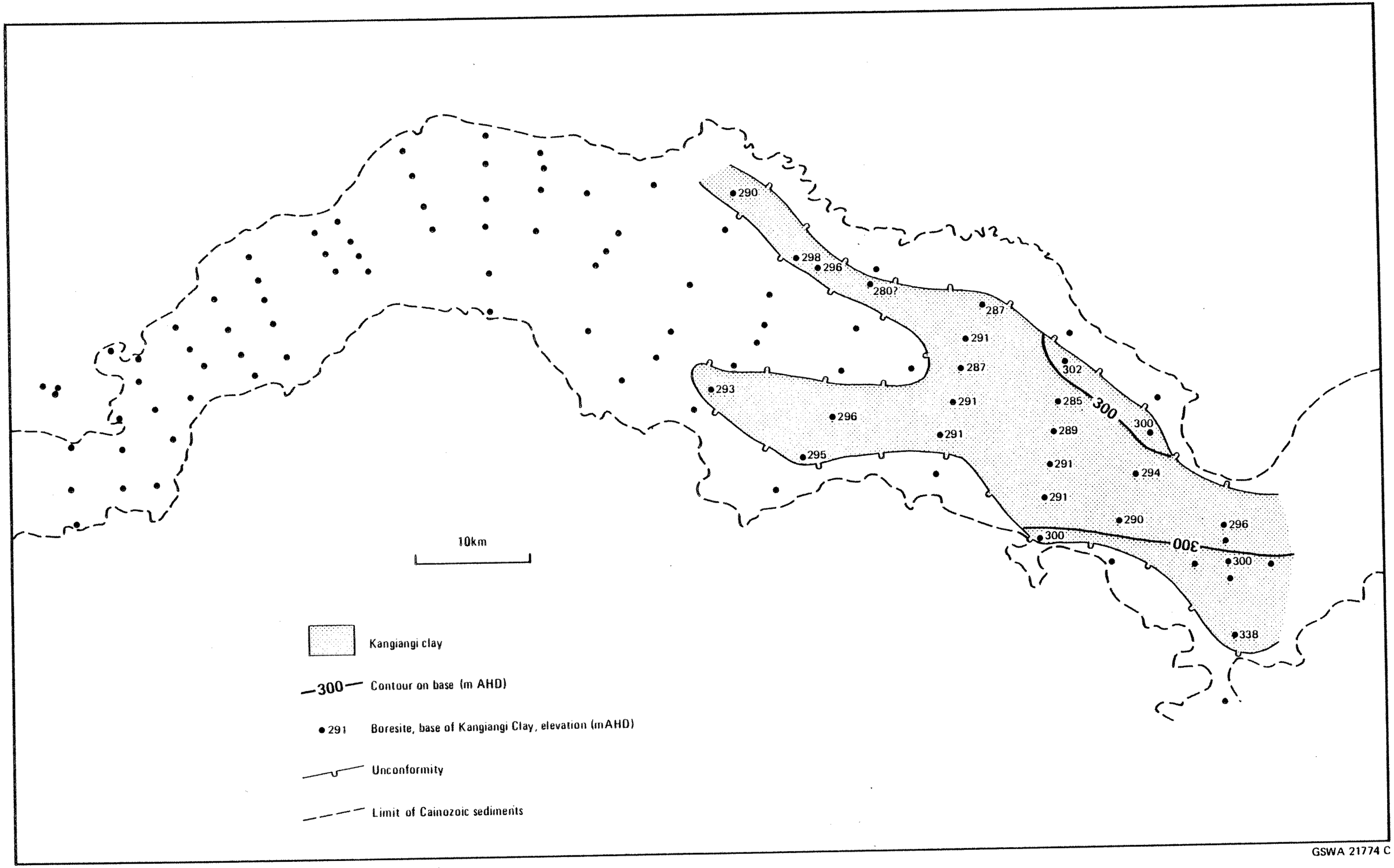


Figure 4C. Extent of Kangiangi Clay, and contours on base.

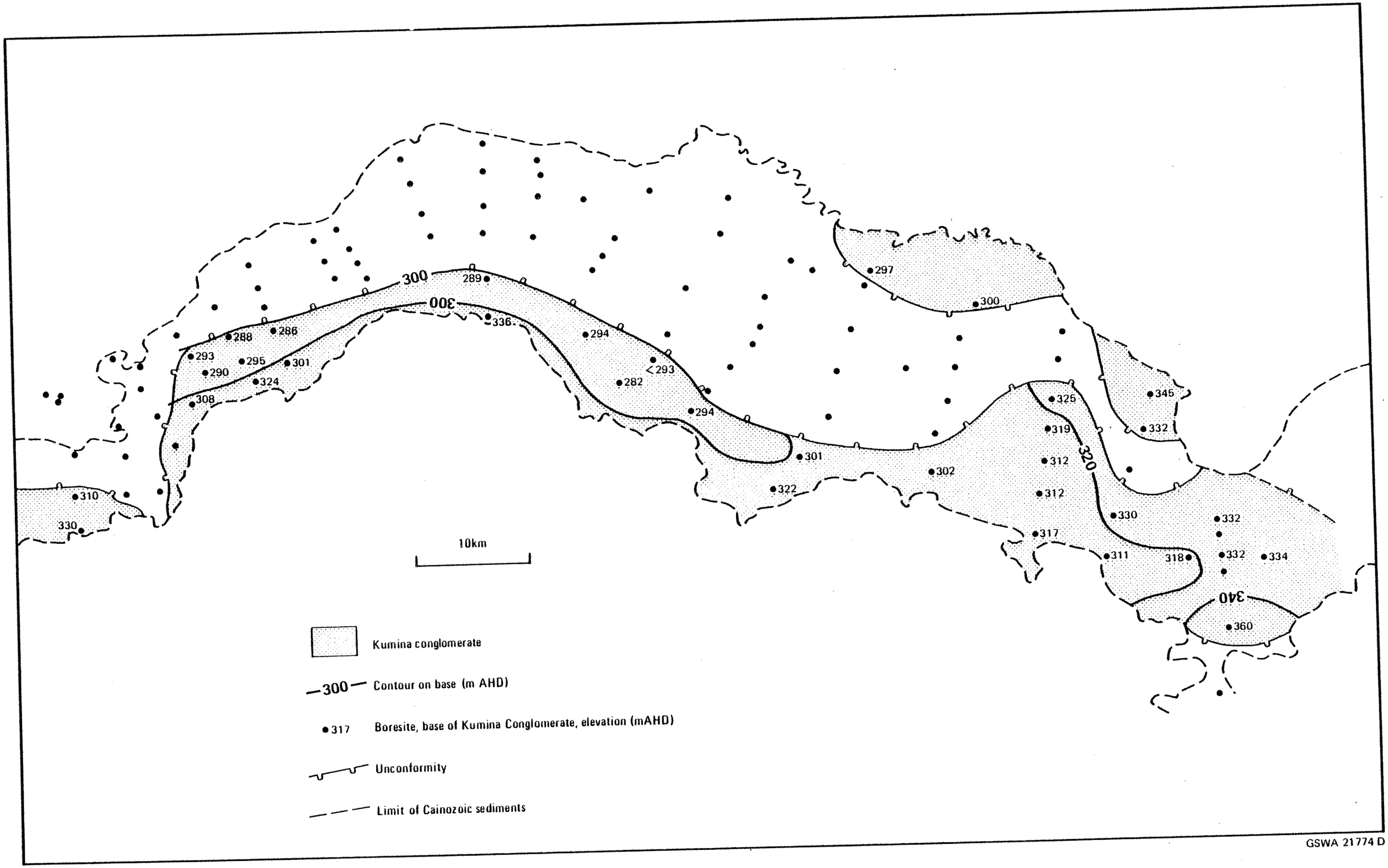


Figure 4D Extent of Kumina Conglomerate, and contours on base.

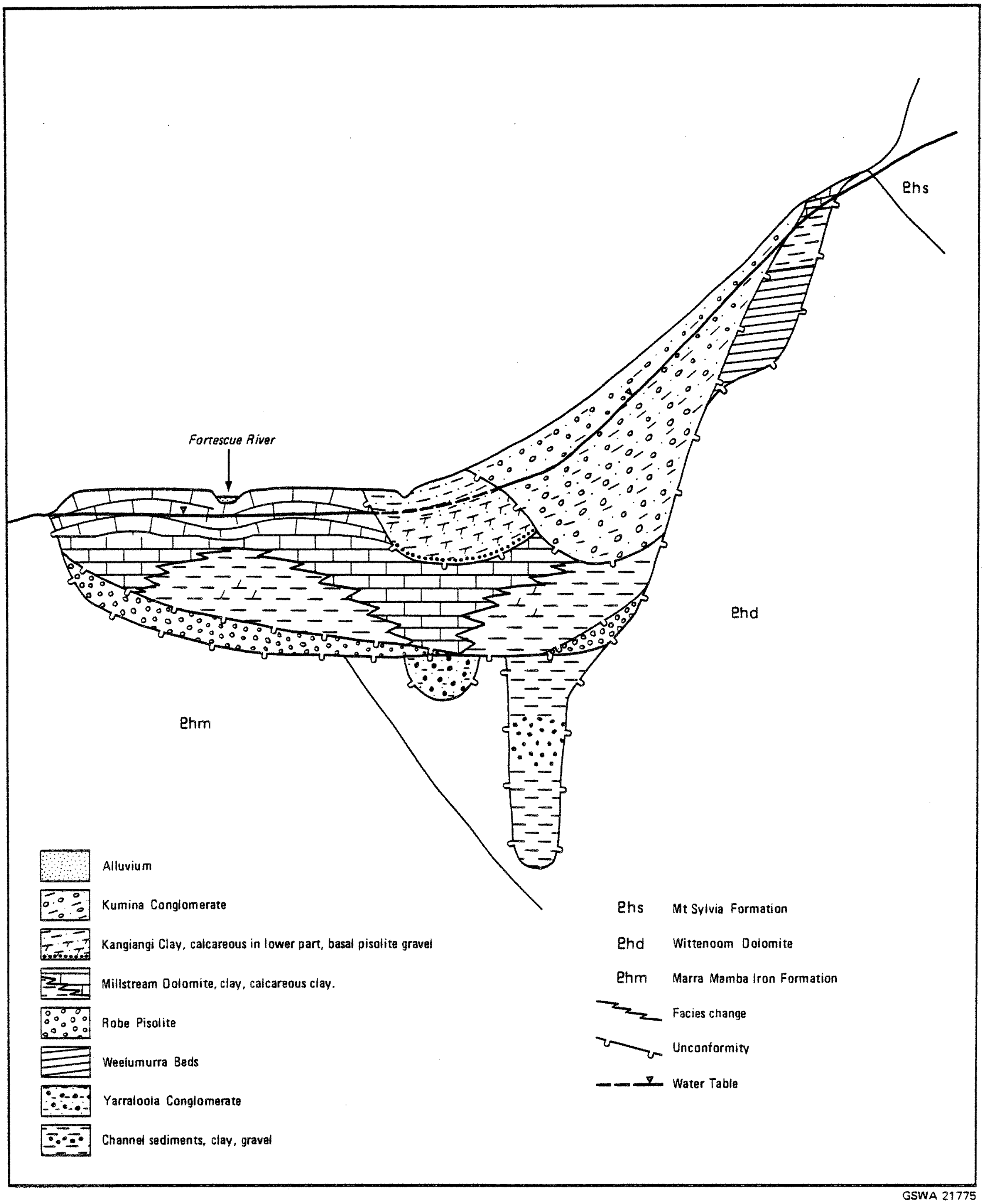


Figure 5. Diagrammatic relationships of Cainozoic sediments.

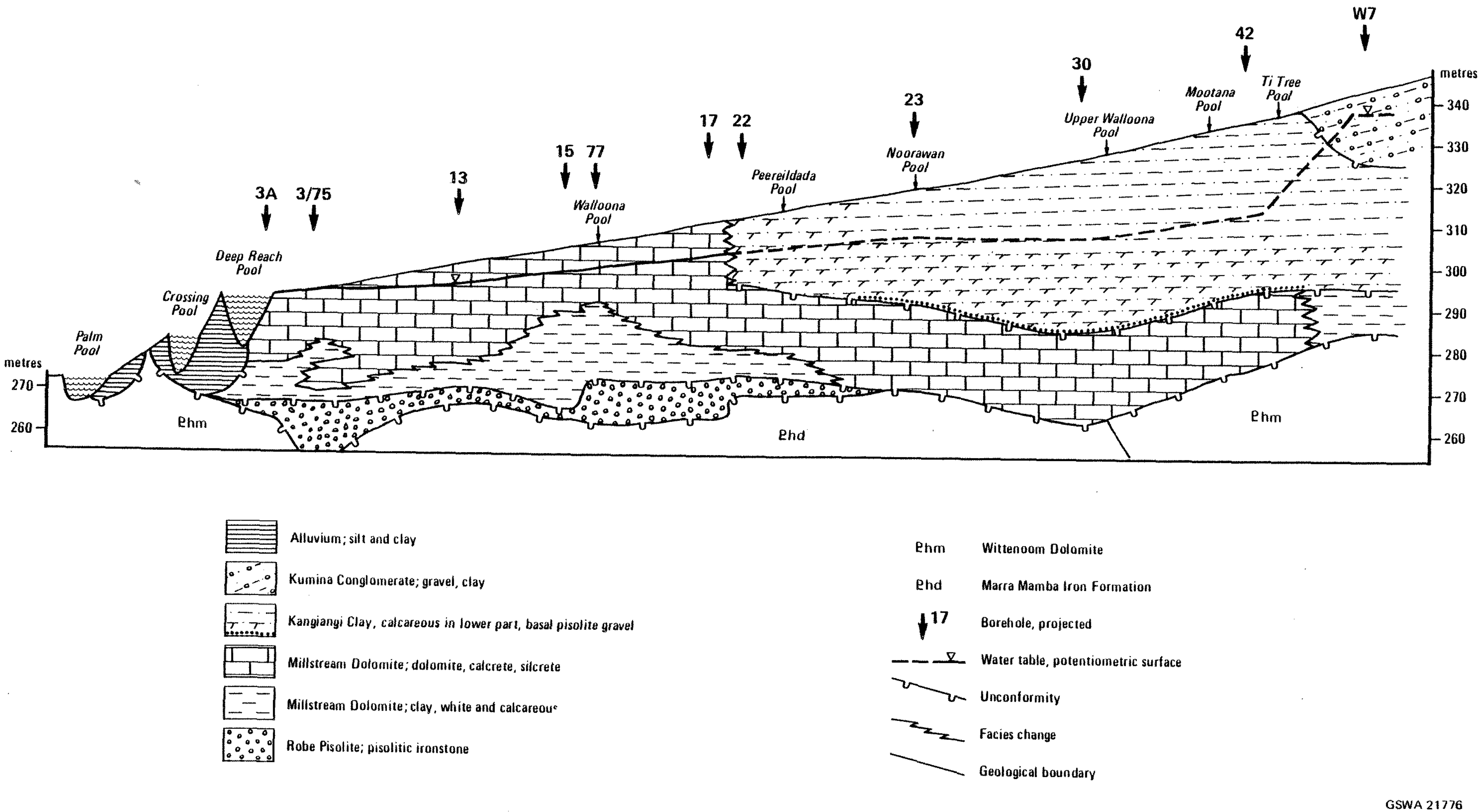


Figure 6. Fortescue River longitudinal profile and geological section.

STRATIGRAPHY

Proterozoic

Roy Hill Shale Member: The Roy Hill Shale Member **(Pfir)** is about 30 to 40 m thick and consists of black carbonaceous shale. It includes thin bands and small nodules of marcasite and pyrite up to 50 mm in diameter, and beds of fibrous calcite up to 100 mm thick. The Roy Hill Shale weathers to a white or variegated shale and the iron sulphides oxidise to goethite.

The member crops out just beyond the northern edge of the Fortescue Plain, and has been recorded in subcrop in bore 1A near Millstream homestead.

The Roy Hill Shale is a unit of the uppermost formation of the Fortescue Group, Jerrinah Formation and is conformably overlain by the Marra Mamba Iron Formation, the lowermost formation of the Hamersley Group.

Marra Mamba Iron Formation: The Marra Mamba Iron Formation **(Phm)** in this area is about 20 m thick, and consists mainly of interbedded dark grey shale and chert with minor banded iron-formation (BIF). A thin (5 mm) band of crocidolite was struck in Bore 63A. The chert is generally black, with pinch and swell structures containing tension cracks that are filled with quartz. When weathered the shale is variegated and the cherts are stained by iron oxides.

The Marra Mamba Iron Formation crops out along the northern edge of the Fortescue Plain, and forms the bedrock to Cainozoic deposits beneath the northern part of the plain.

The Marra Mamba Iron Formation is the lowest unit of the Hamersley Group, and is conformably overlain by the Wittenoom Dolomite. The contact with the Wittenoom Dolomite is exposed in the right bank of the Robe River (latitude 21° 48' 25", longitude 116° 42' 45").

Wittenoom Dolomite: The Wittenoom Dolomite (**Phd**) is about 150 m thick; it consists of a lower section of dolomite with occasional bands of shale and chert, and an upper section of shale with a few layers of dolomite and chert. The dolomite is blue-grey, crystalline and calcitic, and is commonly laminated and flaggy. The chert is black, with pyritic laminae. On weathering the dolomite develops a thin buff skin, and the shale becomes variegated.

The Wittenoom Dolomite, as the lower unit of the Hamersley Group, forms the bedrock to Cretaceous and Cainozoic deposits below the southern part of the Fortescue Plain, and crops out at the foot of the Hamersley Range. It is conformably overlain by younger formations of the Hamersley Group.

Mesozoic

Yarraloola Conglomerate: Yarraloola Conglomerate (**Kny**) occurs at boresites 56 and 65, and is tentatively correlated with the Yarraloola Conglomerate (Barnett, 1981).

At site 56 the conglomerate consists almost entirely of angular to rounded clasts of Wittenoom Dolomite. At site 65 the conglomerate consists of subrounded to rounded pebbles of chert, quartzite, jaspilite, and quartz in a matrix of sand, silt, and clay; it contains layers of silty clay, and becomes very clayey towards the base.

At each site, the conglomerate unconformably overlies Wittenoom Dolomite and is overlain by Robe Pisolite. The conglomerate appears to be confined to a narrow channel, and is absent from other bores in the area.

The Yarraloola Conglomerate is thought to be of Early Cretaceous age (Williams, 1968).

Undifferentiated Units: Sediments (Mu), which infill channels cut into the Proterozoic bedrock and are overlain by Cainozoic Robe Pisolite or Millstream Dolomite, were also encountered at sites 27, 39, 61, and 73.

At site 27, there is a 26 m thick bed of coarse sand to fine gravel of rounded green chert, presumably derived from the Marra Mamba Iron Formation. It may be equivalent to the Yarraloola Conglomerate.

At sites 39, 61 and 73, which are all close to the Hamersley Range scarp, there are channels cut 60 to 70 m below the base of the Cainozoic sediments that occur elsewhere in the valley. These channels are infilled with conglomerate (61), conglomerate and clay (73), and clay (39). The clay ranges in colour from white or yellow to red, and the conglomerate consists of chert, shale, and iron-formation.

Interpretation of the age and relationships of these deposits is complicated by the depth they extend to. The bedrock elevation in the Robe River (about 245 m) and in the Fortescue River (279 m at the bar downstream of Crossing Pool) is much higher than the base of these channels, the lowest of which is 189 m in 73B. The only possible westward outlet is along the present narrow channel of the Jimmawarrada Creek. A possible alternative explanation is that the channels were formed when drainage in the Fortescue Valley was to the east, and subsequent reversal has taken place with tilting to the west.

Cainozoic

Robe Pisolite: The Robe Pisolite (**Czp**) has a diverse lithology, that ranges from massive ironstone to cemented pisolitic ironstone; it locally contains layers of clay and shale. A layer of clay with pebbles, a few metres thick, is common at the base. The massive ironstone contains irregular vugs, up to 300 mm across.

The formation ranges from 3 to 33 m in thickness. It crops out along both sides of the Robe River, and is widespread in the subsurface. It unconformably overlies either the Early Proterozoic formations or the Yarraloola Conglomerate, and is unconformably overlain by younger Cainozoic deposits.

The Robe Pisolite is of Early to Middle Tertiary age.

Weelumurra Beds: The Weelumurra Beds have only been recorded in Bore W6A, where they consist of 34 m of clay, pale grey and brown in the upper part and dark grey and black in the lower part.

The Weelumurra Beds overlie dark grey shale that is presumed to be a shale horizon in the upper part of the Wittenoom Dolomite. These beds are overlain by gravelly conglomerate and calcrete, probably equivalent to the Millstream Dolomite.

The Weelumurra Beds are of Early Tertiary age, and represent a lacustrine deposit which probably formed in the valley behind a bedrock bar at the northern edge of the Hamersley Range.

Millstream Dolomite: The Millstream Dolomite (Czd) is up to 46 m thick, and consists of dolomite with layers of silcrete, illite-nontronite clay, calcareous clay, and conglomerate.

The dolomite is very variable in colour and texture. It is generally calcareous dolomite above the water table, and dolomite below it. It is usually vuggy, and in places is cavernous, with cavities up to 0.5 m high. These cavities are best developed at or near the present water table, and are commonly lined with botryoidal chalcedonic silica. In places there are small sinkholes at the surface.

Veins and beds of silica occur throughout the formation. There are two consistent layers of silcrete: one at an elevation of about 294 m AHD. the present water table level; and the other at about 310 m AHD which may represent a past water table level. A layer of limonitic silcrete, up to 6 m thick, is often present at or near the base of the formation.

Over most of the area, the lower 10-15 m of the formation contains one or more layers of illite-nontronite clay, which in places makes up the entire lower part of the formation. Along the southern margin of the valley only this facies is present, but the presence of siliceous and dolomitized veins indicates that it passes laterally into dolomite towards the valley centre (Fig. 5).

In the Weelumurra area the lateral equivalent of the formation is a red-brown to yellow clay with minor dolomite veins.

The Millstream Dolomite crops out in the western, central and northern parts of the valley, and extends in the subsurface to the southern edge of the valley and to the east.

The formation unconformably overlies the Robe Pisolite over much of the area, and overlaps onto the Marra Mamba Iron Formation in the north and west, and onto the Wittneoom Dolomite in the east. On the south side of the valley the formation is unconformably overlain by the Kumina Conglomerate and in the east by the Kangiangi Clay.

The formation is probably a lacustrine deposit formed during a period of very low erosion rates. Its age is uncertain but probably Middle to Late Tertiary. It is possibly equivalent to the Oakover Formation of the East Pilbara (Noldart and Wyatt, 1962).

Kangiangi Clay: The Kangiangi Clay (Czi) (Barnett, 1981) ranges in thickness up to 47 m and consists of silty-clay with interbeds of porly sorted sand and pebbly gravel. The formation is well-bedded and cemented by iron oxides (near the surface), silica, and carbonate (especially below the water table where nodules and veins are common).

The formation is present only in the eastern part of the area. It is mostly covered by a thin layer of colluvium, but crops out in Kangiangi Creek and the Fortescue River.

The formation unconformably overlies the Millstream Dolomite and Robe Pisolite; a layer of ferruginous pisolitic gravel occurs at the unconformity (Fig. 4). It is overlain by, and possibly interfingers with, the Kumina Conglomerate.

The Kangiangi Clay is apparently a lacustrine deposit, possibly of Tertiary to Pleistocene age.

Kumina Conglomerate: The Kumina Conglomerate (Czg) (Barnett, 1981) is composed of boulders, cobbles, gravel, and sand in a matrix of silty brown clay, usually with a ferruginous section at the base. It includes beds of silty clay. The clasts are generally subrounded to rounded, moderately sorted, and lossely cemented. The formation ranges in thickness up to about 90 m, and is thickest close to the base of the Hamersley Range scarp.

The formation occupies a channel along the southern edge of the valley and forms the piedmont slope to the Hamersley Range. It extends over the full width of the valley in the Weelumurra Creek area.

The Kumina Conglomerate unconformably overlies Proterozoic bedrock and the earlier Cainozoic formations, possibly interfingering with the Kangiangi Clay.

The formation is an alluvial fan deposit formed over a long time range that extends to the present, although it is now being eroded near Kumina Creek.

Miscellaneous Cainozoic deposits: A thin mantle of unconsolidated sediments covers much of the Cainozoic formations. Colluvium and sheet wash deposits (**Czc**) occur on both flanks of the valley associated with the present drainages. Alluvium (Qa) of silt and clay, and river-bed gravel is associated with the Fortescue and Robe Rivers.

Much of the outcrop area of Millstream Dolomite is covered by up to 3 m of red-brown clay which dries out at the end of each wet season to form 'gilgai' (large deep cracks).

HYDROGEOLOGY

INTERRELATIONSHIP OF AQUIFERS

The Cainozoic valley-fill sediments can be considered to be a single flow system even though there are differences in hydraulic properties between and within each formation. The Proterozoic bedrock is effectively a hydraulic boundary to the flow system; the much greater hydraulic gradient in the Proterozoic rocks indicate a much lower regional transmissivity.

The main aquifers are the Millstream Dolomite, the Robe Pisolite, and the Kumina Conglomerate. Channel deposits, where the sediments are gravel, are also locally significant.

Although the Cainozoic sediments have not been investigated east of Weelumurra Creek, the fact that the water table there slopes downwards to the northeast (up the valley) indicates that there is not likely to be much groundwater flow into the investigation area from the upper Fortescue Valley. The investigation area, therefore, covers virtually the whole flow system from its sources of recharge to its discharges into the Fortescue and Robe Rivers.

DESCRIPTION OF AQUIFERS

Millstream Dolomite

The Millstream Dolomite extends over most of the valley, but is absent in the Robe River area (due to erosion) and along the north eastern margin of the valley.

The formation consists of dolomite, calcrete, and silcrete with interbedded white or yellow-brown clay. The dolomite, calcrete, and silcrete facies has a well-developed secondary porosity with cavities, especially close to the water table. Along the southern flank of the valley and in the Weelumurra area, only the clay facies is present.

The aquifer is unconfined where the dolomite crops out, but to the east it is confined by the Kangiangi Clay. The thickness of saturated dolomite is greatest near the centre of the valley (Fig. 7) and reaches a maximum of 33 m in bore 5A. Bore yields are generally high and range up to 5 500 m^3d^{-1}.

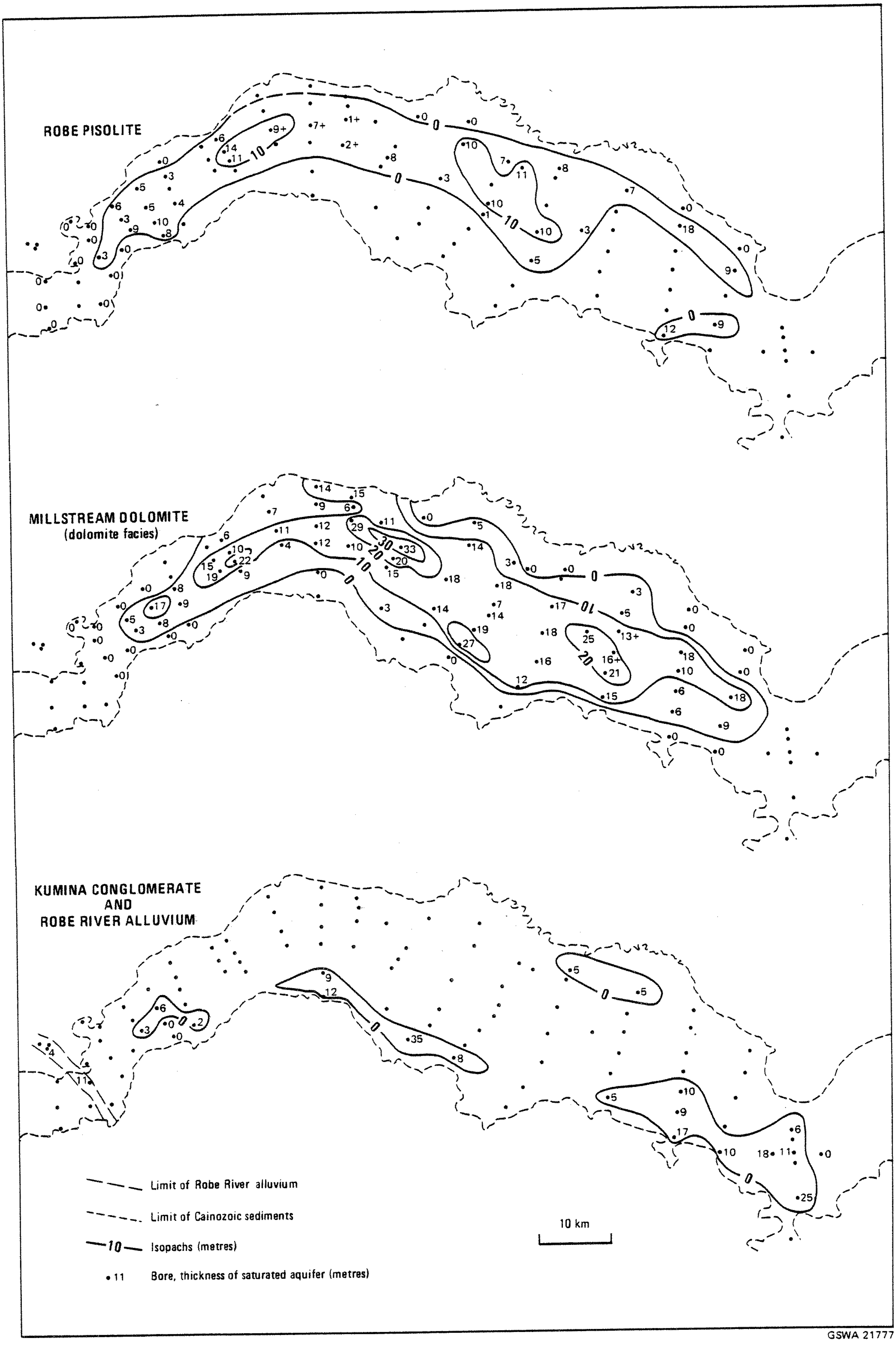


Figure 7. Isopachs of saturated Cainozoic aquifers.

Robe Pisolite

The Robe Pisolite aquifer occurs discontinuously at the base of the Millstream Dolomite and below the Kangiangi Clay, and also outcrops in the Robe River area.

The aquifer consists of vuggy pisolitic ironstone which is interbedded with clay.

In the Robe River area the aquifer is unconfined, but elsewhere it occurs beneath the dolomite or is confined by the Kangiangi Clay. The maximum saturated thickness is 18 m at bore 31 although it is usually much less (Fig. 7). The hydraulic gradient indicates a lower transmissivity than the adjacent Millstream Dolomite, but bore yields of as much as 1 700 m^3d^{-1} are known.

Kumina Conglomerate

The Kumina Conglomerate occurs along the south side of the valley as alluvial fans, and extends across the full width of the valley at Weelumurra Creek.

The formation consists of poorly sorted gravel interbedded with clay.

The aquifer is unconfined but has a significant saturated thickness only in the Kumina Creek-Robe River area, and in the Caliwingina Creek-Weelumurra Creek area (Fig. 7). In places there is a thin perched aquifer at the base where is overlies Kangiangi Clay, and there is a downward head gradient between it and the Millstream Dolomite.

The hydraulic gradient of the water table in the Caliwingina Creek-Weelumurra Creek area is high and indicates a much lower transmissivity than the Millstream Dolomite. The maximum known saturated thickness is 40 m at W4. Borehole yields range up to about 600 m^3d^{-1}.

Yarraloola Conglomerate and Other Channel Deposits

The distribution of these sediments, which occur beneath the Robe Pisolite and Millstream Dolomite, is incompletely known.

They have diverse lithologies ranging from clay to pebble gravels. Yields have been tested in only two bores and the maximum yield of 1 600 m^3d^{-1} shows that they are locally quite productive.

Proterozoic bedrock

The fractured Proterozoic bedrock, which consists of shale, dolomite and iron-formation, has been tested only in the Robe River area and by two bores on the northern flank of the Hamersley Range.

The regional hydraulic gradients show that the transmissivity is much lower than that of the Cainozoic formations, although locally high borehole yields (up to 1 300 m^3d^{-1}) can be obtained.

At the top of the Wittenoom Dolomite there are often cavities, up to 0.5 m deep. Loss of drilling fluid indicates a very high transmissivity in this zone.

AQUIFER CHARACTERISTICS

Specific Yield

Conventional pumping test methods have been ineffective in determining the specific yield of the Millstream Dolomite because the aquifer is so transmissive. An unconventional approach was therefore used in 1975 to measure the specific yield of the aquifer at five sites; the programme included the drilling of five fully cored bore holes, downhole stereoscopic colour photography, gamma gamma logging, and the laboratory determination of porosity and specific retention. The results of the programme are reported in detail by Barnett, McInnes, and Waterton (1977). The results of the study are shown graphically on Figure 8.

The great variation at the five sites, both in saturated thickness and distribution of specific yield, is clearly shown. Storage per unit area (combines specific yield and saturated thickness to give the total volume of water which is aquifer could yield by gravity from a unit area at a particular bore site) ranges from 0.6 to 3.2 m^3m^{-2}.

Secondary porosity is the dominant factor controlling the specific yield of the dolomite. The highest values of specific yield are related to concentrations of large voids and cavities, most of which are within the top 6 m of saturated dolomite. The voids are mostly horizontal or nearly so, and have been recorded up to 0.5 m high; they presumably developed by solution.

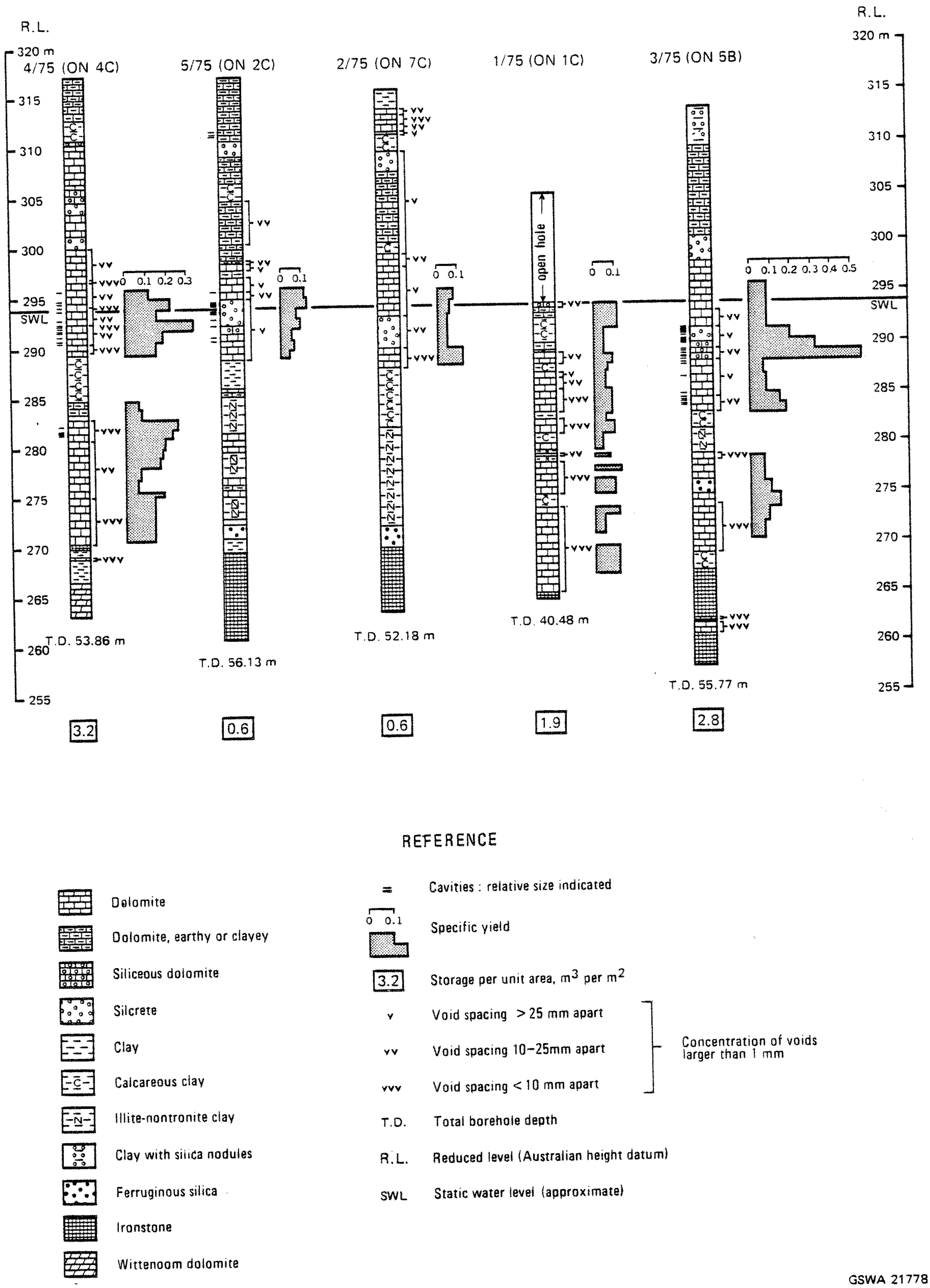


Figure 8. Specific yield and lithology in coreholes 1/75 to 5/75.

The average specific yield is about 0.1, but this is obviously not a statistically reliable value as there is so much variation between the five sites.

The storage per unit depth in the Millstream Dolomite adopted to account for the observed relationship between water-table elevation and discharge (Snowy Mountains Engineering Corporation, 1982) varies according to the water-table elevation (Table 3).

TABLE 3. VARIATION IN SPECIFIC YIELD WITH DEPTH IN THE MILLSTREAM DOLOMITE

Water-table Elevation (m)	Storage per unit depth (10^6 m^3m^{-1})	Specific yield based on aquifer area of 500 km^2
294.0	34.2	0.07
293.8 - 293.9	76.4	0.15
293.6 - 293.7	102.6	0.20
293.4 - 293.5	106.4	0.20

Values from Snowy Mountains Engineering Corporation (1982)

If these storages are applied to an area of 500 km^2 (approximate area of the unconfined dolomite aquifer), the corresponding specific yields range from 0.07 - 0.20. These are slightly higher than values obtained from the coring programme at the same depths.

Transmissivity

Transmissivity has been estimated from pumping tests on single bores and pumped bore-observation bore combinations. The details and results of these tests are shown in Appendices 2 and 3, and summarised in Table 4.

The pumping tests on the Millstream Dolomite were characterised by very high yields with a small rapid drawdown response that could not be analysed. Balleau (1973) reported on testing of the production bores at rates up to 5 500 m^3d^{-1}; nine of these bores drew down less than 0.3 m and in three bores no drawdown at all could be measured. Evidently the regional transmissivity in the area of low hydraulic gradient is very high. Locally the hydraulic conductivity can be expected to vary widely both laterally and vertically, as it will depend on the degree of development of voids and cavities which form a conduit system typical of karst aquifers. The hydraulic conductivity will generally be highest in the few metres jus below the water table, where cavities are best developed (Fig. 8). Variations in the transmissivity of the Millstream Dolomite are apparent from the changes in hydraulic gradient along the Fortescue Valley (Fig. 9).

Most bores in the Robe River-Kumina Creek and Weelumurra Creek areas were also pump tested, but with variable results (Table 4). The Robe Pisolite is locally quite transmissive, with high bore yields. The Kumina Conglomerate generally gives low yields, and the low transmissivity is presumably due to the high clay content and poor sorting. Bore yields from the Wittenoom Dolomite bedrock are locally quite high, although the regional transmissivity is evidently low.

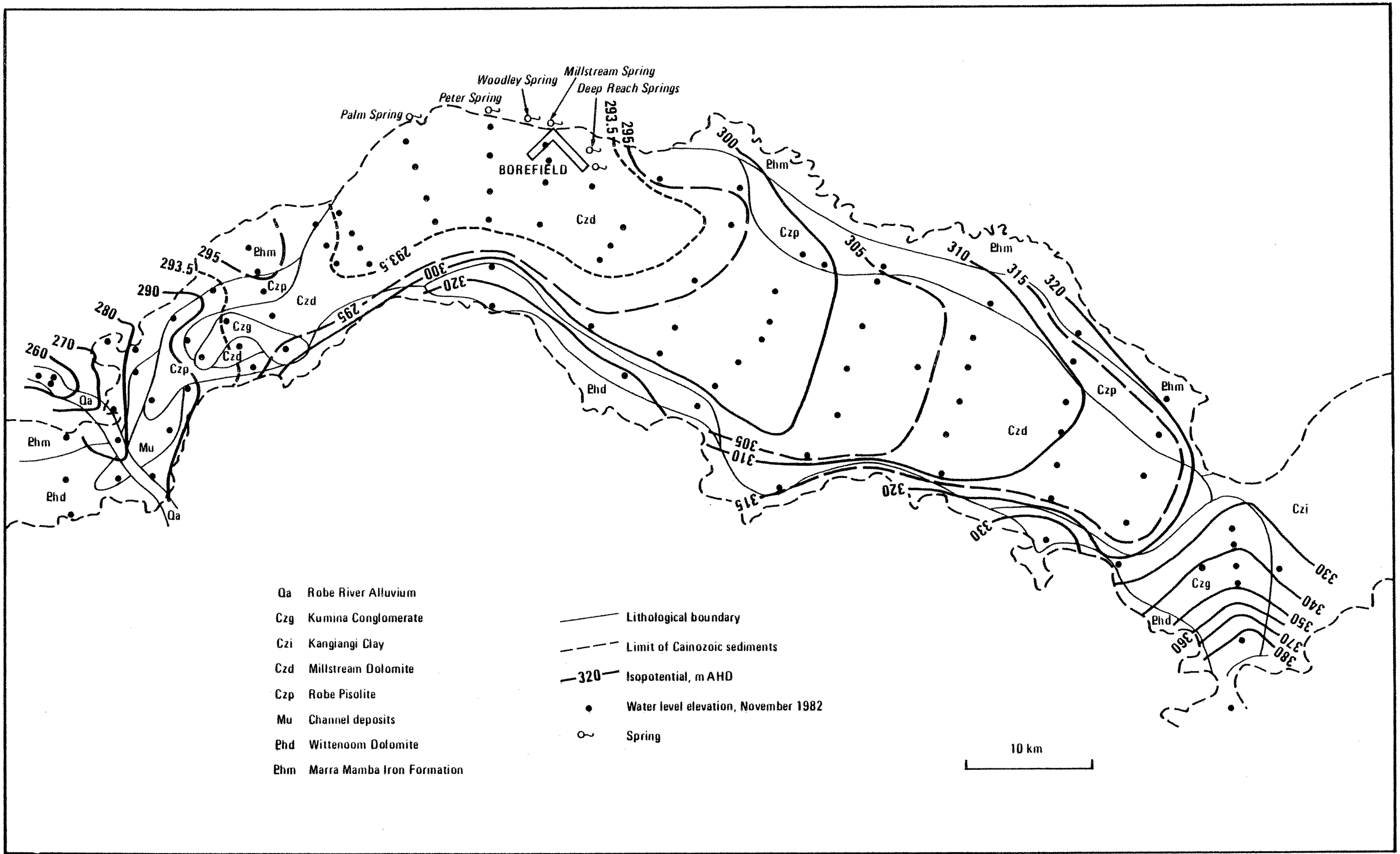


Figure 9. Isopotentials in the Cainozoic aquifers.

TABLE 4. AQUIFER YIELDS AND TRANSMISSIVITIES

Aquifer	No. of bores tested	Maximum yield (m^3d^{-1})	Range of transmissivity (m^2d^{-1})
Alluvium (a)	4	53	14 - 110
Kumina Conglomerate (a)	1	80	6
Kumina Conglomerate (b)	7	653	7 - 110
Millstream Dolomite (c)	30	5 500	low - very high
Millstream Dolomite (d)	2	600	12 - 2200
Robe Pisolite	3	1 708	210 - 5000
Yarraloola Conglomerate	2	1 610	45 - 1400
Wittenoom Dolomite	6	1 310	0.5 - 100
Marra Mamba Iron Fm	3	195	5.5 - 540

(a) Robe River area

(b) Weelumurra

(c) Includes results from Balleau (1973) and Davidson (1969)

(d) Confined

RECHARGE

Recharge from the Fortescue River

The hydrographs for bores in the unconfined part of the Millstream Dolomite show that recharge to the aquifer is closely correlated with river flows (Fig. 10). The magnitude of the water-level rise in the aquifer progressively decreases away from the water course, and there is an increased time lag for the peak water level

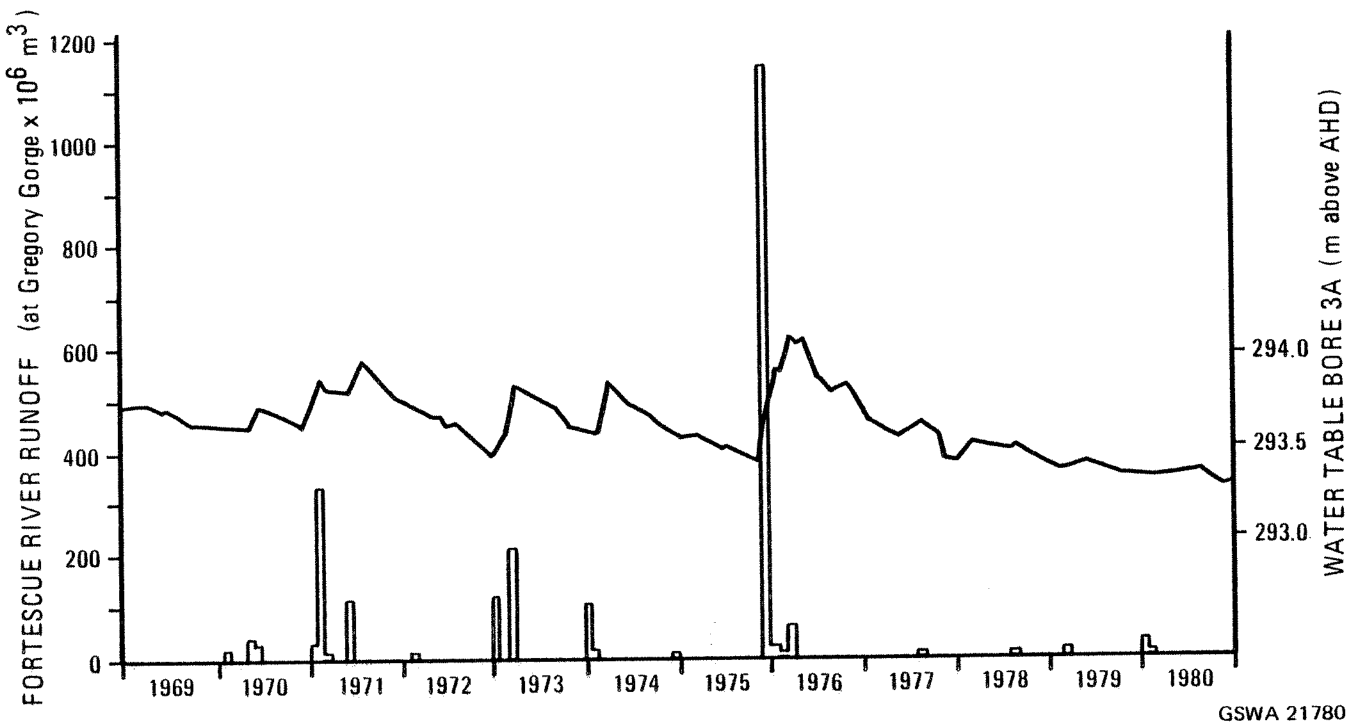


Figure 10. Water table elevation and Fortescue River flow 1968-81.

to be reached. In many of these recharge events there was also potential for recharge to the aquifer directly from rainfall. However, in the flood following Cyclone Joan in December 1975 there was no rainfall at Millstream, so that the rise in water levels can be solely attributed to flood recharge, and the similarity of the other events indicates that flood recharge dominates rainfall recharge.

The difference in water levels between 19 November 1975 and 14 May 1976 (Fig. 11) represents an aquifer volume of 330×10^6 m^3. Applying a specific yield of 0.15 gives an accession to storage of

$$0.15 \times 330 \times 10^6 = 49 \times 10^6 \; m^3.$$

This represents over three times the annual discharge by spring flow of about 15×10^6 m^3.

Recharge from valley flanks and rainfall

As well as recharge to the dolomite aquifer in the centre of the valley from river floods, recharge also takes place from streams draining the Hamersley and Chichester Ranges, and directly from rainfall.

The shorter streams draining the Hamersley Range mainly dissipate on the alluvial fans, whereas the longer ones flow onto the dolomite (south west of Millstream), or across the dolomite and the Kangiangi Clay to join the Fortescue River. The anastomosing gravel beds of Caliwingina and Weelumurra Creeks indicate that much of their flow can infilitrate to the underlying Kumina Conglomerate. Because of the infiltration of surface water on much of the piedmont and dolomite outcrop, it is difficult to separate the effects of rainfall and runoff as a result both will be considered together.

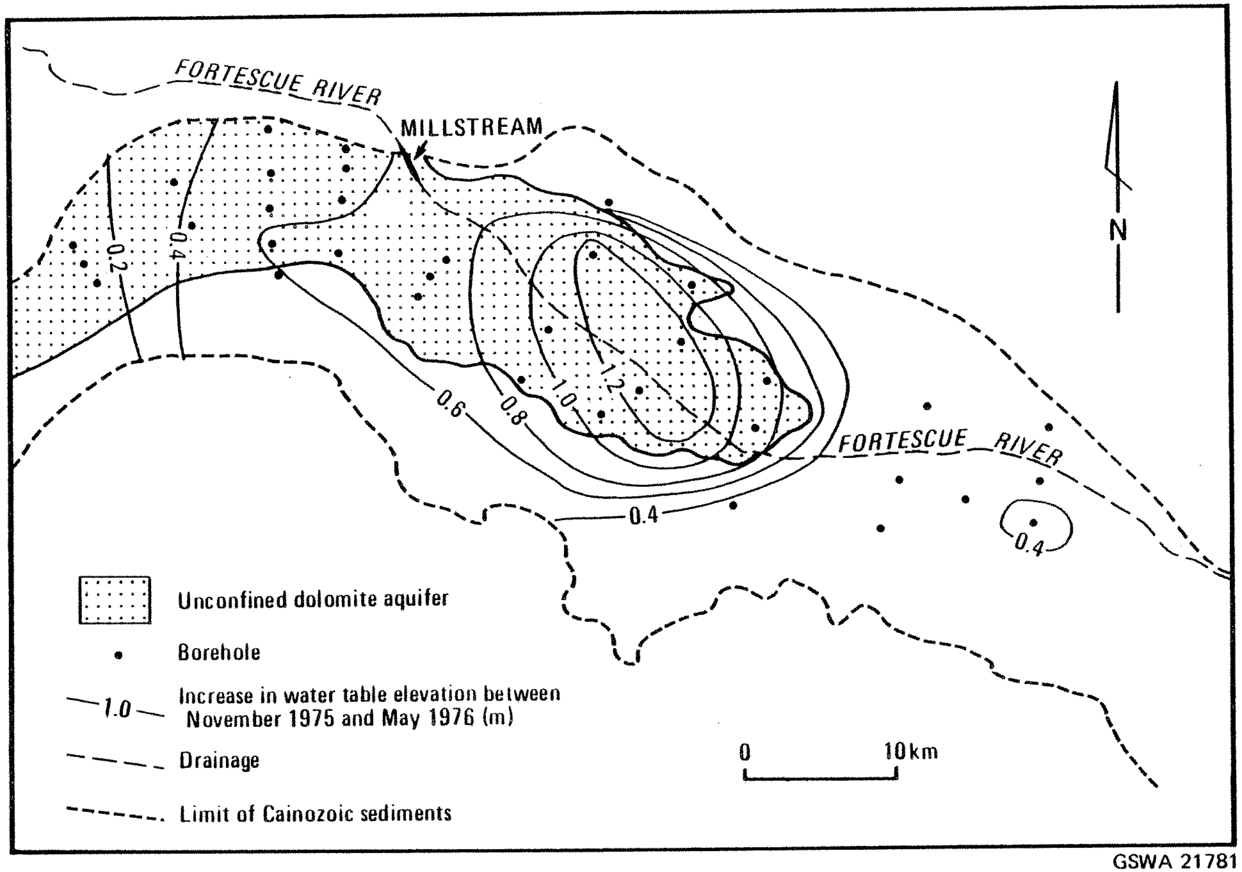


Figure 11. Water-level change after Cyclone Joan floods.

Estimates of recharge to the dolomite and gravel aquifers can be made from a chloride-ion balance. The ratio of the chloride ion in rainfall to that in the groundwater gives the proportion of rainfall contributing to groundwater recharge, assuming that no chloride-ion is lost either by runoff out of the area of contributed from other sources.

Because there is loss of chloride by an unknown proportion of surface runoff, these estimates can only give an idea of the maximum recharge from each source.

The chloride ion content of rainfall has been measured at different locations since 1978 (Appendix 3), and has been found to be about 1.1 mg L^{-1}.

The catchment areas selected include Proterozoic bedrock and it is assumed that groundwater flow in the bedrock is in the same direction as surface runoff.

For the purpose of estimating recharge, the area has been divided into five different catchment areas (Fig. 2):

(a) Hamersley Range-Mount Flora. This catchment area consists of short streams which are dissipated mostly in the piedmont zone or the dolomite outcrop. Some runoff reaches the Fortescue River. Direct recharge to the dolomite aquifer from rainfall also takes place.

The average chloride content of groundwater in 21 analyses (outside the zone of brackish water associated with river recharge) is 110 mg L^{-1}.

The total catchment area (excluding a zone of brackish water in the Millstream Dolomite outcrop) is 740 km^2 and consists of:

Hamersley Range	240 km^2;
piedmont zone	270 km^2; and
Millstream Dolomite	230 km^2.

The total annual rainfall is therefore,

$$0.350 \times 740 \times 10^6 = 260 \times 10^6 \ m^3$$

and the maximum recharge is

$$\frac{1.1}{110} \times 260 \times 10^6 = 2.6 \times 10^6 \ m^3.$$

The actual annual recharge must be less because some runoff reaches the Fortescue River.

(b) Hamersley Range-Mount Pyrton. Streams from this area flow mostly across Kangiangi Clay and join the Fortescue River. The potential for recharge in this catchment is therefore much lower than the Mount Flora catchment. This catchment area is only 400 km^2 therefore the recharge can be expected to be much less than 1.4 x 10^6 m^3.

(c) Caliwingina Creek. This catchment is evidently a major source of recharge as there is a body of perched water in the Kumina Conglomerate and an extensive area of low salinity in the dolomite aquifer.

The average chloride content in three bores is 50 mg L^{-1} and the catchment area of the creek is about 990 km^2, therefore the maximum recharge is

$$\frac{1.1}{50} \times 0.35 \times 990 \times 10^6 = 7.7 \times 10^6 \text{ m}^3.$$

The channels show that some recharge reaches the Fortescue River so this must be a maximum amount.

(d) Weelumurra Creek. This catchment is similar to Caliwingina Creek, except that there is no underlying dolomite aquifer.

The average chloride content in three bores is 26 mg L^{-1} and the catchment area is about 1 120 km^2, therefore the maximum recharge is

$$\frac{1.1}{26} \times 0.350 \times 1\ 120 \times 10^6 = 16 \times 10 \text{ m}^3.$$

(e) The catchment areas on the northern side of the valley draining the Chichester Range between the Fortescue River-Weelumurra Creek confluence and Howlett Creek totals about 990 km^2. The characteristics of these drainages differ from those draining the Hamersley Range; they have lower gradients, defined channels which join the Fortescue River, and they flow over less permeable material. The groundwater salinity on the northern side of the valley is also higher than to the south, and it can be expected that the contribution to groundwater recharge from this area is substantially less than an equivalent area on the Hamersley Range side.

Discussion

These estimates show that recharge direct from rainfall on the dolomite outcrop can only account for a small proportion of total recharge, and that there is a large potential recharge from Caliwingina and Weelumurra

Creeks. The bulge in water-table contours around Weelumurra Creek demonstrates recharge to the Kumina Conglomerate but the contribution to groundwater in the Millstream Dolomite is uncertain. At Caliwingina Creek the potentiometric contours in the Millstream Dolomite (Fig. 9) indicate substantial recharge which could account for a major proportion of the groundwater throughflow in the dolomite aquifer.

GROUNDWATER FLOW

The direction of groundwater flow, shown by the isopotentials (Fig. 9), is from Weelumurra Creek along the Fortescue Valley to discharge near Millstream, with lateral inflow from the valley sides. A groundwater divide across the plain west of Millstream separates groundwater discharging to the Fortescue River from that discharging to the Robe River.

The configuration of the water table in the Kumina Conglomerate of Weelumurra Creek demonstrates recharge from the creek and groundwater flow to the east on the south side of the Fortescue Valley. This implies that groundwater flow from east of the investigation area is small and may be restricted to a narrow zone close to the present course of the Fortescue River that abuts the northern margin of the valley. Groundwater in the Kumina Conglomerate in this area presumably leaks downwards into the Millstream Dolomite (Fig. 6).

Recharge in a similar manner takes place from Caliwingina Creek, although there is a perched water table developed in the Kumina Conglomerate with a hydraulic head of about 8 m above the potentiometric head in the underlying Millstream Dolomite.

Between Weelumurra Creek and Millstream, groundwater flow in the Millstream Dolomite is subparallel to the Fortescue River.

Lateral groundwater flow takes place from the valley flanks, where the hydraulic gradient is steeper due to a reduction in both hydraulic conductivity and aquifer thickness.

Where the Fortescue River traverses dolomite outcrop, groundwater flows away from the river due to recharge, and flow lines reconverge near Millstream where the aquifer discharges to Deep Reach Pool and Millstream Spring. The direction of groundwater flow has not been greatly altered by abstraction from the borefield, which is close to the natural discharge points, but the hydraulic gradient has been steepened (Fig. 12).

The water table in the dolomite just south and west of Millstream is fairly flat, therefore reflecting the high transmissivity. Because of the low hydraulic gradient, comparatively small water-table changes can alter the direction of groundwater flow; following the Cyclone Joan flood, groundwater flow appears to be northerly throughout the western Millstream area (Fig. 12).

The hydraulic gradient steepens at the Millstream Dolomite-Kumina Conglomerate contact near Kumina Creek, this reflects the lower transmissivity of the conglomerate, and steepens abruptly at the boundary of the saturated Cainozoic sediments with the Proterozoic bedrock. Groundwater flow through the Proterozoic bedrock between Millstream and the Robe River discharges to the Fortescue River, Jones Creek, West Creek and the Robe River, where transpiration by vegetation accounts for most of the discharge.

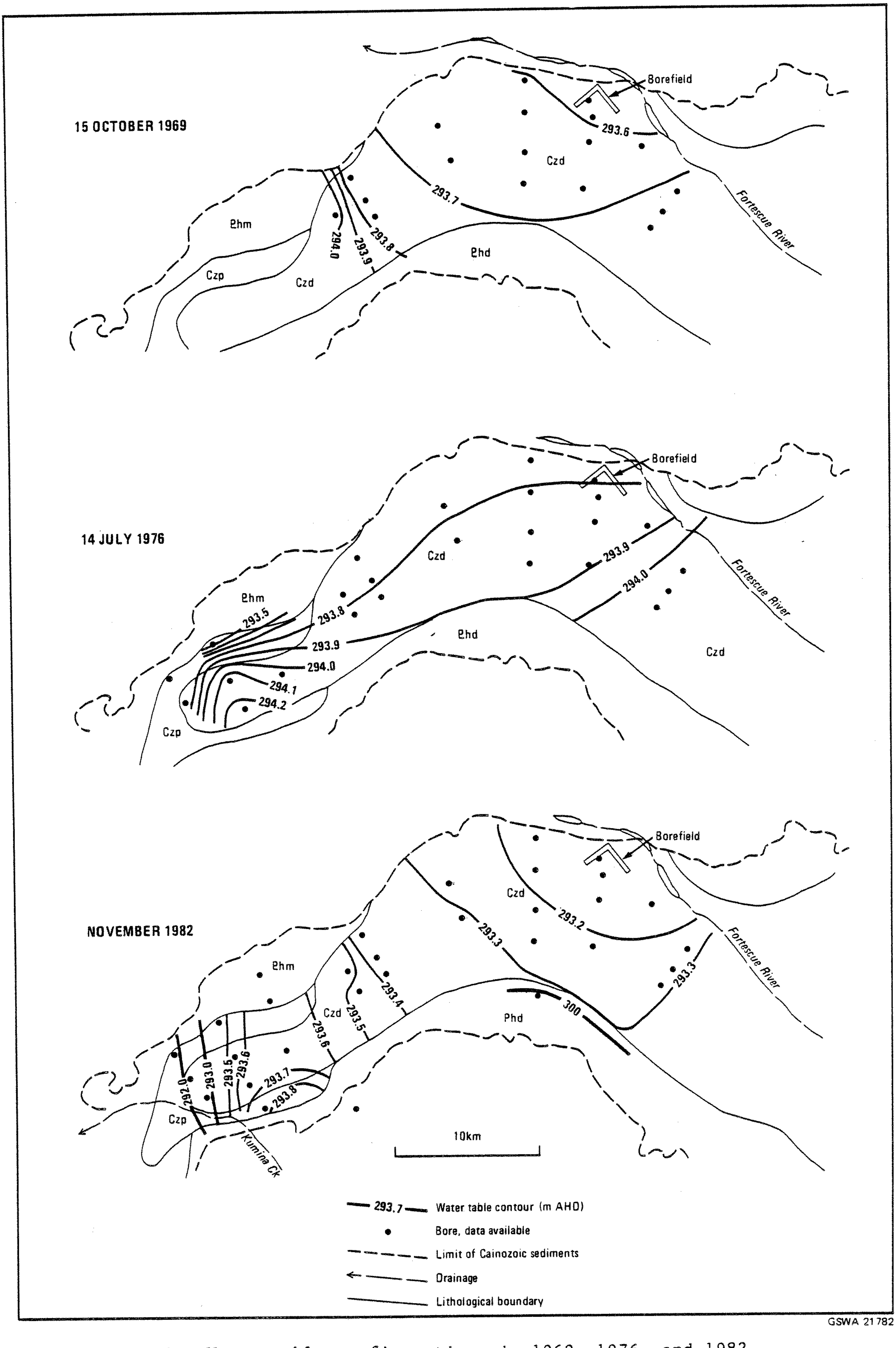


Figure 12. Water-table configurations in 1969, 1976, and 1982.

DISCHARGE

Groundwater discharge from the Cainozoic aquifer takes place between Jones Creek and Millstream by spring flow, and into the Proterozoic bedrock between Millstream and the Robe River by groundwater flow.

The major outlets are Deep Reach Pool and Millstream Spring, which are estimated to discharge 10.3×10^6 m^3 and 3.8×10^6 m^3 respectively per year under natural conditions. Additional spring flow of about 0.7×10^6 m^3 per year is required to account for evaporation from Deep Reach Pool. Estimates are not available for flow from the small springs west of Millstream which have now ceased to flow.

Groundwater outflow (Q) can be calculated from the form of the Darcy equation:

$$Q = Til$$

where T is the transmissivity, i the hydraulic gradient, and l the width across which flow takes place. Selection of an appropriate value for the transmissivity of the Proterozoic bedrock is, however, difficult. Pumping tests tend to measure the transmissivity along the bedding, which is generally the most transmissive plane; whereas the groundwater flow direction along the northern margin of the Cainozoic aquifers is across the bedding of the Marra Mamba Iron Formation. An order of magnitude estimate can be provided by assuming a hydraulic conductivity of 1 m d^{-1} in the direction of groundwater flow through a thickness of 20 m, which gives a transmissivity of 20 m^2d^{-1}.

Groundwater flow to the Fortescue River takes place along a width of about 15 000 m, under a hydraulic gradient of approximately 10^{-2}, therefore annual outflow is

$$20 \times 10^{-2} \times 15\ 000 \times 365 = 1.1 \times 10^{6}\ m^{3}.$$

Similarly, outflow to the Robe River is

$$20 \times 4 \times 10^{-3} \times 15\ 000 \times 365 = 0.4 \times 10^{6}\ m^{3}.$$

Total annual groundwater outflow could therefore be about $1.5 \times 10^{6}\ m^{3}$ which is very much less than the combined spring discharge of $14.8 \times 10^{6}\ m^{3}$.

Of the groundwater flow into the Proterozoic bedrock towards the Robe River and West Creek, most is lost by evapotranspiration from the extensive tracts of vegetation along the creeks. The remainder, which flows out through alluvium in the Robe River and West Creek near bore 66, can be calculated in a similar manner to the groundwater outflow in the bedrock. The hydraulic conductivity of the Robe River alluvium averages $11.5\ m\ d^{-1}$ and the average thickness of saturated alluvium is 6 m, therefore the flow through a 1 km width under the hydraulic gradient of 2.7×10^{-3} between 64A and 66D is

$$11.5 \times 6 \times 2.7 \times 10^{-3} \times 1\ 000 \times 365$$
$$= 0.069 \times 10^{6}\ m^{3}\ yr^{-1}$$

The flow for West Creek under similar conditions is

$$55 \times 40 \times 3.1 \times 10^{-3} \times 365$$
$$= 0.025 \times 10^{6}\ m^{3}\ yr^{-1}$$

so that total outflow from the investigation area via underflow in the Robe River bed is only about $0.1 \times 10^{6}\ m^{3}\ yr^{-1}$. This tends to support the order of magnitude estimate for groundwater throughflow in the Proterozoic bedrock towards the Robe River of $0.4 \times 10^{6}\ m^{3}\ yr^{-1}$, the balance being used by vegetation along the water courses.

WATER QUALITY

Groundwater salinity is least along the valley flanks due to peripheral recharge, and greatest in the centre of the valley where recharge is from the Fortescue River (Fig. 13).

The lowest salinity groundwater (300 - 400 mg L^{-1}) is in the Kumina Conglomerate and Millstream Dolomite aquifers close to Caliwingina and Weelumurra Creeks. Elsewhere in the Millstream Dolomite (away from the river) the salinity ranges from 500 to 1 000 mg L^{-1}.

Close to the Fortescue River in the unconfined dolomite aquifer, and also just to the east where the dolomite is confined, the salinity ranges from 1 000 to 1 500 mg L^{-1}. This area of high groundwater salinity is an enigma because it is definitely associated with the area of river recharge, yet the salinity of river floods ranges from 200 to 300 mg L^{-1}. It seems that there must be a buildup of salts along the river course by evaporation after minor flows and from concentration by the vegetation along the river; these salts having been flushed into the aquifer during major floods. Although the water table is only 5 - 8 m below the river bed, there does not appear to be a large amount of phreatophytic vegetation along the banks.

An anomalous area of high salinity was encountered by bore 42 (2 340 mg L^{-1}) close to the eastern edge of the dolomite aquifer. It may be due to a narrow tongue of saline water that originates from the Fortescue Valley east of Weelumurra Creek, which has been deflected to the northern side of the valley by the recharge mound along Weelumurra Creek.

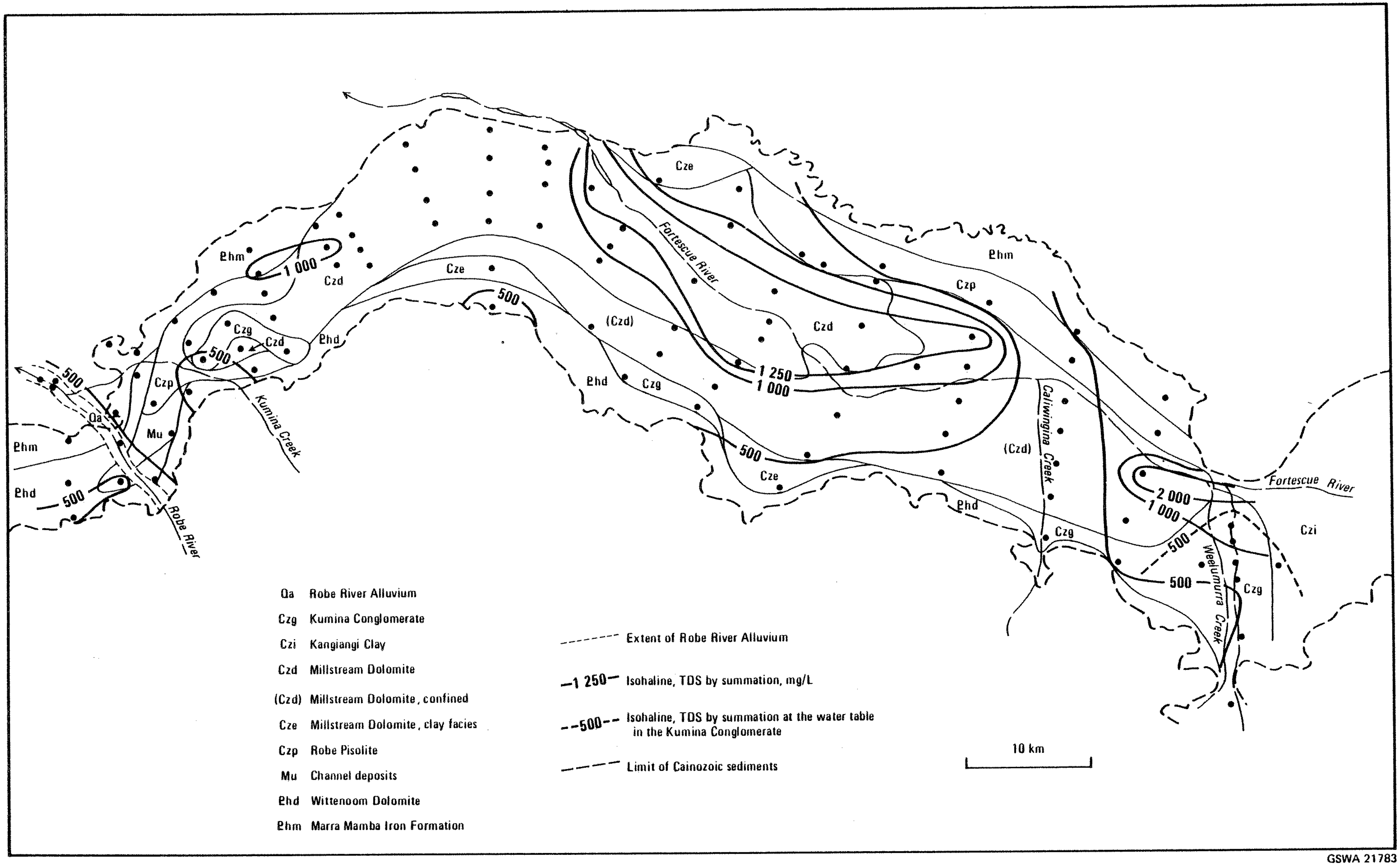


Figure 13. Groundwater salinity in the Cainozoic aquifers.

The chemical composition of the groundwater is dominated by the cations of sodium, magnesium and calcium, and the anions of bicarbonate and chloride, although a few analyses high in sulphate are found in the Marra Mamba Iron Formation (Figs 14 and 15).

As may be expected in a calcareous aquifer with relatively high concentration of total salts, most of the groundwater in the Millstream Dolomite is hard (200-300 mg L^{-1} total hardness as $CaCO^3$) or very hard (over 300 mg L^{-1}); only near Caliwingina Creek is there slightly to moderately hard water (100-200 mg L^{-1}).

The concentration of nitrate in the dolomite aquifer is generally 5-10 mg L^{-1}, but a few higher values of up to 32 mg L^{-1} occur (Fig. 14). In the dolomite aquifer subject to recharge directly from rain, west of Millstream, the range is higher (110-27 mg L^{-1}) even though the total salinity is lower than to the east. Nitrate concentrations are lower in the Caliwingina-Weelumurra Creeks area and very low in the Proterozoic bedrock (less than 1 mg L^{-1}).

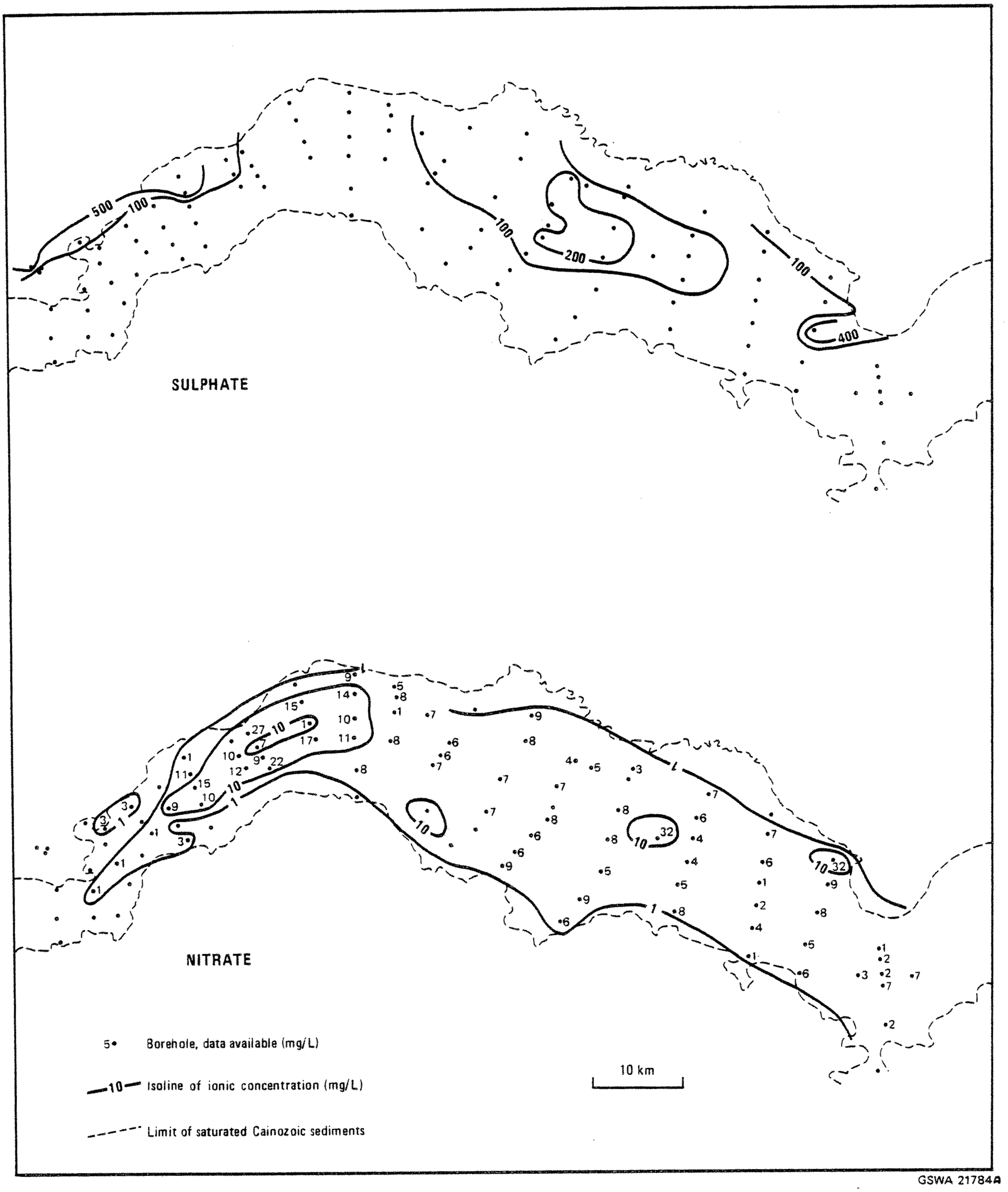
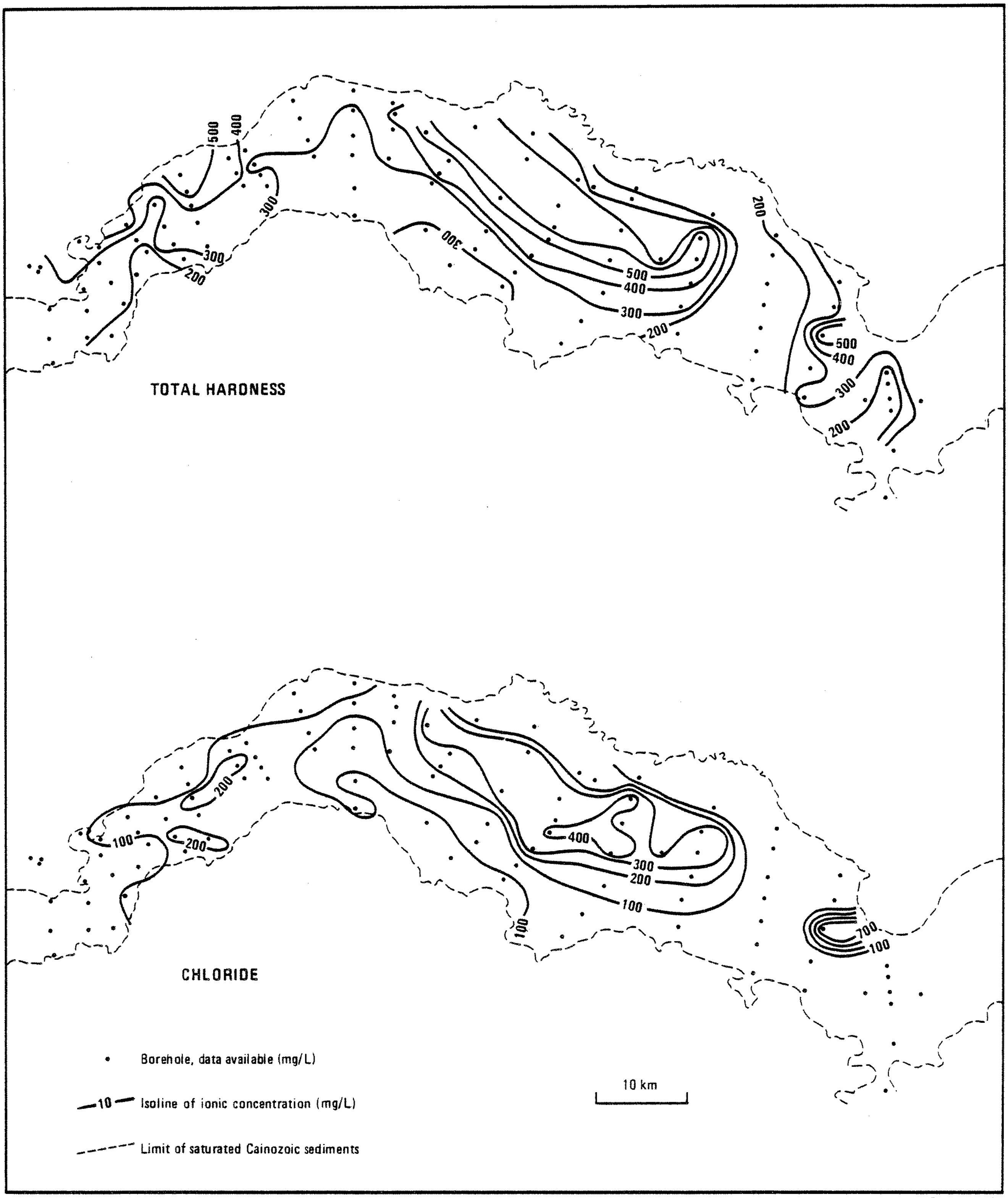


Figure 14. Distribution of total hardness, chloride, sulphate, and nitrate ions in groundwater.



TOTAL HARDNESS
500
400
300
200
CHLORIDE
400
300
200
100
700
Borehole, data available (mg/L)
10 Isoline of ionic concentration (mg/L)
Limit of saturated Cainozoic sediments
10 km

GSWA 21784B

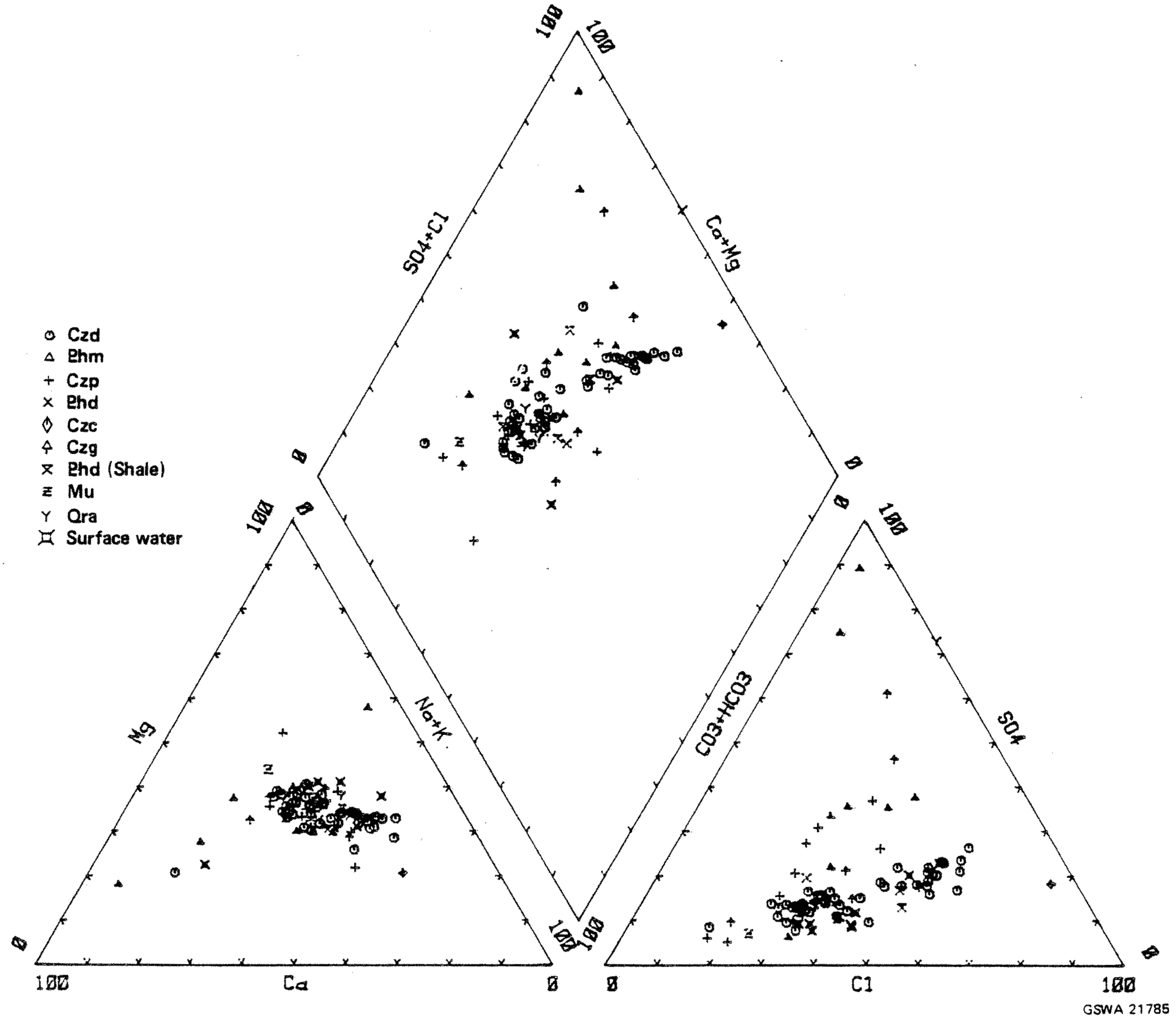


Figure 15. Piper diagram of chemical analyses.

STORAGE

Total storage in the Cainozoic aquifers is estimated to be about 1 700 x 10^6 m^3, by applying an average specific yield of 0.1 to the average saturated thickness. Of this amount nearly 1 400 x 10^6 m^3 has a total salinity of less than 1 000 mg L^{-1} (Table 5).

TABLE 5: STORAGE ESTIMATES

Aquifer	Salinity (mg L^{-1})	Area (km^2)	Storage per unit area	Storage x 10^6 (m^3)
Millstream Dolomite (unconfined)	<1000	250	1.5	375
Millstream Dolomite (unconfined)	>1000	200	1.5	300
Millstream Dolomite (confined)	<1000	450	1.5	675
Millstream Dolomite (confined)	>1000	50	1.5	75
Robe Pisolite	<1000	150	1.0	150
Kumina Conglomerate (Weelumurra)	<1000	120	1.0	120
Kumina conglomerate (Kumina area)	<1000	60	1.0	60

NOTE: Estimates exclude Yarraloola Conglomerate

Taking the total annual groundwater discharge to be about 16 x 10^6 m^3 the storage/discharge ratio is about 100 years.

DEVELOPMENT

Since 1969 groundwater has been pumped from the borefield at Millstream for the West Pilbara Water Supply. The total abstraction to the end of 1982 was about 92×10^6 m^3, and the annual abstraction in 1983-84 was about 10×10^6 m^3.

The effect of abstraction to June 1982 had been to lower the water table by 0.23 m below the average natural mean aquifer level of 293.60 m in the dolomite aquifer close to Millstream, which represents a storage depletion of approximately 23×10^6 m^3. As can be seen from Figure 10, flood recharge events periodically replace the depleted storage.

The lowered water table reduced spring flow into Deep Reach Pool and caused a drying up of the springs to the west. This has had a marked effect on the vegetation supported by Millstream Spring, and the spring is now supplemented by a bore. In 1981-82, 3.3×10^6 m^3 was pumped to supplement the spring and to make up the total outflow (including that from Deep Reach) of approximately 11.9×10^6 m^3 that is necessary to maintain vegetation in the Millstream Delta and Fortescue Pools System.

Abstraction from the Millstream borefield will be substantially reduced with the augmentation of the West Pilbara Water Supply by the Harding River Dam, which began in 1985. It is therefter intended to use the Millstream borefield only when the Harding Dam storage is depleted.

CONCLUSIONS

The investigation has proved a large resource, total storage of about 1 700 x 10^6 m^3 of fresh or marginal quality water (less than 1 500 mg L^{-1} TDS) in aquifers in the western Fortescue Valley, and has identified areas where groundwater salinity is significantly lower than in the present borefield.

Exploratory drilling has delineated a complex sequence of Cainozoic sediments, which form an interconnected flow system, and has identified the sources of recharge and directions of groundwater flow.

Monitoring of water levels has demonstrated the importance of recharge from infrequent river flows, but because of the variability of runoff the average recharge from this source cannot be determined from the comparatively short period of record.

Abstraction, currently at 10 x 10^6 m^3 yr^{-1}, has caused a small drop in the water table, but this has been sufficient to significantly reduce spring flow, with a consequent effect on the spring-supported vegetation. The environmental effects of spring flow diversion can be minimised by supplementation of the springs from groundwater.

The large groundwater storage in the dolomite aquifer can be utilised at present abstraction rates. Continued monitoring of water levels should show to what extent the aquifer storage will be replenished by periodic river floods.

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APPENDIX 1. SUMMARY OF BOREHOLE DATA

Bore	Reduced level casing top (m AHD)	Reduced level natural surface (m AHD)	Date drilled: Commenced	Date drilled: Completed	Total Depth (m)	Status	Screened (m bns)	Aquifer (see legend below)	SWL (a) (m)	Salinity (mg L^{-1} TDS) (Summation)	Yield (m^3d^{-1})	Remarks
1A	–	–		01.04.68	40.8	–	11.8-17.9	Czd	2.2	879	1 620	
1B	300.66	300.5			27.8	OBS	7.0-13.1	Czd	6.7	919	1 620	
1C	–	–		20.05.68	41.4	OBS	12.2-18.2	Czd	10.9	772	1 620	
1D	–	314.8			45.1	OBS	21.6-27.7	Czd	20.7	739	1 620	
2A	–	–	22.05.68	03.08.68	23.7	–	–	Czd	–	–	–	Dry
2B	–	315.2	27.05.68	09.08.68	55.2	OBS	22.7-28.9	Czd	–	672	1 630	
2C	–	316.9	27.07.68	29.07.68	59.4	OBS	27.3-42.1	Czd	23.1	760	–	
2D	–	317.6	11.08.68	25.09.68	45.1	–	24.4-30.5	Czd	–	631	2 790	
3A	–	301.4	16.08.68	09.10.68	36.5	OBS	10.6-16.1	Czd	7.5	1 330	2 790	

(a) Static Water Level

Legend:
- Qha – Alluvium
- Czc – Colluvium
- Czg – Kumina Conglomerate
- Czd – Millstream Dolomite
- Czp – Robe Pisolite
- Mu – channel deposits, undifferentiated
- Kny – Yarraloola Conglomerate
- Phm – Marra Mamba Iron Formation
- Phd – Wittenoom Dolomite
- Ph – Proterozoic, undifferentiated
- Pd – Dolerite
- ABD – Abandoned
- OBS – Observation

Bore	Reduced level casing top (m AHD)	Reduced level natural surface (m AHD)	Date drilled Commenced	Date drilled Completed	Total Depth (m)	Status	Screened (m bns)	Aquifer (see legend)	SWL (a) (m)	Salinity (mg L^{-1} TDS) (Summation)	Yield (m^{3}d^{-1})	Remarks
4A	–	316.3	18.07.68	01.09.68	57.0	OBS	22.8-28.9	Czd	22.6	623	2 790	
4B	–	317.5	10.08.68	11.08.68	45.7	OBS	24.0-30.2	Czd	23.6	714	–	
4C	–	317.1	07.08.68	09.08.68	55.7	OBS	23.9-42.5	Czd	23.0	714	–	
4D	–	317.8	12.08.68	05.09.68	46.9	–	22.5-28.6	Czd	23.6	884	720	
5A	–	305.3	12.08.68	14.08.68	46.3	OBS	17.0-35.0	Czd	11.3	1 170	–	
5B	–	313.6	14.08.68	21.10.68	45.7	OBS	22.5-28.6	Czd	19.3	1 114	2 790	
5C	–	309.6	15.08.68	16.08.68	36.5	OBS	18.6-24.6	Czd	15.6	644	–	
6A	–	317.5	05.08.68	05.08.68	30.4	ABD	–	Phm	20.6	–	–	
6B	–	315.8	04.08.68	15.09.68	35.3	OBS	20.6-26.7	Czd	21.8	801	160	
6C	317.78	317.54	28.10.77		41.6	OBS	26.9-39.6	Phm	20.19	1 122	<100	
7A	–	308.4	02.08.68	03.08.68	38.1	OBS	15.2-27.4	Czd	14.52	702	–	
7B	–	315.0	12.08.68	30.09.68	47.5	OBS	24.4-31.1	Czd	21.1	771	2 790	
7C	–	315.6	29.07.68	01.08.68	53.3	OBS	18.8-37.2	Czd	21.7	592	–	
7D	–	317.1	12.08.68	26.09.68	45.1	OBS	24.0-30.1	Czd	23.2	684	2 790	
8A	–	318.2	05.08.68	05.08.68	18.3	ABD	–	Phm?	–	–	–	Dry
8B	–	316.5	05.08.68	14.09.68	44.1	OBS	23.7-29.5	Czd	22.1	1 074	–	

(a) Static Water Level

Bore	Reduced level casing top (m AHD)	Reduced level natural surface (m AHD)	Date drilled: Commenced	Date drilled: Completed	Total Depth (m)	Status	Screened (m bns)	Aquifer (see legend)	SWL (a) (m)	Salinity ($mg\ L^{-1}$ TDS) (Summation)	Yield (m^3d^{-1})	Remarks
8C	-	317.8	06.08.68	11.09.68	49.3	OBS	24.6-31.4	Czd	23.4	700	2 585	
9	317.38	317.00	12.02.72	02.11.72	229.2	OBS	48.3-56.3	Czp	23.50	737	1 310	
10	362.84	362.34	11.03.72	10.10.72	219.8	OBS	38.0-62.0	Phd	12.24	499	1 310	
11	378.31	378.01	05.04.72	19.07.72	169.3	ABD	-	-	-	-	-	
11A	-	-	21.07.72	20.11.72	110.0	OBS	65.0-85.3	Czg	57.78	-	-	
12A	318.37	318.18	19.09.74	21.09.74	43.0	OBS	30.2-36.5	Czd	22.52	555	-	
13A	307.23	306.52	16.09.74	19.09.74	38.9	OBS	13.8-28.4	Czd	12.81	1 287	-	
13B	-	-	21.09.79	27.09.79	36.6	OBS	14.7-27.1	Czd	-	1 224	1 000	
13C	-	-	01.10.79	17.10.79	45.5	OBS	14.7-27.0	Czd	-	-	-	
14A	313.80	313.17	03.10.74	12.10.74	57.6	OBS	23.0-33.6	Czd	19.71	1 170	-	
15A	-	-	23.09.74	26.09.74	23.5	ABD	-	-	-	-	-	
15B	320.23	319.48	27.09.74	02.10.74	38.7	OBS	24.0-33.3	Czd	21.80	1 382	-	
15C	-	-	31.10.79	02.11.79	39.8	OBS	26.0-32.2	Czd	-	1 576	580	
15D	-	-	04.11.79	06.11.79	29.5	ABD	-	Czd	-	-	-	
15E	-	-	18.03.82	23.03.82	57.3	OBS	26.0-32.0	Czd	21.00	1 595	730	
16A	317.55	317.07	15.10.74	18.10.74	43.5	OBS	27.6-36.7	Czd	19.31	1 298	-	

(a) Static Water Level.

Bore	Reduced level casing top (m AHD)	Reduced level natural surface (m AHD)	Date drilled: Commenced	Date drilled: Completed	Total Depth (m)	Status	Screened (m bns)	Aquifer (see legend)	SWL (a) (m)	Salinity (mg L^{-1} TDS) (Summation)	Yield (m^3d^{-1})	Remarks
17A	321.85	321.78	21.10.74	22.10.74	43.9	OBS	24.0-37.5	Czd	18.12	1 465	-	
17B	-	-	18.10.74	22.10.74	60.8	OBS	25.4-37.7	Czd	-	-	>1 000	
17C	-	-	23.10.79	24.10.79	41.5	OBS	25.4-37.7	Czd	-	-	>365	
18A	-	-	23.10.79	28.10.74	37.5	OBS	26.5-35.5	Czd	20.40	1 329	-	
19A	325.86	325.26	29.10.74	31.10.74	51.4	OBS	39.3-45.8	Czc	-	1 166	-	
20A	316.53	316.00	02.11.74	07.11.74	39.7	OBS	23.6-31.7	Czd	19.00	1 260	-	
21A	333.74	333.03	08.11.74	09.11.74	39.7	OBS	17.0-25.3	Czg	-	-	-	Dry
22A	317.98	317.57	22.07.75		24.8	OBS	18.2-24.8	Czd	17.60	525	Poor	
22B	-	-	09.07.76	12.07.76	50.4	OBS	16.6-47.3	Czd	-	776	250	
23A	330.25	329.89	17.07.75	18.07.75	55.9	OBS	29.3-55.5	Czd	24.42	690	Good	
23B	-	-	19.07.82	23.07.82	60.5	OBS	38.5-50.5	Czd	24.3	474	600	
24A	326.51	325.95	15.07.75	16.07.75	51.9	OBS	25.6-51.8	Czd	20.11	981	180	
25A	325.46	324.96	24.07.75	25.07.75	51.4	OBS	21.7-47.9	Czd	19.00	1 208	Good	
26A	330.34	329.83	29.07.75	30.07.75	46.2	OBS	26.4-45.8	Czd	23.96	1 370	Good	
27A	363.09	362.54	16.08.75	19.08.75	48.4	OBS	32.2-44.8	Czg	40.94	322	-	
27B	363.817	363.39	09.07.82	13.07.82	120.0	OBS	74.0-120	Czd/Mu	49.42	347	63	

(a) Static Water Level.

Bore	Reduced level casing top (m AHD)	Reduced level natural surface (m AHD)	Date drilled		Total Depth (m)	Status	Screened (m bns)	Aquifer (see legend)	SWL (a) (m)	Salinity ($mg\ L^{-1}$ TDS) (Summation)	Yield (m^3d^{-1})	Remarks
			Commenced	Completed								
28B	331.27	330.82	13.08.75	15.08.75	38.4	OBS	27.4-31.4	Czg	30.34	1 470	-	
28C	351.937	351.53	14.07.82	17.07.82	90.5	OBS	61.0-90.5	Czd	38.43	363	365	
29A	339.84	339.39	11.08.75	12.08.75	60.4	OBS	46.9-53.4	Czd	32.30	489	Good	
30A	332.15	331.91	07.08.75	08.08.75	64.5	OBS	29.0-55.4	Czd	24.74	406	Good	
30B	-	-	23.07.82	28.07.82	73.0	OBS	45.0-57.0	Czd	24.8	480	400	
31A	332.03	331.55	31.07.75	04.08.75	46.3	OBS	26.3-46.0	Czp/Phm	20.98	331	-	
31B	-	-	29.07.82	30.07.82	42.0	OBS	33.3-39.0	Czp	20.84	334	1 540	
32A	311.45	310.90	18.05.76	19.05.76	46.4	OBS	20.4-46.4	Czd/Phm	13.66	784	700	
33A	317.24	316.75	29.04.76	30.04.76	32.5	OBS	23.0-32.4	Czp	18.19	612		
34A	324.20	323.65	30.04.76	03.05.76	37.4	OBS	20.1-36.5	Czp/Phm	16.88	369	100	
35A	335.53	333.11	04.05.76	06.05.76	65.0	OBS	26.2-61.2	Czd/Czp	26.46	339	850	
36A	-	-	06.05.76	10.05.76	10.6	ABD	-	-	-	-		
36B	345.43	344.99	10.05.76		43.5	OBS	21.8-38.6	Phm	25.44	536	<100	
37A	322.86	322.31	11.05.76	13.05.76	52.7	OBS	26.0-52.0	Czd	24.45	588	1 500	
38A	-	358.94	07.07.76	08.07.76	69.7	ABD	-	-	-	-	-	
38B	359.085	358.68	01.06.82	09.06.82	94.5	OBS	50.0-80.0	Czd/Czp	51.95	369	63	

(a) Static Water Level.

Bore	Reduced level casing top (m AHD)	Reduced level natural surface (m AHD)	Date drilled: Commenced	Date drilled: Completed	Total Depth (m)	Status	Screened (m bns)	Aquifer (see legend)	SWL (a) (m)	Salinity (mg L^{-1} TDS) (Summation)	Yield (m^3d^{-1})	Remarks
39A	-	380.02	23.08.76		11.9	ABD	-	-	-	-	-	
39B	381.144	380.26	12.06.82	26.06.82	165.0	OBS	100 - 120	Mu	46.76	285	63	
40A	-	-	04.08.76	05.08.76	7.0	ABD	-	-	-	-	-	
40B	368.54	368.16	10.08.76	16.08.76	81.7	ABD	-	-	47.61	-	-	
40C	368.608	368.25	03.07.82	07.07.82	98.0	OBS	44.5-90.0	Czg/Czd	47.62	807	125	
41A	351.32	351.08	26.07.76	04.08.76	79.5	ABD	-	-	36.44	-	-	
41B	351.22	351.01	17.08.76	19.08.76	62.7	ABD	-	-	-	-	-	
41C	351.787	351.12	26.06.82	02.07.82	82.5	OBS	40.0-80.0	Czd/Czp	37.64	710	462	
42A	341.78	341.17	15.07.76	23.07.76	68.3	OBS	29.1-66.7	Czd	28.76	2 340	450	
43A	339.51	339.14	14.07.76	15.07.76	61.9	OBS	29.0-61.0	Czp/Phm	25.71	515	350	
44A	352.48	351.81	12.07.76	13.07.76	42.7	OBS	32.0-42.7	Phm	29.07	783	Very poor	
45A	309.52	309.01	20.05.76	21.05.76	40.1	OBS	14.1-40.1	Czp/Phm	12.94	942	480	
46A	321.80	321.28	26.05.76	28.05.76	46.4	OBS	30.0-46.4	Czd	27.96	734	>160	
47A	313.42	313.04	01.06.76	02.06.76	27.2	OBS	21.2-26.4	Phm	20.09	390	<100	
48A	318.15	317.82	27.05.76	31.05.76	53.7	OBS	26.4-53.7	Czd/Czp	24.30	-	-	
49A	324.60	324.03	02.06.76	04.06.76	59.0	OBS	32.0-57.9	Czd/Czp	30.67	-	-	

(a) Static Water Level.

Bore	Reduced level casing top (m AHD)	Reduced level natural surface (m AHD)	Date drilled Commenced	Date drilled Completed	Total Depth (m)	Status	Screened (m bns)	Aquifer (see legend)	SWL (a) (m)	Salinity (mg L^{-1} TDS) (Summation)	Yield (m^3d^{-1})	Remarks
1/76	318.51	318.21	11.76		51.4	OBS	27.0-50.4	Czd/Czp	-	707	2 735	
2/76	324.36	324.06	11.76		56.6	OBS	37.9-55.6	Czd/Czp	-	753	545	
49C	323.96	323.78	15.08.78	24.08.78	53.5	OBS	31.0-53.4	Czd/Czp	-	-	-	
50A	311.31	310.82	21.06.76	22.06.76	46.9	OBS	17.4-44.4	Phm?	28.56	756	<35	
51A	311.75	311.30	08.06.76	09.06.76	52.5	OBS	19.7-46.0	Czp/Phd	18.20	558	>146	
52A	319.80	-	09.06.76	18.06.76	45.0	ABD	-	-	-	-	-	
52B	-	-	09.06.76	18.06.76	14.4	ABD	-	-	-	-	-	
52C	319.88		09.06.76	18.06.76	48.4	ABD	-	-	-	-	-	
52D	319.80		29.06.76	01.07.76	52.6	ABD	-	-	-	-	-	
52E	320.07		08.07.78	14.07.78	54.6	ABD	-	-	-	-	-	
52F	320.08	319.86	06.09.78	11.09.78	68.0	OBS	49.9-67.9	Czp	26.97	458	1 340	
53A	303.90	303.36	24.06.76	25.06.76	66.7	OBS	21.1-65.0	Ph	13.67	372	<100	
54A	290.80	289.76	23.06.76	24.06.76	18.9	OBS	8.3-18.4	Phm	9.22	845	>215	
55A	294.47	293.97	29.06.76		19.6	OBS	9.6-19.6	Phd	10.02	523	>210	
56A	298.66	297.96	28.06.76		54.0	OBS	12.2-53.6	Czp/?Kny	11.25	-	-	
56B	299.70	299.00	18.07.78	25.07.78	54.0	OBS	29.8-53.9	Kny	-	584	1 610	

(a) Static Water Level

Bore	Reduced level casing top (m AHD)	Reduced level natural surface (m AHD)	Date drilled Commenced	Date drilled Completed	Total Depth (m)	Status	Screened (m bns)	Aquifer (see legend)	SWL (a) (m)	Salinity ($mg\ L^{-1}$ TDS) (Summation)	Yield (m^3d^{-1})	Remarks
57A	316.03	315.53	14.05.76	18.05.76	38.3	OBS	18.4-38.0	Czp	16.92	974	Very good	
58A	340.26	340.00	14.06.78	01.07.78	88.1	OBS	74.9-87.8	Phd	40.67	756	<100	
59A	334.47	334.21	17.06.78	27.06.78	112.0	OBS	103.6-110.2	Phd	40.31	634	<100	
59B	334.93	334.74	25.08.78	31.08.78	113.0	OBS	103.5-110.5	Phd	-	-	145	
60A	316.00	315.76	19.05.78	22.05.78	48.5	OBS	41.8-47.8	Phd	26.76	403	>160	
61A	326.53	326.46	26.10.77	27.10.77	32.5	OBS	3.1-32.5	Czg	19.19	-	-	Open Hole
61B	326.75	326.55	27.05.78	13.06.78	142.0	OBS	93.9-139.8	Czg/Mu	39.28	701	<100	
62A	283.53	283.34	06.07.78	07.07.78	20.0	OBS	10.6-19.8	Phm	4.86	671	190	
62B	283.04	282.74	28.07.78	10.07.78	23.0	OBS	8.9-15.2	Pd	-	-	<100	
63A	294.44	294.03	18.10.77	20.10.77	22.5	OBS	15.8-22.2	Phm	16.86	515	<100	
64A	284.68	283.46	31.10.77	01.11.77	33.0	OBS	12.6-32.1	Qha/Phd	4.60	205	<100	
65A	-	-	20.10.77	24.10.77	42.0	ABD	-	-	-	-	-	
65B	301.55	301.39	25.05.78	26.05.78	58.6	OBS	25.8-58.2	Kny	15.94	556	>170	
66A	-	-	03.07.78	04.07.78	6.6	ABD	-	-	-	-	>55	
66B	-	-	04.07.78	05.07.78	3.0	ABD	-	-	-	-	-	
66C	-	-	18.09.78	20.09.78	7.1	ABD	-	-	-	-	-	

(a) Static Water Level.

Bore	Reduced level casing top (m AHD)	Reduced level natural surface (m AHD)	Date drilled: Commenced	Date drilled: Completed	Total Depth (m)	Status	Screened (m bns)	Aquifer (see legend)	SWL (a) (m)	Salinity ($mg\ L^{-1}$ TDS) (Summation)	Yield (m^3d^{-1})	Remarks
66D	262.21	261.26	20.09.78	21.09.78	12.0	OBS	0-12.0	Qha	3.49	445	-	
67A	300.01	299.59	25.10.77		17.5	OBS	11.0-17.4	-	Dry	-	-	
68A	314.70	314.32	25.10.77	26.10.77	29.7	OBS	23.0-29.5	Czp	20.23	420	<100	
69A	352.93	352.73	23.05.78	24.05.78	83.0	OBS	61.4-80.7	Phd	66.10	1 035	<100	
70A	322.42	322.14	27.10.77	28.10.77	29.5	OBS	22.8-29.3	Phm	24.41	1 385	<100	
71A	337.661	337.47	19.04.82	29.04.82	79.6	OBS	30.0-48.0	Czg	34.42	804	Low	
72A	325.347	324.86	30.04.82	05.05.82	66.0	OBS	20.0-57.0	Czd	29.87	801	150	
73A	-	-	01.04.82	06.04.82	52.0	ABD	-	-	-	-	-	
73B	346.095	345.59	14.04.82	15.04.82	157.8	OBS	110 - 140	Mu	43.26	719	150	
74A	331.940	331.37	25.05.82	29.05.82	66.5	OBS	35.0-57.0	Czd	31.40	592	63	
74B	331.788	331.43	13.08.82	18.08.82	61.0	OBS	45.0-57.0	Czd	-	530	336	
75A	365.395	364.76	11.05.82	15.05.82	81.3	OBS	30.0-80.0	Czd	51.08	471	Low	
76A	319.463	319.28	24.03.82	31.03.82	59.3	OBS	15.0-37.0	Czd	14.92	1 193	580	
77A	312.64	312.23	25.10.79	30.10.79	57.5	OBS	15.1-21.2	Czd	14.47	1 209	65	
78A	258.08	257.16	27.09.78	29.09.78	21.5	OBS	3.0-19.0	Qha	4.42	1 420	<100	
79A	263.31	262.22	22.09.78	25.09.78	18.6	OBS	3.0-18.0	Qha	4.76	364	>25	

(a) Static Water Level.

Bore	Reduced level casing top (m AHD)	Reduced level natural surface (m AHD)	Date drilled		Total Depth (m)	Status	Screened (m bns)	Aquifer (see legend)	SWL (a) (m)	Salinity (mg L^{-1} TDS) (Summation)	Yield (m^3d^{-1})	Remarks
			Commenced	Completed								
W1A	369.50	369.32	30.05.75	05.06.75	61.0	OBS	39.2-51.5	Czg	31.87	719	<100	
W2A	362.76	362.54	15.05.75	22.05.75	76.0	OBS	49.0-66.9	Czg	23.22	1 071	<100	
W3A	368.29	367.51	26.05.75	27.05.75	74.0	OBS	57.7-63.7	Czg	34.64	922	130	
W4A	-	-	15.04.75	23.04.75	56.0	ABD	-	-	-	-	-	
W4B	-	-	23.04.75	30.04.75	85.0	ABD	-	-	-	-	-	
W4C	375.25	375.06	30.04.75	06.05.75	71.0	OBS	51.8-70.3	Czg	-	410	765	
W5	395.91	395.32	.06.75	08.05.75	67.4	OBS	-58.2	Czg	-	793	196	
W6	425.15	424.96	.12.75	14.05.75	69.0	ABD	-	-	-	515	-	
W7A	359.187	358.85	06.08.82	12.08.82	74.0	OBS	26.0-38.0	Czg	0.98	393	190	
W8A	371.627	371.23	31.07.82	05.08.82	86.0	OBS	34.0-52.0	Czg	8.29	390	650	

(a) Static Water Level

Legend:
- Qha - Alluvium
- Czc - Colluvium
- Czg - Kumina Conglomerate
- Czd - Millstream Dolomite
- Czp - Robe Pisolite
- Mu - channel deposits, undifferentiated
- Kny - Yarraloola Conglomerate
- Phm - Marra Mamba Iron Formation
- Phd - Wittenoom Dolomite
- Ph - Proterozoic, undifferentiated
- Pd - Dolerite
- ABD - Abandoned
- OBS - Observation

APPENDIX 2. PUMPING TEST DETAILS

Bore	Date of Testing		Tested Interval (m)	Aquifer	Static Water Level (m below casing top)	Constant Rate Rest			Step-drawdown test	
	Commenced	Completed				Q (m^3d^{-1})	Duration (hours)	Final Drawdown (m)	Range of Q (m^3d^{-1})	% Efficiency
1/76	06.12.76	08.12.76	27.0-46.4	Czd/Czp	24.7	1 375	10	1.85	545-2735	88-18
2/76	08.12.76	09.12.76	37.9-53.4	Czd/Czp	30.6	545	8	7.1	160- 545	88-50
9	06.07.72	25.07.72	48.3-61.0	Czp	23.5	982	192	12.8	546-1309	50-23
10	11.08.72	15.08.72	38.0-62.0	Phd	12.2	1 310	72	21.3	546-1418	-
13B	28.08.82	30.08.82	14.7-27.1	Czd	13.2	1 710	8	0.49	285-1710	7
15C	31.08.82	01.09.82	26.0-32.2	Czd	21.3	1 543	8	1.14	254-1543	28
17B	02.09.82	03.09.82	25.4-37.7	Czd	17.8	1 543	8	1.14	254-1543	24
23B	04.09.82	06.09.82	38.5-50.5	Czd	24.3	600	8	5.2	132- 654	16
30B	09.09.82	10.09.82	45.0-57.0	Czd	24.8	396	8	12.4	70- 396	51
31B	07.09.82	09.09.82	33.0-39.0	Czp	20.8	1 585	8	1.45	264-1585	20
46A	21.08.79	21.08.79	30.0-46.4	Czd	27.6	161	4	0.36	33- 161	90-66
50A	24.08.79	27.08.79	17.4-44.4	?Phm	28.7	130	4	0.16	26- 103	Not analysable
51A	23.08.79		19.7-46.0	Czd/Czp	18.8	146	4	2.48	32- 146	76-40
52F	05.09.79	07.09.79	49.9-67.9	Czp	26.9	1 343	12	7.2	212-1343	78-42
53A	20.10.78	30.10.78	21.1-65.0	Phd (a)	15.3	41	3.5	22.8	10- 41	Not analysable
54A	27.08.79	28.08.79	8.3-18.4	Phm	9.3	195	4	0.10	41- 195	Not analysable

(a) Shale section.

Bore	Date of Testing: Commenced	Date of Testing: Completed	Tested Interval (m)	Aquifer	Static Water Level (m below casing top)	Constant Rate Rest: Q (m^3d^{-1})	Constant Rate Rest: Duration (hours)	Constant Rate Rest: Final Drawdown (m)	Step-drawdown test: Range of Q (m^3d^{-1})	Step-drawdown test: % Efficiency
55A	28.08.79	29.08.79	9.6-19.6	Phd (b)	10.2	192	4	0.24	39- 192	86-67
56B	10.09.79	10.09.79	29.8-53.9	Kny	11.2	1 610	12	4.4	350-1610	56-22
58A	22.08.79	22.08.79	74.9-87.8	Phd (a)	40.7	46	0.5	6.5	-	-
59A	04.09.79	05.09.79	103.6-110.2	Phd	40.2	101	4	1.6	22- 101	80-35
60A	17.08.79	20.08.79	41.8-47.8	Phd	26.7	163	4	1.15	35- 163	91-71
61B	14.08.79	15.08.79	93.9-139.8	Czg, Phd (a)	39.2	80	4	4.9	17- 80	80-68
62A	30.08.79	31.08.79	10.6-19.8	Phm	5.1	189	4	3.4	41- 189	95-76
64A	14.11.78	15.11.78	12.6-32.1	Qha, Phd	5.3	39	12	(c)1.24	7- 39	80-77
65B	16.08.79	16.08.79	25.8-58.2	Kny	16.5	170	4	2.7	37- 170	95-81
66D	10.10.78	11.10.78	3.5-12.0	Qha	3.5	53	12	(d)0.07	12- 53	Not analysable
69A	16.10.78	18.10.78	61.4-80.7	Phd	66.1	14	12	1.13	2- 14	Not analysable
74B	24.10.82	25.10.82	35.0-57.0	Czd	31.4	336	8	10.8	54- 336	39
78A	02.10.78	04.10.78	3.0-19.0	Qha	4.6	27	12	4.6	5- 27	Not analysable
79A	05.10.78	06.10.78	3.0-18.0	Qha	5.2	27	12	(e)0.04	5- 27	Not analysable

(a) Shale section.

(b) Weathered.

(c) Drawdown after 6 hours.

(d) Drawdown after 1 hour.

(e) Drawdown after 0.5 hour.

Bore	Date of Testing		Tested Interval (m)	Aquifer	Static Water Level (m below casing top)	Constant Rate Rest			Step-drawdown test	
	Commenced	Completed				Q (m^3d^{-1})	Duration (hours)	Final Drawdown (m)	Range of Q (m^3d^{-1})	% Efficiency
W1A	01.08.75	01.08.75	39.2-51.5	Czg	31.9	26	2	6.6	-	-
W2A	31.07.75	31.07.75	49.0-66.9	Czg	23.2	(f) 26-7	2	15.8	-	-
W3A	29.07.75	29.07.75	57.7-63.7	Czg	34.6	131	3	9.0	-	-
W4C	24.07.75	26.07.75	51.8-70.3	Czg	29.8	546	24	5.8	325- 765	Not analysable
W5A	14.07.75	14.07.75	47.0-58.2	Czg	9.8	196	24	16.3	-	-
W7	15.09.82	15.09.82	26.0-38.0	Czg	20.9	170	6	3.6	57- 190	81
W8	11.09.82	14.09.82	34.0-52.0	Czg	28.3	588	6	3.4	98- 653	62

(f) Bailed, rate reduced because of large drawdown.

Values for hydraulic conductivity refer to the screened or slotted interval (after subtraction of obviously impermeable intervals in a few cases).

For aquifer legend see end of Table 1.

APPENDIX 3. PUMPING TEST RESULTS

Bore	Transmissivity (m^2d^{-1})	Hydraulic Conductivity $(m\ d^{-1})$	Type of Analysis	Reliability of Analysis	Remarks
1/76	910	39	Theis	Good	Controlled test - Observation Bore 48A
2/76	35	2	Theis	Good	Controlled test - Observation Bores 49A, 49C
9	210	16.5	Theis	Good	No response in Bore 7D 23 m away, slotted 24.4-31.2 in Czd
10	97	4	Theis	Good	
13B	(50 000)	(4 000)	Walton (a)	Poor	Less than 0.01 m drawdown in observation bores at 20 m
15B	(5 600)	(900)	Walton (a)	Poor	0.08 m drawdown in 15E at 20 m
17B	1 290	107	Theis	Good	Observation Bores 17A & 17C
23B	120	10	Theis	Fair	Pumped bore analysis, observation bore drawdown only 0.04 m
30B	2 200	180	Theis	Good	Observation Bore 30A, Max. drawdown 0.1 m
31B	(5 260)	(880)	Walton (a)	Poor	Drawdown in observation bore 31A, only 0.007 m
46A	420	45	Theis	Good	
50A	540	90	Boulton	Fair	Originally tested 26-30.10.78. Results poor so bore retested
51A	10	0.5	Boulton	Fair	
52F	230	15	Boulton	Fair	Controlled test - Observation Bores 52D, 52E
53A	0.5	0.01	Theis	Fair	

(a) Specific capacity.

NOTE: ( ) derived from unreliable analysis.

Bore	Transmissivity (m^2d^{-1})	Hydraulic Conductivity ($m\ d^{-1}$)	Type of Analysis	Reliability of Analysis	Remarks
54A	(3 500)		Walton (a)	Poor	Originally tested 7-10.11.78 results from both test series not analysable - probably because aquifer is fractured rock
55A	(1 500)		Walton (a)	Poor	Originally tested 2-3.11.78 results from both test series not analysable - probably because aquifer is weathered rock
56B	1 400	39	Boulton	Good	Controlled test - Observation Bore 56A
58A	1	0.05	Boulton	Fair	
59A	24	5	Theis	Fair	Controlled test - Observation Bore 59B
60A	100	17	Theis	Fair	
61B	6	0.25	Boulton	Fair	No reaction in nearby Bore 61A (perched water in Czg)
62A	55	6	Theis	Fair	Apparent match may be invalid as aquifer is fractured rock. Bore 62B was tested at 62 m^3d^{-1} for 30 minutes (drawdown 6.45 m) in fractured dolerite.
	12	0.6	Boulton	Good	
64A	45	2	Theis	Good	
65B	42	9	Boulton	Good	

(a) Specific capacity.

NOTE: ( ) derived from unreliable analysis.

Bore	Transmissivity (m^2d^{-1})	Hydraulic Conductivity ($m\ d^{-1}$)	Type of Analysis	Reliability of Analysis	Remarks
66D	10	0.5	Boulton	Fair	
69A	125	10	Theis	Fair	Observation bore 74A
74B	1.4	0.1	Boulton	Fair	
78A	110	14	Boulton	Fair	
79A	45	3.7	Walton (a)	Poor	Bailed
W2A	7	0.4	Walton (a)	Poor	Bailed, rate reduced because of large drawdown
W3A	12	2.0	Walton (a)	Poor	
W4C	110	5.9	Theis	Poor	
W5A	14	0.8	Theis	Poor	
W7	10	0.8	Theis	Fair	Pumped bore only
W8	36	2.0	Theis	Fair	Pumped bore only

(a) Specific capacity.

NOTE: ( ) derived from unreliable analysis.

APPENDIX 4. CHLORIDE CONTENT OF RAINFALL

Site	Sample Period	Laboratory Number	Rainfall (mm)	Chloride (mg L^{-1})	Weighted Average Chloride (mg L^{-1})
Bore 13A	13.04.78-25.05.78	83798	26.0	1.6	
	27.07.78-07.09.78	86765	127.0	0.2	
	07.09.78-19.10.78	81110	1.6	11.7	1.0
	17.11.78-21.03.79	84009	96.4	0.9	
	05.10.79-03.04.80	81W5008	169.0	1.4	
	03.04.80-18.06.80	81W5009	49.0	1.1	
Bore W4C	14.03.78-13.04.78	82437	21.8	1.0	
	23.05.78-05.09.78	86763	127.5	0.4	
	04.10.79-03.01.80	81W5002	119.2	1.7	0.9
	31.01.80-02.04.80	81W5003	156.0	0.7	
	02.04.80-19.06.80	81W5004	86.0	0.8	
Bore 56A	22.04.78-24.05.78	83799	29.0	0.9	
	26.07.78-06.09.78	86764	129.5	0.2	
	26.10.78-15.11.78	81111	8.2	9.4	1.2
	15.11.78-22.03.78	84010	194.5	0.5	
	30.01.80-31.03.80	81W5010	260.0	2.0	
Fish Pool	13.04.78-25.07.78	86768	55.0	0.8	
	25.05.78-24.07.78	86767	89.0	1.5	
	19.01.79-22.01.79	81109	14.5	4.6	
	22.01.79-27.03.79	84011	188.6	0.7	
	25.06.79-23.10.79	81W4997	5.8	9.3	1.4
	23.10.79-22.01.80	81W4998	57.7	3.0	
	22.01.80-11.03.80	81W4999	43.5	1.7	
	11.03.80-01.04.80	81W5000	10.6	1.8	
	18.06.80-02.10.80	81W5001	98.4	1.2	
				AVERAGE	1.1

APPENDIX 5. WATER ANALYSES

Bore	Cond. ($mS\ m^{-1}$) (25°C)	Ca	Mg	Na	K	Cl	SO_4	HCO_3	NO_3	SiO_2	B	F	Hardness $CaCO_3$	pH	T.D.S. (SUM) ($mg\ L^{-1}$)	Cond. Factor	Lab. No. & Remarks ($mg\ L^{-1}$)
		($mg\ L^{-1}$)															
1A	102	63	52	93	18	137	71	396	5	43	–	0.8	371	7.8	879	8.2	No. 9370; Fe 0.1
1B	114	86	49	85	12	147	70	408	3	58	–	0.7	417	7.4	919	7.5	No. 9372; Fe <0.1
1C	98	72	50	62	9	126	80	330	1	41	–	0.8	386	7.5	772	7.4	No. 9371; Fe 0.1
1D	89	68	40	63	10	104	59	329	8	57	–	0.6	336	7.4	739	7.7	No. 10725; Fe 0.1
2A																	Abandoned Bore
2B	83	57	39	61	7	93	39	317	15	44	–	–	303	7.4	672	7.6	No. 13766; Fe 0.1
2C	101	76	49	63	9	135	86	317	1	24	–	–	392	7.3	760	7.3	No. 13767; Fe 0.1
2D	70	48	33	64	7	91	29	281	17	61	–	–	256	7.6	631	8.1	No. 15285; Fe 0.1
3A	182	99	74	178	22	329	165	396	7	60	–	–	552	7.4	1 330	7.0	No. 17139; Fe 0.1
4A	80	49	32	73	5	120	48	238	7	51	–	–	254	7.2	623	7.2	No. 14022; Fe 0.1
4B	98	58	52	76	5	166	47	274	27	7	–	2.1	359	7.4	714	7.2	No. 13462; Fe 0.1
4C	93	60	41	80	8	109	79	317	9	10	–	0.8	319	7.4	714	7.6	No. 13463; Fe 0.1
4D	110	75	43	99	10	138	87	354	22	56	–	–	364	7.5	884	7.5	No. 14644; Fe 0.1
5A	158	73	70	166	16	273	179	336	6	51	–	–	470	7.9	1 170	7.1	No. 14023; Fe 0.1
5B	151	84	63	140	18	253	134	360	6	56	–	–	496	7.1	1 114	7.0	No. 17140; Fe 0.1
5C	82	44	40	68	8	108	57	262	7	50	–	–	275	8.0	644	7.2	No. 14645; Fe 0.1
6B	112	79	49	83	7	222	88	207	15	51	–	–	400	7.6	801	6.7	No. 15129; Fe 0.1
6C	140	178	54	64	8	46	587	171	1	12	–	0.7	666	7.1	1 122	7.9	No. 86408

Bore	Cond. ($mS\ m^{-1}$) (25°C)	Ca	Mg	Na	K	Cl	SO_4	HCO_3	NO_3	SiO_2	B	F	Hardness $CaCO_3$	pH	T.D.S. (SUM) ($mg\ L^{-1}$)	Cond. Factor	Lab. No. & Remarks ($mg\ L^{-1}$)
		....	($mg\ L^{-1}$)	...	....												
7A	86	56	43	62	10	92	60	324	9	46	–	–	317	7.6	702	7.6	No. 14024; Fe 0.1
7B	89	69	44	67	10	112	65	336	14	54	–	–	253	7.4	771	8.1	No. 15281; Fe 0.1
7C	70	52	36	47	8	85	51	256	10	47	–	–	278	7.5	592	7.8	No. 13768; Fe 0.1
7D	77	59	36	63	8	86	45	323	11	53	–	–	295	7.6	684	8.2	No. 15286; Fe 0.1
8A	Dry																
8B	153	82	50	177	8	336	128	232	10	51	–	–	411	7.8	1 074	6.7	No. 15130; Fe 0.1
8C	94	55	40	72	8	115	64	281	12	53	–	–	302	7.7	700	6.9	No. 14646; Fe 0.1
9	95	74	43	59	9	93	75	357	1	27	–	–	362	7.4	737	7.5	No. 16780/72; Fe 0.05
10	66	40	27	56	9	71	65	214	1	17	–	–	211	6.9	499	7.3	No. 15173/72; Fe 0.05
11																	
12A	73	42	34	48	8	80	40	244	7	52	0.1	0.4	245	7.9	555	6.9	No. 24574
13A	195	83	79	182	21	358	162	336	7	58	0.1	0.7	532	8.0	1 287	6.3	No. 24575
13B	183	77	74	183	20	328	168	308	6	59	–	0.7	497	7.6	1 224	6.4	No. 86512
13B	190	84	76	188	22	347	190	342	7	57	–	0.7	520	7.5	1 313	6.6	No. 82W/5869; Fe 0.05
14A	178	68	67	180	21	322	168	278	8	57	0.1	0.7	446	7.9	1 170	6.2	No. 24576
15B	208	86	84	202	22	382	184	351	9	61	0.1	0.6	561	7.6	1 382	6.3	No. 24577
15C	241	102	91	241	24	448	227	373	7	61	–	0.7	630	7.4	1 576	6.3	No. 86511
15C	232	105	91	236	25	425	225	397	8	64	–	0.7	640	7.6	1 576	6.5	No. 82W/5870; Fe 0.05
15E	239	112	92	242	25	443	222	390	6	63	–	0.7	660	8.2	1 595	6.4	No. 82W/4963

Bore	Cond ($mS\ m^{-1}$) (25°C)	Ca	Mg	Na	K	Cl	SO_4	HCO_3	NO_3	SiO_2	B	F	Hardness $CaCO_3$	pH	T.D.S. (SUM) ($mg\ L^{-1}$)	Cond. Factor	Lab. No. & Remarks ($mg\ L^{-1}$)
		($mg\ L^{-1}$)															
16A	208	55	78	228	24	394	221	235	7	54	0.9	0.8	458	7.9	1 298	6.0	No. 28000
17A	236	74	88	246	27	455	225	287	8	53	0.8	0.9	547	7.6	1 465	6.0	No. 28001 17B V. Similar
17B	235	88	88	249	27	443	243	329	7	60	-	0.8	580	7.4	1 535	6.2	No. 82W/5871; Fe 0.05
18A	200	76	74	217	22	376	217	281	8	56	1.0	0.8	495	7.9	1 329	6.4	No. 28002
19A	217	73	48	261	19	528	170	61	1	5	0.6	-	380	7.8	1 166	5.3	No. 80446 Bailed sampled
20A	188	77	74	190	20	340	187	311	6	54	0.7	0.6	497	7.6	1 260	6.4	No. 28003
21A	Dry																
22A	75	(N.B. AT START OF AIRLIFTING)												8.2	525(a)	7.0	No. 23487; NaCl 59
22B	105	60	46	86	10	158	77	281	5	52	0.39	0.4	339	8.1	776	6.9	No. 22247
23A	88	54	42	66	10	121	66	271	4	56	0.1	0.4	308	8.2	690	7.2	No. 23484
23B	87	50	39	67	10	112	53	85	1	57	0.21	0.4	290	8.6	564	5.8	No. 82W/7875; CO_3 90; Fe 0.09
24A	138	67	57	125	16	215	123	317	4	56	0.3	0.5	402	8.2	981	6.7	No. 23485
25A	179	84	73	161	20	319	152	332	6	60	0.49	0.6	510	8.1	1 208	6.4	No. 23486
26A	202	82	75	221	22	382	227	293	7	60	0.35	0.7	514	7.9	1 370	6.5	No. 23493
27A	42	17	16	37	7	56	28	107	2	51	0.24	0.3	108	7.1	322	6.4	No. 23494
27B	40	23	18	28	5	34	16	165	4	54	0.18	0.2	130	8.0	347	7.3	No. 82W/5253

(a) Derived from conductivity

Bore	Cond. ($mS\ m^{-1}$) (25^oC)	Ca	Mg	Na	K	Cl	SO_4	HCO_3	NO_3	SiO_2	B	F	Hardness $CaCO_3$	pH	T.D.S. (SUM) ($mg\ L^{-1}$)	Cond. Factor	Lab. No. & Remarks ($mg\ L^{-1}$)
		($mg\ L^{-1}$)															
28B	201	186	86	119	17	185	643	201	4	28	0.46	0.5	818	8.1	1 470	7.2	No. 23495
28C	43	23	19	31	6	37	18	171	2	56	0.20	0.2	140	7.9	363	7.1	No. 82W/5254
29A	69	35	26	45	7	58	37	220	1	60	0.27	0.2	194	7.8	489	7.3	No. 23496
30A	49	30	21	31	8	42	31	174	6	62	0.13	0.5	161	8.1	406	7.0	No. 23481
30B	58	32	21	52	9	58	33	204	1	69	0.23	0.6	170	7.5	480	7.0	No. 82W/7876; Fe 0.05
31A	39	23	16	26	8	33	49	107	7	62	0.09	0.3	123	7.3	331	6.9	No. 23482
31B	41	23	16	29	8	37	49	107	1	64	0.14	0.3	120	7.6	334	6.5	No. 82W/7877; Fe 0.06
32A	106	61	39	101	12	141	183	183	9	54	0.35	0.5	313	7.8	784	6.9	No. 17219; Mn 0.05
33A	82	39	29	78	14	114	101	165	5	66	0.33	0.8	216	7.7	612	6.6	No. 17220; Mn 0.05
34A	44	23	11	46	6	38	62	110	3	69	0.29	0.5	102	7.9	369	6.8	No. 17221; Mn 0.05
35A	34	22	14	28	5	21	10	165	7	67	0.17	0.3	113	7.6	339	8.0	No. 17222; Mn 0.06
36B	79	52	27	54	13	108	135	98	1	49	0.23	0.2	241	6.6	536	6.2	No. 17226
37A	75	48	34	52	9	80	47	265	6	46	0.28	0.4	260	7.8	588	7.2	No. 17227
38B	48	20	17	42	9	78	21	107	8	67	0.23	0.3	120	7.5	369	6.3	No. 82W/5249
39B	36	14	13	34	7	45	17	104	1	50	0.23	0.3	88	7.5	285	6.5	No. 82W/5250
40C	100	58	43	93	10	92	96	363	6	44	1.2	0.6	320	7.9	807	7.6	No. 82W/5251
41C	88	37	45	78	13	90	77	308	5	56	0.44	0.5	280	8.4	710	7.4	No. 82W/5252; CO_3 6
42A	345	120	124	437	40	728	456	369	8	58	0.05	–	810	8.0	2 340	6.6	No. 22248
43A	65	43	27	49	10	62	66	214	9	34	0.4	0.4	218	8.0	515	7.4	No. 22238

Bore	Cond. ($mS\ m^{-1}$) (25^oC)	Ca	Mg	Na	K	Cl	SO_4	HCO_3	NO_3	SiO_2	B	F	Hardness $CaCO_3$	pH	T.D.S. (SUM) ($mg\ L^{-1}$)	Cond. Factor	Lab. No. & Remarks ($mg\ L^{-1}$)
		.... ($mg\ L^{-1}$)															
44A	103	60	39	90	12	114	105	275	32	55	0.59	0.4	311	7.0	783	7.1	No. 22249
45A	129	85	48	110	18	138	231	290	1	21	0.45	0.5	410	8.0	942	7.1	No. 17228
46A	98	65	37	79	9	133	63	285	10	52	0.24	0.6	314	7.5	734	6.9	No. 80443
47A	44	56	11	16	2	25	18	204	1	58	0.18	0.1	185	7.0	390	7.5	No. 17223
48A	95	51	43	81	7	130	49	284	9	53	0.25	1.0	304	8.0	707	6.9	Bore 1/76; No. 86770
49A	112	50	53	96	11	203	92	207	1	41	0.28	0.4	343	8.1	753	6.4	Bore 2/76; No. 86771; Cr 0.02
50A	98	88	46	44	5	114	29	372	3	54	0.22	0.8	409	7.7	756	7.2	No. 85130
51A	77	49	36	49	8	103	49	225	1	39	0.14	0.3	270	7.6	558	6.7	No. 08444
52F	58	35	26	39	6	66	28	211	1	46	0.16	0.2	194	7.5	458	7.1	No. 85129
53A	53	24	22	47	6	74	27	157	1	15	0.21	0.5	151	7.6	372	6.7	No. 86776
54A	118	72	57	77	9	162	60	354	3	50	0.28	0.6	415	7.4	845	6.7	No. 85044
55A	65	35	42	31	5	49	16	293	1	52	0.21	0.2	250	7.7	523	7.2	No. 80959
56B	76	50	40	38	5	64	25	311	1	50	0.16	0.2	290	7.6	584	7.0	No. 85126
57A	135	73	53	124	26	164	248	256	4	53	0.43	0.7	400	8.0	974	7.0	No. 17225
58A	117	65	42	104	10	203	69	250	1	12	0.30	0.4	335	7.9	756	6.4	No. 85133
59A	82	51	36	67	9	102	56	275	3	34	0.24	0.4	275	7.6	634	7.3	No. 85128
60A	52	34	24	33	6	61	23	190	1	31	0.11	0.2	184	7.6	403	7.2	No. 80445
61B	100	71	41	68	8	126	101	256	1	20	0.20	0.5	346	8.3	701	6.8	No. 85132; CO_3 9

Bore	Cond. ($mS\ m^{-1}$) ($25^{o}C$)	Ca	Mg	Na	K	Cl	SO_4	HCO_3	NO_3	SiO_2	B	F	Hardness $CaCO_3$	pH	T.D.S. (SUM) ($mg\ L^{-1}$)	Cond. Factor	Lab. No. & Remarks ($mg\ L^{-1}$)
		....	....	....	....	....	($mg\ L^{-1}$)	....	....	....	....	....	....				
62A	92	63	36	53	25	86	147	220	1	40	0.3	0.7	305	7.4	671	6.8	No. 85127
63A	72	10	51	56	7	105	35	227	1	24	0.27	0.5	235	8.5	515	6.8	No. 86405
64A	26	11	10	23	4	39	11	75	1	31	0.15	0.1	68	7.6	205	6.7	No. 80962
65B	76	40	33	56	6	82	42	256	1	40	0.21	0.3	236	8.2	556	6.8	No. 85131
66D	60	34	29	41	7	72	40	191	1	31	0.17	0.1	204	7.7	445	6.9	No. 86772
67A	Dry																
68A															420		
69A	157	110	62	109	12	267	124	329	1	22	0.25	0.7	530	8.2	1 035	6.5	No. 86775
70A	162	300	43	24	14	30	855	79	1	30	–	0.2	926	7.0	1 385	8.3	No. 86407
71A	101	52	35	115	16	135	62	348	8	30	1.1	1.2	270	8.3	810	7.7	No. 82W/4964; CO_3 6
72A	107	67	43	91	14	125	84	317	22	37	0.58	0.8	340	8.4	807	7.2	No. 82W/4965; CO_3 6
73B	110	56	49	74	10	173	95	214	9	38	0.31	0.9	340	7.9	719	6.2	No. 82W/4967
74A	74	45	31	60	9	69	51	275	9	43	0.39	0.4	240	8.1	592	7.4	No. 82W/5248
74B	65	41	29	46	8	54	48	256	5	43	0.19	0.4	220	7.7	530	7.5	No. 82W/5868; Fe 0.05
75A	62	44	26	45	7	56	50	219	6	18	0.17	0.7	220	8.5	477	7.4	No. 82W/4968; CO_3 6
76A	171	66	54	203	19	285	169	229	32	65	–	0.9	390	8.5	1 205	6.6	No. 82W/4966; CO_3 12
77A	180	63	72	191	21	329	191	296	1	45	–	0.8	453	7.9	1 209	6.5	No. 86514
78A	208	80	83	121	82	191	713	2	1	83	–	1.1	542	3.9	1 359	6.1	No. 86773; Fe 60
79A	48	25	21	40	5	58	30	155	1	30	0.15	0.2	148	7.7	364	7.0	No. 86774

Bore	Cond. ($mS\ m^{-1}$) (25^oC)	Ca	Mg	Na	K	Cl	SO_4	HCO_3	NO_3	SiO_2	B	F	Hardness $CaCO_3$	pH	T.D.S. (SUM) ($mg\ L^{-1}$)	Cond. Factor	Lab. No. & Remarks ($mg\ L^{-1}$)
		($mg\ L^{-1}$)															
W1A	91	48	33	95	13	102	60	293	3	53	0.73	0.4	256	8.3	719	7.3	No. 23488; CO_3 18
W2A	156	86	57	150	11	182	351	204	1	28	0.44	0.5	450	7.6	1 071	6.7	No. 23489
W3A	117	65	55	93	16	140	66	415	7	64	0.76	0.6	388	7.6	922	7.3	No. 23490
W4C	46	35	22	25	8	30	20	180	7	67	0.21	0.3	178	8.3	410	7.4	No. 23491; CO_3 15
W5A	99	51	50	80	14	106	63	332	2	73	0.54	0.8	333	8.4	793	7.3	No. 23510; CO_3 21
W7	41	30	19	24	6	23	13	198	2	78	0.18	0.3	150	7.4	393	7.7	No. 82W/8078
W8	42	31	21	24	6	26	18	195	2	67	0.18	0.2	160	8.3	390	7.7	No. 82W/8077
Robe River	48	26	23	33	6	59	21	162	1	30	0.16	0.2	160	7.5	361	6.9	No. 83796; Flowing 5.7.78
Deep Reach Pool	177	79	66	180	19	303	170	336	7	52	–	0.6	469	7.7	1 212	6.6	No. 83797 Sampled 28.5.78
Kumina Creek	32	15	15	21	5	39	11	104	1	29	0.23	0.1	99	7.5	239	6.6	No. 22237; Flowing 3.7.76 (Near 55A)
West Creek	106	100	24	43	3	135	50	250	1	47	0.15	0.2	349	7.5	652	5.7	No. 85045
Caliwingina Creek	35	14	17	27	6	53	14	101	1	44	0.21	0.1	105	7.4	276	6.6	No. 22251; Flowing 8.9.76 (Casing site)
Fortescue River	171	62	66	174	19	309	180	244	3	45	–	0.6	427	7.5	1 103	6.2	No. 85046; Between Crossing Pool and Deep Reach Near W6

Bore	Cond. ($mS\ m^{-1}$) (25°C)	Ca	Mg	Na	K	Cl	SO_4	HCO_3	NO_3	SiO_2	B	F	Hardness $CaCO_3$	pH	T.D.S. (SUM) ($mg\ L^{-1}$)	Cond. Factor	Lab. No. & Remarks ($mg\ L^{-1}$)
		($mg\ L^{-1}$)															
Weelumurra Creek	145	43	59	165	5	173	65	552	2	64	0.9	1.0	391	8.3	1 110	7.2	No. 22252; CO_3 9; Flowing 12.8.76 Near W6

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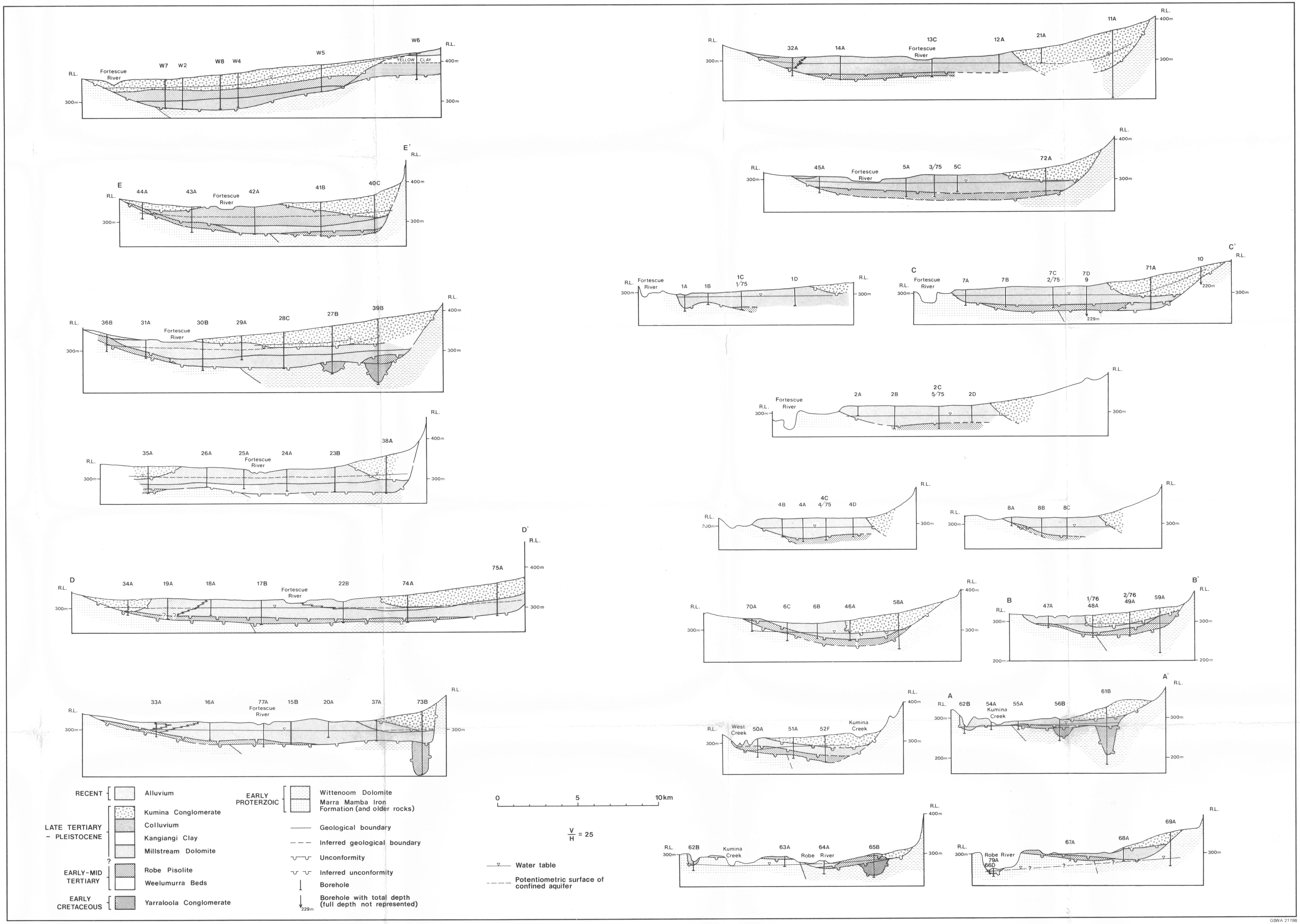
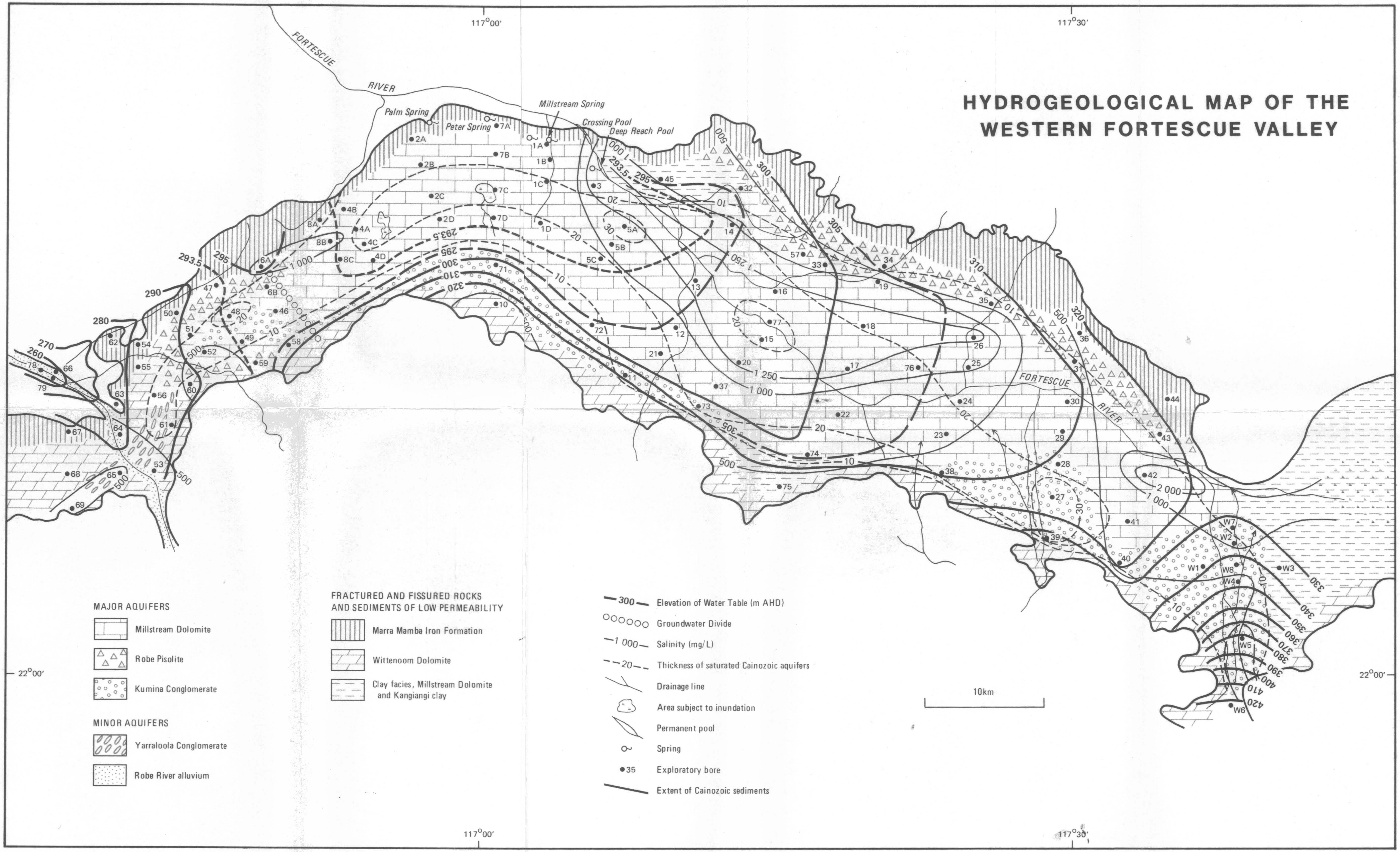
Geological cross-sections of the western Fortescue Valley

PLATE 1



GSWA 21786

PLATE 2


HYDROGEOLOGICAL MAP OF THE WESTERN FORTESCUE VALLEY
117°00'
117°30'
22°00'
FORTESCUE RIVER
Palm Spring
Peter Spring
Millstream Spring
Crossing Pool
Deep Reach Pool
10km
MAJOR AQUIFERS
Millstream Dolomite
Robe Pisolite
Kumina Conglomerate
MINOR AQUIFERS
Yarraloola Conglomerate
Robe River alluvium
FRACTURED AND FISSURED ROCKS AND SEDIMENTS OF LOW PERMEABILITY
Marra Mamba Iron Formation
Wittenoom Dolomite
Clay facies, Millstream Dolomite and Kangiangi clay
300 Elevation of Water Table (m AHD)
Groundwater Divide
1 000 Salinity (mg/L)
20 Thickness of saturated Cainozoic aquifers
Drainage line
Area subject to inundation
Permanent pool
Spring
35 Exploratory bore
Extent of Cainozoic sediments