A HYDROGEOLOGICAL INVESTIGATION OF THE GROOTEGELUK MINE

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SUBMITTED IN FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE IN GEOHYDROLOGY, IN THE DEPARTMENT OF GEOGRAPHY, RHODES UNIVERSITY, GRAHAMSTOWN.

JANUARY 1989

ABSTRACT

The study concerns an assessment of the hydrogeological impact of an open cast coal mine in the North Western Transvaal Province of South Africa. The hydrogeological impact of the mine is assessed in terms of groundwater quality and levels. A monitoring system was installed to enable the present and future impact of mining operations on the hydrogeological regime to be assessed.

Grootegeluk Mine is situated in the Waterberg Coal Field of South Africa and began production in 1980. The mine extracts fifteen million tons of mine material annually from a single open pit. Forty percent of the mined material is saleable product and the remaining sixty percent is stacked on discard dumps. The Daarby fault forms the northern boundary of the open pit and serves to bring the younger Letaba and Clarens Formations into contact with the older Beaufort and Ecca Groups. The mine discards are deposited north of the fault on a different hydrogeological environment from which they are mined.

Dewatering of the mine open pit has resulted in a steady decline in water levels in the Ecca Group, south of the Daarby fault. In contrast, water levels north of the Daarby fault in the Letaba and Clarens Formations have risen.

The short term hydrochemical impact of the mine discard dumps and slimes dams have resulted in a rise in the calcium, sulphate, chloride, fluoride and nitrate concentrations of the ambient groundwater. The longer term hydrochemical impact from the waste dumps, acid mine drainage, is not evident at present in the groundwater below the waste dumps. However, it is expected to manifest itself during the next ten years.

A monitoring system was installed at the mine to allow groundwater levels and quality to be monitored. By measuring

groundwater quality and levels the impact of the mine on the regional hydrogeology can be monitored and assessed presently, and during the next forty years of production. Monitoring will also enable the timeous implementation of remedial measures at an early stage and eliminate the need for large late stage "clean up" operations. Future monitoring of both water levels and quality will be crucial in evaluating the mine's impact on the regional groundwater regimes over the next forty years of production.

The remedial measures recommended for leachate presently emanating from the waste dumps and slimes dams north of the Daarby fault, are a number of collector wells drilled into the basalts and sandstone north of the Daarby fault. The proposed positions of the wells (boreholes) are as close as possible to the dumps and slimes dams with expansion taken into consideration. The boreholes should be designed to lower the water level in the vicinity of the dumps in order to create a nett groundwater gradient towards the dumps and as a result, halt the spread of leachate away from the dumps.

Grootegeluk plans to backfill the open pit with plant discards on completion of the mining of zone 2. The backfilled material will consist of the currently produced plant waste and will be covered with overburden and topsoil. It is expected that the backfilling will have a major impact on groundwater quantity if no remedial measures are implemented. The two remedial measures discussed are chemical treatment of the discard material before backfilling or the continual abstraction of water from the pit resulting in a nett groundwater inflow into the pit. No material from the present waste dumps and slimes dams will be transported into the open pit as backfill material.

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ACKNOWLEDGEMENTS

I WOULD LIKE TO EXPRESS MY APPRECIATION TO THE FOLLOWING:

- MY SUPERVISOR, MR ANDREW STONE
- THE IRON AND STEEL CORPORATION OF SOUTH AFRICA LIMITED FOR ALLOWING ME TO USE THE PROJECT
- CLARIS DREYER AND THE PERSONNEL OF THE GEOLOGY DEPARTMENT AT GROOTEGELUK MINE FOR THEIR ASSISTANCE THROUGHOUT THE PROJECT
- CHRIS LANGTON FOR PROOF READING THE SCRIPT

THE AIMS AND OBJECTIVES OF THE STUDY

The aim of the study is to provide a sound scientific explanation of the hydrogeology of the Grootegeluk Coal Mine. The investigation determines the existing hydrogeology by identifying and quantifying the existing hydrogeological parameters. Once the in-situ hydrogeology was evaluated the short and long term impacts of the mining operations on the hydrogeology were determined. Methods of reducing the adverse hydrogeological impact of the mining operations are assessed and proposed.

Specific Aims of the Investigation

i. to identify and quantify the regional hydrogeological environments and their associated parameters.

ii. to identify and quantify the impact of the Grootegeluk open pit on local aquifers.

iii. to identify the effect of the mine process plants and waste dumps on the hydrogeology north of the Daarby fault in terms of groundwater levels and chemistry.

iv. to estimate the relationships between recharge and abstraction of groundwater.

v. to identify in the light of previous research by Walsh (1982) and Olem et al (1983) the chemical processes responsible for the groundwater contamination at the Grootegeluk Coal Mine.

vi. to investigate literature concerning the alternatives for the control and abatement of the hydrogeological impacts of coal mines and coal mine spoils and to assess their applicability to Grootegeluk.

Hypotheses

A number of hypotheses have been formulated in order to provide a scientific basis for the study. The hypotheses are divided into the hydrodynamics and hydrochemistry of the hydrogeological regime at the Grootegeluk Mine.

Hydrodynamics

i. water levels in the Ecca Group in the vicinity of the mine will be lowered by mine dewatering.

ii. lowering the groundwater levels will not occur homogeneously around the open pit due to the fractured nature of the aquifer.

iii. recharge to the Letaba Basalts and Clarens Sandstone Formations will be increased locally because of mine plant, slimes dams and waste dumps.

iv. the permeability across the Daarby fault is low and forms a leaky boundary between the Clarens and Letaba Formations and the Ecca Group.

Hydrochemistry

i. the hydrochemistry of the groundwaters in the Clarens Formation will differ from those in the Ecca Group.

ii. the hydrochemistry of the aquifers surrounding the mine will be altered by mining operations, particularly in terms of an increase in the total dissolved solid content and a decrease in the pH north of the Daarby fault.

The hypotheses concerning the groundwater levels are discussed in Chapters 6 and 9 (Section 5). The hypotheses concerning the hydrochemistry are investigated and discussed in Chapters 5 and 9 (Section 6).

1.0 INTRODUCTION

The increased demand for coal in South Africa to help meet the growing energy requirements, the goal of energy self-sufficiency and export, has generated increased activity in coal mining industry in South Africa over the last twenty years.

Coal in South Africa is mined either by subsurface or opencast methods depending on the depth and quality of the coal seams. Both mining methods result in the disturbance of the existing hydrological environment in the vicinity of the mine in terms of groundwater levels and water chemistry. Groundwater levels are usually lowered by mine dewatering and the alteration of the in-situ hydrochemistry occurs both in the short and long term. Short term alteration of the hydrochemistry hinges mainly on the quantities of soluble and exchangeable elements and compounds present in the mined material. The predominant long term chemical effect is the alteration of the hydrochemistry, by the generation of acid mine drainage from oxidation of iron sulphides present in the discard dumps, stock piles and the mine open face.

Grootegeluk is a large open cast mine situated in the Waterberg Coal Field of South Africa. The mine has been in operation since 1980 and to date (November 1988) 150 million tonnes of material have been mined from the open pit. Approximately forty percent of the mined material is saleable product and the remaining sixty percent is discarded onto dumps north of the open pit.

The majority of the coal is transported to the nearby Matimba Power Station (power station grade coal) with the higher grade coking coal being railed to the Iscor Steel Works at Vanderbijlpark and Pretoria.

The Grootegeluk Coal Mine has at present forty years of proven coal reserves and during this period 650 million tons of material will be removed from the open pit and processed. Once all economical coal is exploited it is planned to backfill the pit with plant waste and overburden. Grootegeluk plans to backfill the open pit with plant discards, overburden and interburden on completion of the mining of zone 2. The plant waste will be covered with overburden and topsoil. It is expected that the backfilling will have a major impact on groundwater quality if no remedial measures are implemented. The two remedial measures discussed are chemical treatment of the discard material before backfilling or to extract water from the pit resulting in a nett groundwater inflow into the pit. This would halt the migration of highly mineralized leachate created by interaction of the backfilled material and groundwater from the open pit into the surrounding aquifer.

PLATE 1 OVERALL VIEW OF THE OPEN PIT LOOKING EAST (August 1987)

PLATE 2 THE OPEN PIT LOOKING SOUTHEAST WITH THE WATERBERG IN THE BACKGROUND. (February 1988)

2.0 PHYSIOGRAPHY

2.1 Location

The Grootegeluk Coal Mine is situated in the Northern Transvaal Province of South Africa. The mine is centered on latitude 23°40' South and longitude 27°33' East, approximately 21 km west of the town of Ellisras (Figure 1).

2.2 Climate

The climate is semi-arid with a mean annual precipitation of 484mm per annum (twenty year record). Most of the rainfall is experienced in summer with very minor falls (less than 10mm) being recorded in winter. Air temperatures vary from a maximum of 40°C in December to a minimum of 1°C in June/July. The potential evapotranspiration of the area is in the order of 2000mm per annum (mine weather station and South African Weather Bureau data).

2.3 Vegetation

The mine area is covered with dense bushveld vegetation consisting of grass, shrubs, small trees and isolated larger trees up to 8m high. The Acocks' classification for the area is Mixed Bushveld (Acocks 1975).

2.4 Topography

The area around the mine varies between 900 metres and 922 metres above mean sea level. The topography is generally featureless except for elevation differences of Nelsonskop (922m) in the north and the Waterberg Mountains (1400m) in the south (Figure 2).

2.5 Geomorphology

The Waterberg Coalfield which includes the Grootegeluk Mine forms part of the Palala plateau and is situated approximately 900m above sea level.

This flat bush covered plain is mostly underlain by rocks of the Karoo Supergroup and contrasts sharply with the mountainous nature of the country to the south, which is formed by the sediments of the Waterberg Group (Figure 2).

The Limpopo River with its tributaries, the Palala, Mogol and Matlabas rivers were responsible for the denudation of the Palala Plateau. The Mogol river occupies the central portion of the plateau while the Palala river is situated on the eastern rim of the plateau. Both rivers flow from south to north across the plateau.

The only prominent landmarks to the west of the Mogol river are Nelsonskop (922m), the Bull (935m) and the Cow and Calf (Figure 2). These inselbergs are erosional relics of the Clarens sandstone. To the east of the Mogol river, a few flat topped mountains consisting of horizontal layered Middle Ecca sandstone rise above the flat countryside.

The peneplain is a matured landscape where very little incision is taking place. The drainage system is poorly developed because of the flat country, the sandy nature of the terrain as well as the low annual rainfall. Although no natural drainage channels occur within the mine area, a few scattered shallow depressions (pannetjies) can be found on the farms surrounding the mine.

2.6 Hydrology

The study area has very little surface drainage except for the Sandloopspruit which is ephemeral and drains into the northerly flowing Mogol River. Figure 3 shows the only ephemeral stream on Iscor's properties to be 1000m north of the slimes dam on the boundary of farms Appelvlakte 448 LQ and Vooruit 449 LQ. Due to the flat topography, highly permeable soils and the absence of any surface water drainage courses, it is anticipated the mine will not have any direct impact on the surface hydrology. The major impact on the hydrology of the Sandloopspruit catchment is expected to be on the groundwater hydrology.

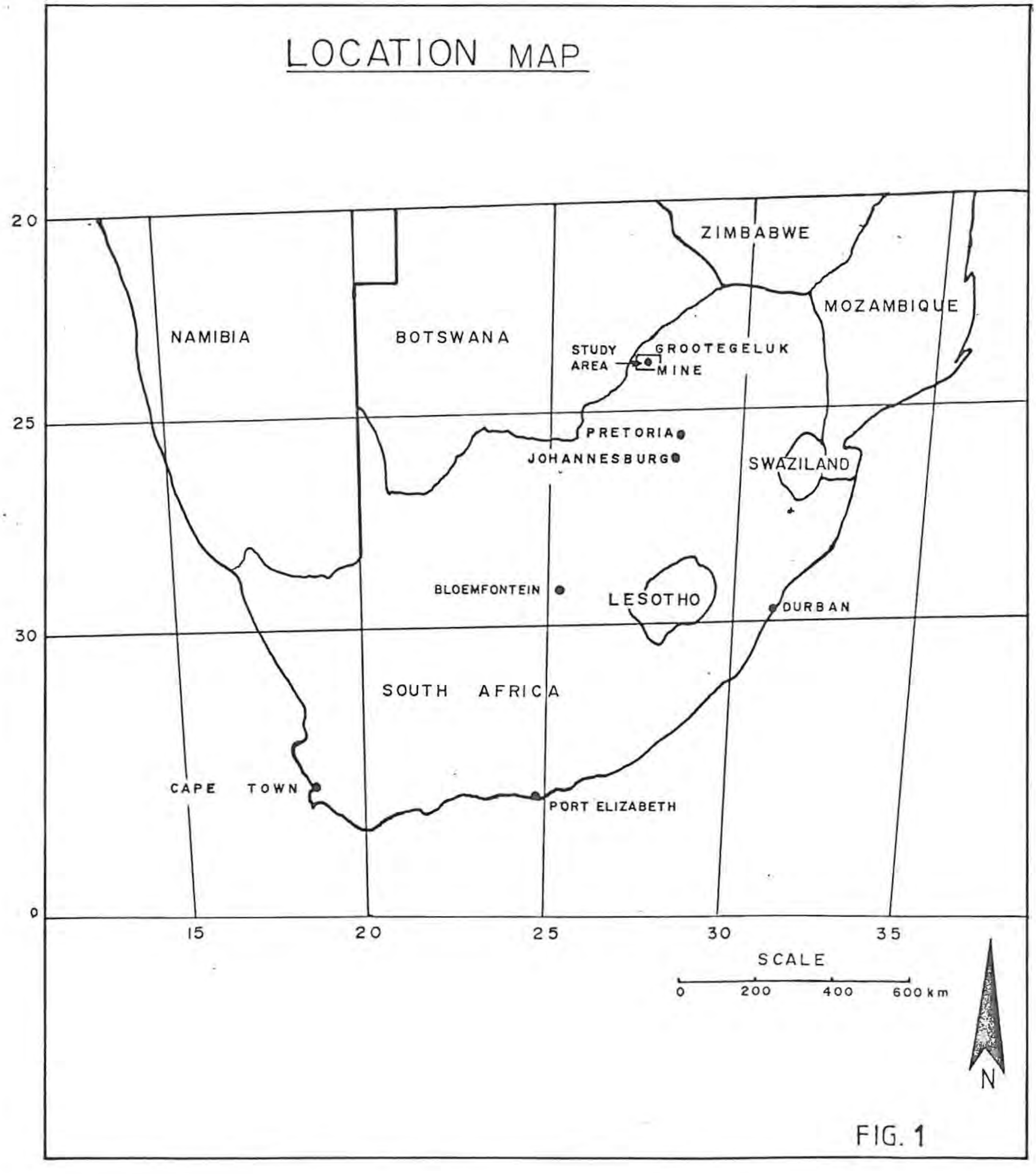

LOCATION MAP
20
25
30
0
15
20
25
30
35
NAMIBIA
BOTSWANA
ZIMBABWE
MOZAMBIQUE
STUDY AREA
GROOTEGELUK MINE
PRETORIA
JOHANNESBURG
SWAZILAND
BLOEMFONTEIN
LESOTHO
DURBAN
SOUTH AFRICA
CAPE TOWN
PORT ELIZABETH
SCALE
0
200
400
600 km
N

FIG. 1

3.0 GEOLOGY

3.1 Introduction

The geology of the mine area consists of a series of arenaceous and argillaceous sedimentary formations capped by an extrusive basalt. The area has been subjected to post depositional tectonic activity resulting in a number of faults. The present geology is complicated by the faults, which bring differing lithologies of varying ages into contact with each other. The Waterberg Coal Field is fairly unique in South Africa as it has not been intruded by Karoo age dolerite dykes.

Outcrops are scarce and hamper geological mapping and as a result compilation of a geological map (Figure 4) of the mine area was accomplished by using:

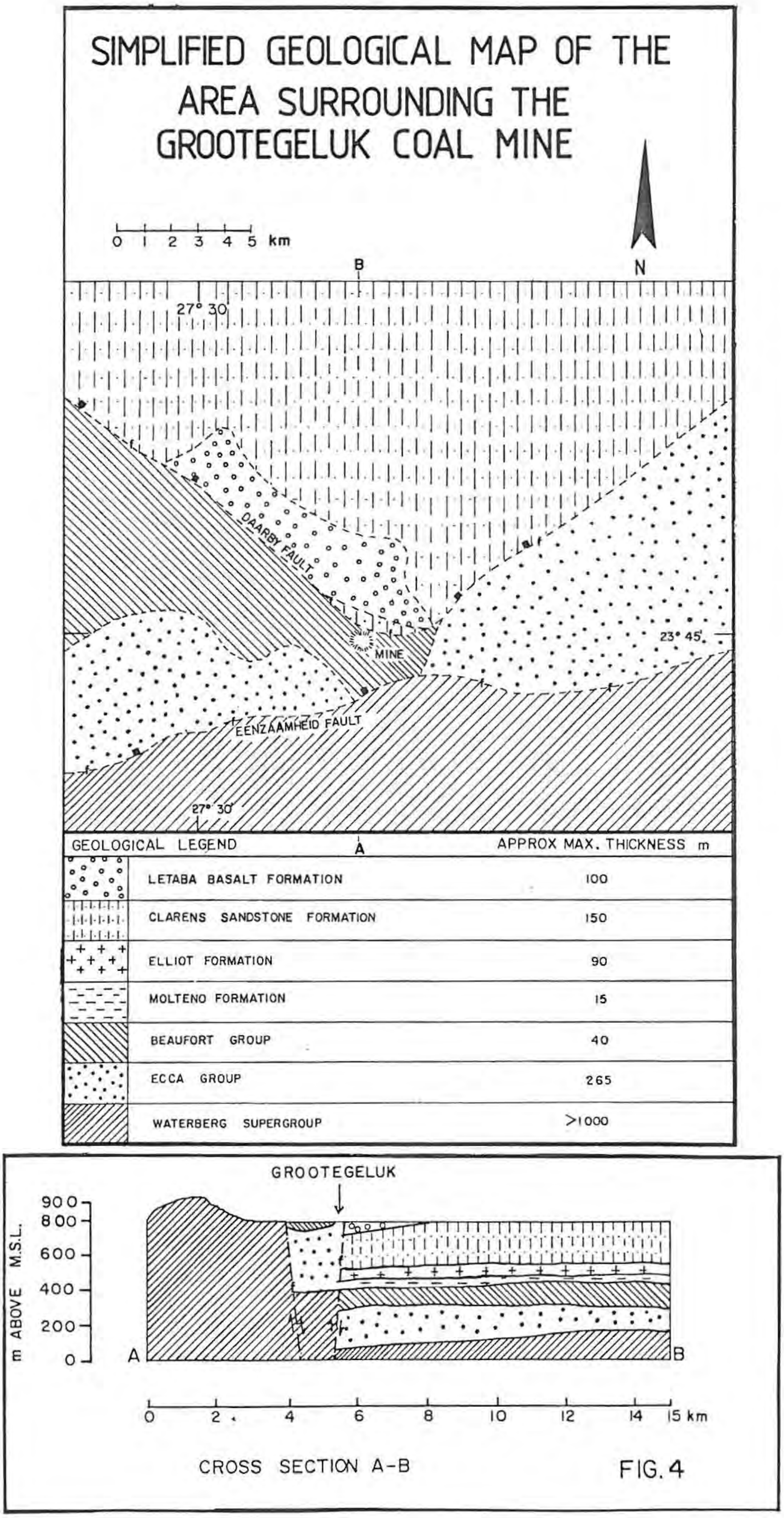
- The geological maps of the area prepared by the Geological Survey of South Africa. (Sheet 2326 Ellisras).
- Grootegeluk Mine geological maps.
- Borehole logs from the South African Department of Mines, Grootegeluk exploration boreholes and boreholes drilled for the purpose of this study.
- Interpretation of aerial photographs and airborne magnetic data.
- Limited surface mapping.

TABLE 1: LITHOSTRATIGRAPHY OF THE GROOTEGELUK AREA

AGE	SUPERGROUP	GROUP	SUBGROUP	FORMATION	LITHOLOGY	MAXIMUM THICKNESS (m)
Recent				Alluvium	Soil, sand, calcrete and ferricrete	20
Jurassic				Letaba	Basalt	100
				Clarens	Fine grained red to cream sandstone and siltstone	150
				Red Beds	Mudstone and siltstone	70
				Molteno	Sandtone with scattered pebbles	15
Triassic	Karoo					
		Beaufort			Shale and mudstone	40
				Upper	Shale, carbonaceous shales & coal	63
Permian		Ecca		Middle	Shale, carbonaceous shales, coal and sandstone	48
				Lower	Sandstone and siltstone	110
		Dwyka			Diamictite	5
Mokolian		Waterberg	Kransberg	Mogalakwena	Three conglomeritic layers with intermediate sandstone	1500

(SACS 1980)

SIMPLIFIED GEOLOGICAL MAP OF THE AREA SURROUNDING THE GROOTEGELUK COAL MINE



GEOLOGICAL LEGEND		APPROX MAX. THICKNESS m
°	LETABA BASALT FORMATION	100
¦	CLARENS SANDSTONE FORMATION	150
+	ELLIOT FORMATION	90
–	MOLTENO FORMATION	15
▧	BEAUFORT GROUP	40
∴	ECCA GROUP	265
▨	WATERBERG SUPERGROUP	>1000

CROSS SECTION A-B

FIG. 4

3.2 The Lithostratigraphy of the Grootegeluk Area

The lithostratigraphy of the Grootegeluk Area can be divided into eight distinct sedimentary units capped by an extrusive igneous layer. The lithostratigraphic units with the exception of the Waterberg Group have poor surface expression and are covered by a veneer of recent (2 Ma) sand. The lithostratigraphical units are shown in Table 1, and are described below.

3.2.1 The Waterberg Group

The Waterberg Group is of Mokolian age and outcrops to the south of the mine forming topographically high sandstone hills. The Waterberg Group represents a major sedimentary cycle that was predominantly continental and arenaceous. The bulk of the detritus making up the Waterberg is thought to originate from weathering of Rooiberg Group and Bushveld Igneous Complex (Truswell 1977).

Sedimentary structures indicate that most of the transport was from south to north (De Vries 1968). The general sedimentation was controlled by the rate of subsidence, which was discontinuous and oscillatory permitting removal of earlier formed sediments resulting in a number of unconformities. Deposition is thought by Truswell (1977) to incorporate only a small period of the total time sequence.

The Waterberg Group is divided into the Kransberg, Matlabas and Nylstroom Subgroups. The Mogolakwena Formation of the Kransberg Subgroup is the only lithology in the proximity of the mine.

The Mogolakwena Formation is divided into three conglomeritic layers with intermediate sandstones. The sequence is reported by SACS (1980) to be between 1250 and 1500m thick. The Mogolakwena Formation is described as a light to dark purple brown, coarse grained sandstone and grit, with at least three zones of conglomerate, boulder conglomerate and sandstone with grit (SACS 1980).

The Sandriviersberg Sandstone Formation of the Kransberg Supergroup has been completely eroded in the study area and is not discussed further.

After deposition of the Waterberg there was a considerable hiatus of some 1100 million years, during which no recorded sediments or other lithologies were deposited. The next period of deposition, initiated by subsidence, was that of the Karoo Sequence. The Waterberg Group forms the floor on which the Karoo Sequence was deposited.

3.2.2 The Karoo Sequence

The Karoo Sequence underlying the mine area consists of sandstones, mudstones, shales, coal and basalt and has virtually no outcrop.

The Karoo sedimentation was initiated by Permocarboniferous (345Ma) glaciation, known in South Africa as the Dwyka. The succeeding Permian and Triassic rocks were of fluvial origin, although some deltaic deposits are present. The Karoo sedimentation culminated in an aeolian phase (Clarens Formation) and is capped by an extrusive basalt (Letaba Formation).

3.2.2a Dwyka Group

There is no evidence of vast thicknesses of Dwyka tillite in the Waterberg Coal Field, but there are reports of a one to five metre thick erosional conglomerate (diamictite) at the base of the Karoo, overlying the Waterberg Group (Department of Mines of S.A. exploration holes 1944 - 1957 and Grootegeluk exploration boreholes). The diamictite is found to be fill depressions in the Waterberg Group.

3.2.2b Ecca Group

The Ecca Group is of major importance as it contains the coal which is mined at Grootegeluk. The Ecca Group comprises a lower arenaceous portion, and an upper portion which is more argillaceous and contains numerous coal seams. The Ecca Group was deposited in a fluvial deltaic environment covering much of what is South Africa today. Paleontological and mineralogical evidence suggests a brackish environment prevailed.

The Ecca Group as developed at Grootegeluk is subdivided into the Upper, Middle and Lower Ecca. The Upper Ecca is at present being exploited by the mine with expansion to Middle Ecca in the future. The coal layers have been divided into 11 zones with a total thickness of 111m (as shown in Table 2). The Upper and Middle Ecca are separated by a unit locally called "the interbeds", which is a series of finely laminated carbonaceous shales to coaly shales, 2,6m thick.

The Lower Ecca

The lower Ecca consists predominantly of individual sandstone and siltstone layers of varying thicknesses. The total thickness of the unit is 110m. The Lower Ecca does not contain any coal measures and as a result is of no economic importance to the Grootegeluk Mine.

The Middle Ecca

The Middle Ecca has a thickness of 48m of which the upper half consists of coal alternating with shale. The lower portion of the Middle Ecca contains alternating coal and sandstone layers. The contact between the Middle and Lower Ecca is defined as the base of the last coal seam (Table 2).

The Upper Ecca

The Upper Ecca has a thickness of 60m and consists of alternating carbonaceous shales, coal and mudstone. The unit is divided into five coal zones by the Grootegeluk Mine all of which are mined (Table 2).

TABLE 2 : TYPICAL SECTION OF THE UPPER AND MIDDLE ECCA

	ZONE	SCALE 1:500	AV THICKNESS (m)	% COAL (mass)	LITHOLOGY	TOTAL THICKNESS
UPPER ECCA	ZONE 11	▤	7,56	38,33	Bright coal (without siderite) intercalated with grey mudstone, carbonate lenses +/- 50cm x 3m	7,6
	ZONE 10	▤	9,37	53,86	Bright coal with little siderite intercalated with carbonaceous shale; carbonate lenses +/- 50cm x 3m; thick coal bands in lower half	17,0
	ZONE 9	▤	6,53	48,34	Bright coal with prominent siderite at base intercalated with carbonaceous shale; thick coal band in lower half	23,5
	ZONE 8	▤	9,04	42,82	Bright coal; prominent siderite at base; intercalated with carbonaceous shale; thick coal bands in lower half	32,5
	ZONE 7	▤	10,15	39,94	Bright coal sideritic throughout, intercalated as numerous thin bands with carbonaceous shale; prominent sideritic band at base	42,7
	ZONE 6	▤	6,54	32,17	Bright coal, very sideritic in lower half, intercalated as numerous thin bands with carbonaceous shale	49,3
	ZONE 5	▤	13,54	21,97	Carbonaceous shale with thin coal bands in lower two thirds; siderite less prominent	62,8
	Interbeds		2,60	-	Carbonaceous shale to coaly shale	65,4
MIDDLE ECCA	ZONE 4	■	4,02	99,13	Coal, dull, heavy, some bright coal in lower half and at top, few thin shale bands; yields coking fraction	69,4
	Interbeds		4,28		Shale, black to dark grey, carbonaceous; 1m fossileferous siltstone at base	73,7
	ZONE 4A	■	1,52	96,37	Coal, dull, few bright stringers, thin shale bands	75,2
	Interbeds		4,28		Shale, dark grey	79,5
	ZONE 3	■	7,82	96,41	Coal, dull, bright laminae in lower 1,Sm which yields low ash slightly coking coal, few thin shale bands	87,3
	Interbeds	⁘	4,54		Sandstone with shale bands	91,8
	ZONE 2	■	3,73	98,22	Coal, dull, bright laminae in lower 2m which yields low ash slightly coking coal; thin shale bands	95,5
	Interbeds	⁘	13,85	-	Sandstone, medium to coarse grained, few thin shale bands, thin coal band near top	109,4
	ZONE 1 Sample No 32	⁘ ■	1,55	98,54	Coal, dull, very few bright laminae, thin shale bands	110,0

(GROOTEGELUK MINE 1980)

3.2.2c The Beaufort Group

The Beaufort Group has very limited surface expression in the study area and it attains a maximum thickness of 40m. The Group conformably overlies the Ecca Group.

Only the lower portion of the Beaufort Group is encountered in the mine area and is found south of the Daarby fault. It consists essentially of blue-grey mudstones. The lower contact of the Beaufort Group is taken as the layer above the uppermost coal seam of the Upper Ecca.

3.2.2d The Molteno Formation

The Molteno Formation has a thickness of 15m in the Grootegeluk area (Mine exploration borehole logs). The formation consists essentially of white, medium to coarse grained sandstone with scattered pebbles. The Molteno Formation is of fluvial origin and the formation has no outcrop in the Grootegeluk area.

3.2.2e Elliot Formation (Red Beds)

The Elliot Formation commonly known as the Red Beds is a series of reddish coloured mudstones and siltstones and was deposited in a quiet marine environment, thought to have been alluvial flats (Truswell 1977). The Red Beds have no outcrop in the Grootegeluk area.

3.2.2f Clarens Formation

The Clarens Sandstone Formation was deposited in a more arid environment than the fluviatile Red Beds. It has been postulated that the Clarens Formation is partly an aeolian deposit (Truswell 1977). The sandstone in the study area is a moderately cemented, white or cream coloured, fine grained sandstone. The formation thins northwards from the Daarby fault where it reaches a maximum thickness of 150m.

3.2.2g Letaba Formation

The Letaba basalt is a very limited in extent in the Grootegeluk area. It forms a fault-bounded (north and south) lenticular wedge north of the Daarby fault (Figure 4). The Letaba Formation reaches a maximum thickness of approximately 120m juxtaposed with the Daarby fault and is faulted out within two kilometres north of the Daarby fault. Drilling (WBR boreholes, Chapter 9) indicates the basalt to be fractured and amygdaloidal. The contact between the basalt and the underlying Clarens sandstone is an erosional surface with considerable hydrogeological significance (Refer to Chapter 9 Section 2).

3.2.2h Recent Deposits

The major portion of the mine area is covered by a veneer of one to three metres of sand. The northern portion of the mine area (north of the Daarby fault) is covered by sands derived from weathering of the Clarens sandstone. This observation is supported by the well sorted nature of the sand. The southern portion of the mine area (south of the Daarby fault) is covered by sands derived from weathering of the Waterberg Group. Here the sands have angular grains and are poorly sorted. Where soils are developed, they consist of loose to medium dense, fine to medium grained sand. Calcrete is often developed above the Ecca and Beaufort Groups and may vary in thickness from 1 to 8m (Mine exploration borehole logs). The drilling has shown that the development of the calcrete is structurally controlled and is associated with faults and joints in the in situ rock masses and the movement of groundwater.

3.3. The Grootegeluk Coal Deposits

Grootegeluk Coal Mine produces blending coking coal and middlings from the Upper and Middle Ecca bright coal zones. The Upper and Middle Ecca are discussed individually.

3.3.1 The Upper Ecca

The Upper Ecca consists of intercalated shale and bright coal with an average thickness of 60m. The unit displays such a well developed cyclic repetition of coal-shale horizons that it can be divided into 7 zones. These 7 zones (11-5) were formed by a sedimentation cycle that recurred 7 times (Table 2).

The coal-bearing strata (zones 11-5) are extracted by opencast mining on 4 pit benches (benches 2-5) that follow specific geological contacts. Coking and middlings grade coal are obtained from benches 2-4 (zones 11-6) while bench 5, consisting of zone 5 and the underlying carbonaceous shale, is only mined for middlings. At present the pit is only developed to the base of the Upper Ecca (zone 5).

3.3.2 Middle Ecca

The Middle Ecca consists of 5 predominantly dull coal seams (zones 4-1), interbedded with carbonaceous shale, siltstones and sandstones with a total average thickness of 60m. A 1m siltstone horizon containing plant fossils overlies zone 4A and forms a marker horizon in the mine area.

Middle Ecca coal is suitable for power generation as well as direct reduction and formcoke. The Middle Ecca zones (4-2) will be extracted from 7 pit benches. Selective mining will be practiced to separate the coal zones (seams) from the interbedded shale and sandstone.

Mining of the first Middle Ecca coal seam (zone 4) commences in 1990. At present the extraction of zone 1, the lowermost Middle Ecca coal seam has not been contemplated by Grootegeluk.

3.4 Structural Geology

The faulting in the Waterberg Coal field is of Jurasic age and is thought to have occurred prior to the mass intrusion of dolerite dykes over South Africa (Truswell 1977). The Karoo Sequence in the study area has been faulted by two major faults with displacements greater than 250m. Minor faults between the major faults are also present. Detailed knowledge of the minor faulting is limited to the area surrounding the open pit, where extensive exploratory drilling has taken place. The positions of the major faults are shown on figures 4 and 5.

3.4.1 The Daarby Fault

The Daarby fault is a major north east then north west trending fault. It is proposed by the Grootegeluk Mine that it is a combination of two faults. Because the two faults have the same throw and throw directions, both faults have been termed as the Daarby fault. There is also evidence from exploration drilling on the farm Turfvlakte where faults were intersected that there is a link between the Eenzaamheid and Daarby faults.

The Daarby fault has a downthrow of 360m to the north. The fault dips at an angle of between 50^{o} and 60^{o} to the north and serves to bring the upthrown Beaufort and Ecca Groups in the south into contact with the downthrown Letaba, Clarens and Red Bed Formations in the north. Packer testing of a borehole drilled through the fault zone has shown the fault to be impermeable (Chapter 9).

3.4.2 The Eenzaamheid Fault

The Eenzaamheid fault situated south of the Daarby fault, has a throw of 250m to the north. The angle of the fault is near vertical. The fault brings the upthrown Waterberg Group on the southern side of the fault into contact with the downthrown Beaufort and Ecca Groups on the northern side of the fault (Figure 4).

3.4.3 Minor Faults

Between the Daarby and Eenzaamheid faults specifically on the farms Turfvlakte 463LQ and Enkelbult 462LQ is a series of associated smaller faults. The area covered by the farms Turfvlakte and Enkelbult is where the faults (Daarby and Eenzaamheid) are in the closest proximity (two kilometers apart) and where the Daarby fault takes its so-called "90° bend" (Grootegeluk Mine geological records). The most comprehensive exploration drilling has taken place on the two farms yielding more information concerning the structural geology.

The associated step faults have varying strikes, throws and throw directions (Grootegeluk exploration boreholes). The most important hydrogeological aspect of the faulting is the resultant increase in the in situ rock permeability of both the Beaufort and Ecca Groups.

4.0 PRINCIPLES OF GROUNDWATER CONTAMINATION BY COAL MINES AND DUMPS

4.1 Introduction

Mines of any sort, are in general, potential sources of ground and surface water contamination because of the disruption of the natural geological formations which directly affects the hydrogeology. Surface and subsurface mines specifically constitute a groundwater contamination source largely as a result of the nature of the minerals extracted. In coal mines the contamination can be divided into short and long term hydrochemical contamination. The short term contamination is due to base and ion exchange reactions between water and the host sediments. The long term hydrochemical impact of coal mines is the generation of acid mine drainage.

4.2 Short Term Contamination

"The severity of short term contamination of groundwater in areas of increased (coal) extraction hinges mainly on the quantities of contaminants present in the overlying rock and in the mine workings" (Hodgson 1982 p 182). The volume of possible contaminants in the associated host rock varies depending on the nature of the host rock. The processes resulting in the initial contamination are however similar in all the differing strata. These processes are base exchange reactions and direct dissolution of ions into the groundwater.

Coal is a sedimentary deposit and is usually associated with argillaceous sediments. Argillaceous sediments such as shale, coal and mudstone constitute the main source of the chemical compounds giving rise to short term contamination.

These rock lithologies are largely impermeable to water in their natural environment but mining operations, increase the permeabilities and expose increased surface areas of the sediments to air and water. This results in the release of chemical elements that are contained in the sediments into the natural groundwater by either base exchange or direct solution.

4.2.1 Base Exchange

Base exchange is a process by which ions of the same charge are exchanged. The argillaceous sediments associated with coal layers contain monovalent cations such as sodium and potassium which are adsorbed onto clay particles. These are exchanged by bivalent cations such as calcium and magnesium. As a result, the Ca and Mg content of the groundwater is decreased with a corresponding increase in the Na and K concentrations (Hodgson 1982).

4.2.2 Direct Solution

Ions which dissolve directly into the groundwater and do not require a process of base exchange, are the second cause of short term contamination. These are predominantly Na, K, U, $CaCO_3$ and to a limited extent SO_4 (Hodgson 1982). The contribution of these elements to increasing the total dissolved solids depends on their availability. The ions are generally found within pores of sediments, as anhydrous salts and as fracture fillings.

Libicki (1983) in a research project involving laboratory tests found that certain chemical elements and compounds could be divided into leachability groups. Differing leachability characteristics depended on the degree of leachability which is measured on a time scale. Libicki's classification fell into the following three groups:

Group 1: The components most easily leached; Cl, SO_4, Na and K

Group 2: The components of medium leachability; Cu, Zn, Hg, Sr, Cd, B, Mn, Mo and CN.

Group 3: The components characterized with the slowest leaching; Mg, Al, Cr, As, Pb, NH_4 and Ca.

4.3 Acid Mine Drainage

The term "acid mine drainage" originated in the United States of America in describing water of a low pH emanating from disused mines and mine spoils. The mechanisms of acid mine drainage have been studied and well documented by Boyer and Gleason (1977), Walsh (1982) and Kim et al (1982).

Briefly defined, acid mine drainage from coal mines and coal refuse piles occurs because of the weathering of pyrite.- Pyrite in coal and overlying strata, when exposed to air and water oxidizes, producing ferrous iron and sulphuric acid. The ferrous iron is further oxidized and produces anhydrous iron oxide and more acidity. The acid lowers the pH of the water making it corrosive. Action by certain bacteria also catalyze pyrite weathering by catalyzing ferrous iron oxidation to ferric iron and speeding up the process of acid formation.

The mechanism, principles and impacts of acid mine drainage have been studied at length during the past decade. Perhaps the most comprehensive investigation is by Walsh (1982), funded by the U.S. Bureau of Mines. The study investigates the principals of acid mine generation occurring at sixty two mines in the United States of America.

Walsh (1982) found that pyrite weathered by two methods, namely oxidation and the action of bacteria in the following steps;

1. Pyrite weathering, to form acid in coal mine drainage, results from chemical oxidation by either ferric iron or oxygen in presence of water.

2. Under field conditions, weathering based on oxidation by ferric iron predominates, with rates varying over the range of 0,001 to 0,1 mM H+/g-pyrite/day.

3. Iron bacteria, especially Thiobacillus ferrooxidans, catalyze pyrite weathering (by a factor of three) by catalyzing ferrous iron oxidation to ferric iron. These bacteria are ubiquitous in coal mines with significant populations observed even at the active mine face (Walsh 1982).

4.3.1 Oxidation of Pyrite

"The rate of oxidation of pyrite is shown to be related to pyrite form, to pyrite concentrations, to oxygen concentration and to ferric iron concentration" (Walsh 1982).

Pyrite Form

Pyrite forms identified by Caruccio (1975) were massive secondary pyrite and framboidal pyrite. Caruccio postulated that acid mine drainage only occurred in areas where coal contained framboidal pyrite, which is more reactive and less stable than secondary pyrite.

Further work by Walsh (1982) and Kim et al (1982) contradicted Caruccio and postulated that it was impossible to identify framboidal pyrite. Walsh (1982) attempted to determine the crystalline form of pyrite which proved impossible due to low pyrite contents of coal (1-3%). Microscopic analysis of coal samples following the method of Caruccio, were examined by Walsh without any characterisable pyrite crystals being observed. Secondary pyrite may occur in coal as individual crystals, large clusters of crystals or as fine fracture filling.

Pyrite Concentrations

The potential of coal refuse piles to produce acid mine drainage is directly related to the pyrite concentration of the coal and associated sediments. The sulphur content of coal seams however does not forecast acid production in mine drainage upon seam mining (Kim et al 1982).

Pyrite concentration in coal varies and coal with pyrite is considered undesirable and is usually discarded onto waste dumps. This results in waste dumps being greater potential sources of acid mine drainage due to the increased pyrite concentrations.

4.3.2 The Processes of Pyrite Oxidation

The oxidation of pyrite is controlled by the presence of oxygen and the pH of the water. The oxidation of pyrite can be divided into four stages and the following summary appears in papers by Kim et al (1982), Clark and Crawshaw (1979) and Walsh (1982).

Stage 1 Oxidation of pyrite is usually described by the reaction (1) below, in which pyrite, oxygen and water form sulphuric acid and ferrous sulphate.

$$2FeS + 7O_2 + 2H_2O = 4H+ + 2Fe^{2+} + 4SO_4{}^{2-} \qquad (1)$$

Stage 2 Oxidation of the ferrous iron produces ferric iron according to the following reaction.

$$2Fe^{2-} + 1/2O_2 + 2H^+ = 2Fe^{3+} + H_2O \qquad (2)$$

Stage 3 Hydrolysis of ferric iron results in an insoluble ferric hydroxide ("yellow boy") precipitating and the generation of more acid described by the following reaction.

$$Fe^{3+} + 3H_2O = Fe(OH)_3 + 3H^+ \qquad (3)$$

The above reactions are correct at a pH above 4,0. Only stage one of the three reactions varies with pH. Also of great significance is the oxidation of pyrite by a bacterium, Thiobacillus ferrooxidans.

At near neutral pH (stage 1) the rates of oxidation by air and Thiobacillus ferrooxidans are comparable (Kim et al 1982). This stage is typical of freshly exposed coal or refuse. Although the concentration of pyrite at this stage may be high, the rate of pyrite oxidation is relatively low and natural groundwater alkalinity may effectively neutralize the acid formed.

Stage 4 When the neutralizing capacity of the environment is exceeded the pH of the groundwater decreases. With a decrease in pH it was found by Kim et al (1982) and Olem et al (1983) that the rate of iron oxidation by Thiobacillus ferrooxidans increases. The increased activity of the bacteria increases acid production which further lowers the pH. As the pH in the vicinity of the pyrite becomes less than 3 it was found that there was an increase in the stability of iron and a decrease in the rate of iron hydroxide, $Fe(OH)_3$, precipitation. At this point, ferrous iron is oxidized by Thiobacillus ferrooxidans and the ferric iron in turn oxidizes the pyrite. This is explained by the reaction below.

$$FeS + 14Fe^{3+} + 8H_2O = 15Fe^{2+} + SO_4{}^{2-} + 16H^+ \qquad (4)$$

(Kim et al 1982).

At stage four the rate of acid production is high and is limited by the concentration of ferric iron.

Inhibition of Thiobacillus ferrooxidans and the elimination of oxygen will reduce the acid production. Inhibition of Thiobacillus ferrooxidans alone as found by Kim et al (1982) would prevent ferric oxidation.

4.4 Present Research in South Africa

Work is at present being undertaken in South Africa by Bosch and Loos (1987) in investigating methods of reducing the formation of acid mine drainage. Research by Bosch and Loos reports reaction rates under South African conditions and the following points have been established namely:

1. In experimental coal waste dumps situated on concrete pads (where no buffering can take place), that acid mine drainage is evident from the dumps within three months of the pyrite being exposed to oxygen.

2. Calculations based on the concentrations of iron and sulphate in leachate from a 55 tonnes experimental dump, indicates that the dump has the potential of producing acid mine drainage from the weathering of pyrite for a period of 500 years.

3. Spontaneous combustion in the dumps results in an alkali ash residue which may neutralize the acid generated in the dump but this is likely to be effective for a limited period only (20 years).

4. The bacteria (Thiobacillus ferrooxidans) are more active in wet warm periods (summer) and almost inactive during cold dry periods (winter).

Work by Bosch and Loos for the South African Water Research Commission is still incomplete and is expected to be completed by 1990.

5.0 THE REGIONAL GROUNDWATER CHEMISTRY

5.1 Introduction

A regional groundwater sampling programme in the vicinity of the Grootegeluk Mine was implemented in 1984, to determine the regional hydrochemical parameters and to characterize the aquifer units around the mine. By determining the hydrochemistry of the regional aquifers, the impact of mining operations on the aquifers can be assessed presently and in the future.

5.2 Aims of the Hydrochemical Investigation

The aim of the regional hydrochemical study at Grootegeluk is to identify and understand the natural groundwater chemistry of each of the aquifer units and to enable the impact of mining, on the hydrochemistry of the different aquifers to be assessed.

The aim of the chemical investigation of the groundwater can be divided into three individual tasks, namely:

1. To establish a regional hydrochemical data base of the groundwater in the vicinity of Grootegeluk.

2. To identify individual groundwater regimes in terms of their hydrochemistry.

3. To identify and determine the impact of the mining operations on the individual groundwater regimes.

5.3 The Regional Sampling Programme

Prior to the implementation of this investigation in 1984, the existing groundwater hydrochemical data base consisted of 23 samples taken in the vicinity of the mine by Iscor in February 1975. An additional six samples were taken by Iscor during July 1976. The results of the chemical analysis of the samples taken from the boreholes are shown in the Appendix 1.

To supplement and expand the existing data base an additional twenty one groundwater samples from domestic and agricultural boreholes were taken during 1985 (Appendix 1). The positions of the sampled boreholes are shown on figure 5.

5.3.1 Sample collection and field techniques

Information concerning the 1975 and 1976 sampling programmes indicate that all borehole water samples were pumped samples (personal communication Grootegeluk Geological Department personnel). The pumping periods varied from running the pump for five minutes before the sample was taken or longer if the pump had been running for some period of time. Samples 3, 11 and 18 (collected during the 1975 sampling programme) were standing water samples. All samples taken during 1976 were pumped samples.

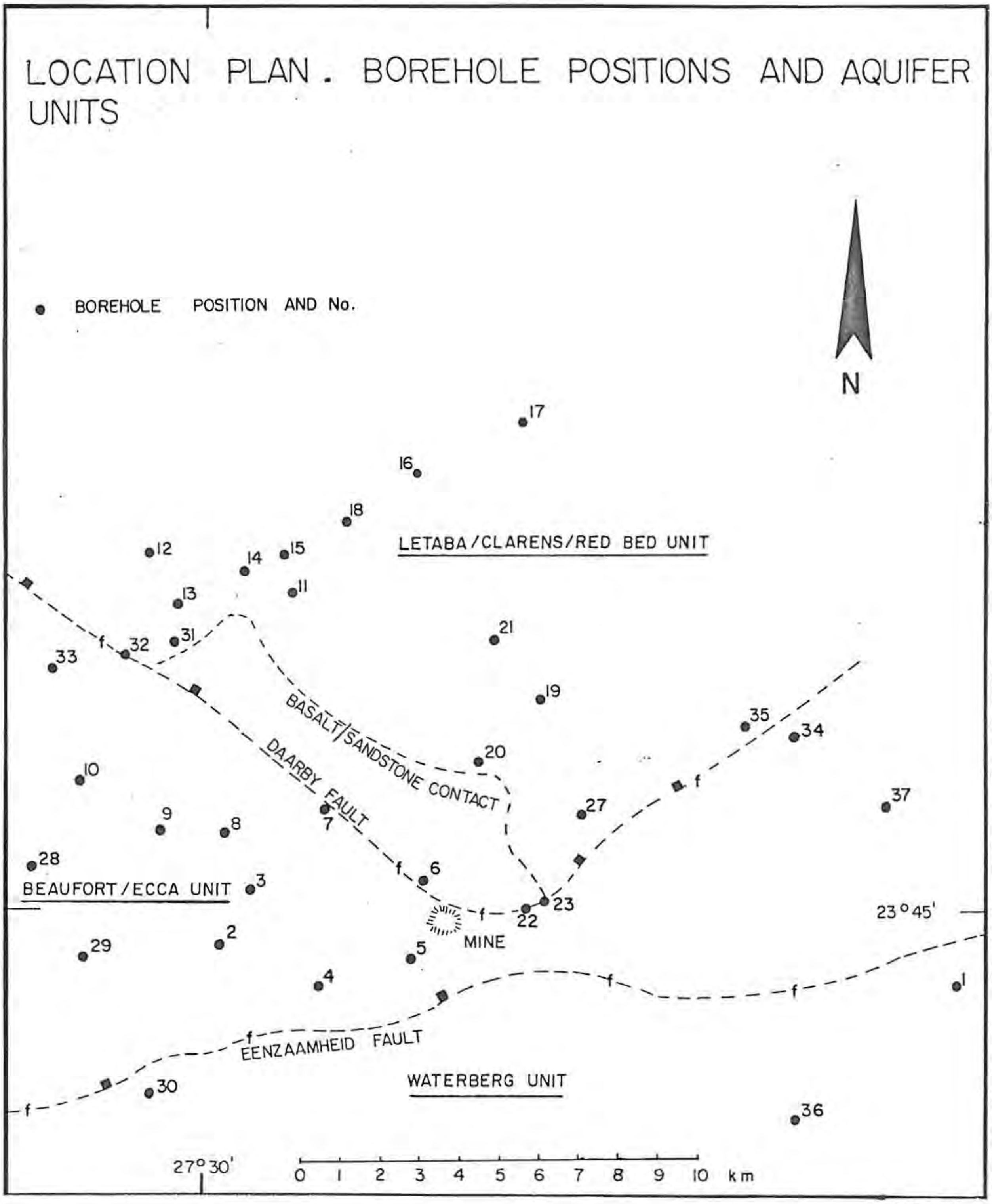
During the 1985 sampling programme all samples taken were pumped water samples. The samples were only taken 15 or more minutes after the start of pumping. Samples were taken in sterilized glass bottles, refrigerated and then sent for analysis at the Iscor Laboratory, Pretoria.

The geology of the area surrounding the Grootegeluk Mine is fairly complex because of the great variation of geological units and their complex structural relationships. The resulting hydrogeological environments are therefore also complex. The subdivision of the hydrogeological environments around the mine is made on three fault bounded geological areas. Each of the individual hydrogeological environments do not contain any of the same geological formations. The three main fault founded aquifer units are named in accordance with the geology, namely:

1. The Letaba/Clarens/Red Bed unit.
2. The Beaufort/Ecca unit.
3. The Waterberg unit.

The Letaba/Clarens/Red Bed unit occurs north of the Daarby fault, the Beaufort/Ecca unit between the Daarby and Eenzaamheid faults and the Waterberg unit south of the Eenzaamheid fault (Figure 5).

The boreholes sampled during the regional sampling programme were all privately drilled for agricultural or domestic water supplies. Unfortunately no detailed geological information of the boreholes sampled is available. Due to the geological complexity of the area, a number of the boreholes sampled, intersected a number of geological formations. However none of the same geological formations were intersected by boreholes in the three different aquifer units.



LOCATION PLAN. BOREHOLE POSITIONS AND AQUIFER UNITS

FIG. 5

5.3.2 The Results of the Regional Sampling Programme

A total of 51 (23 in 1975, 7 in 1976, and 21 in 1985) samples were taken during the regional sampling programmes and chemically analysed. However, a number of boreholes were repeatedly sampled during each of the sampling programmes and as a result only 37 individual boreholes water analyses are available.

The chemical analyses of the samples from the regional sampling programme for each year are plotted in Piper, Durov and areal distribution diagrams (Figures 6 to 11).

5.3.3 Piper Diagram

"A Piper diagram is a trilinear plot of the major cations and anions of the dissolved solids in water", (Piper, 1944). A Piper diagram enables the hydrochemical data from each water sample to be displayed in a visual form for comparison of samples and allows characterization of the different waters.

Figure 6 shows the trilinear plot of the hydrochemistry for the three sampling periods 1975, 1976, and 1985. Plotted on the piper diagram (Figure 6) are the major anion and cation concentrations, the borehole number and the aquifer unit in which it is situated.

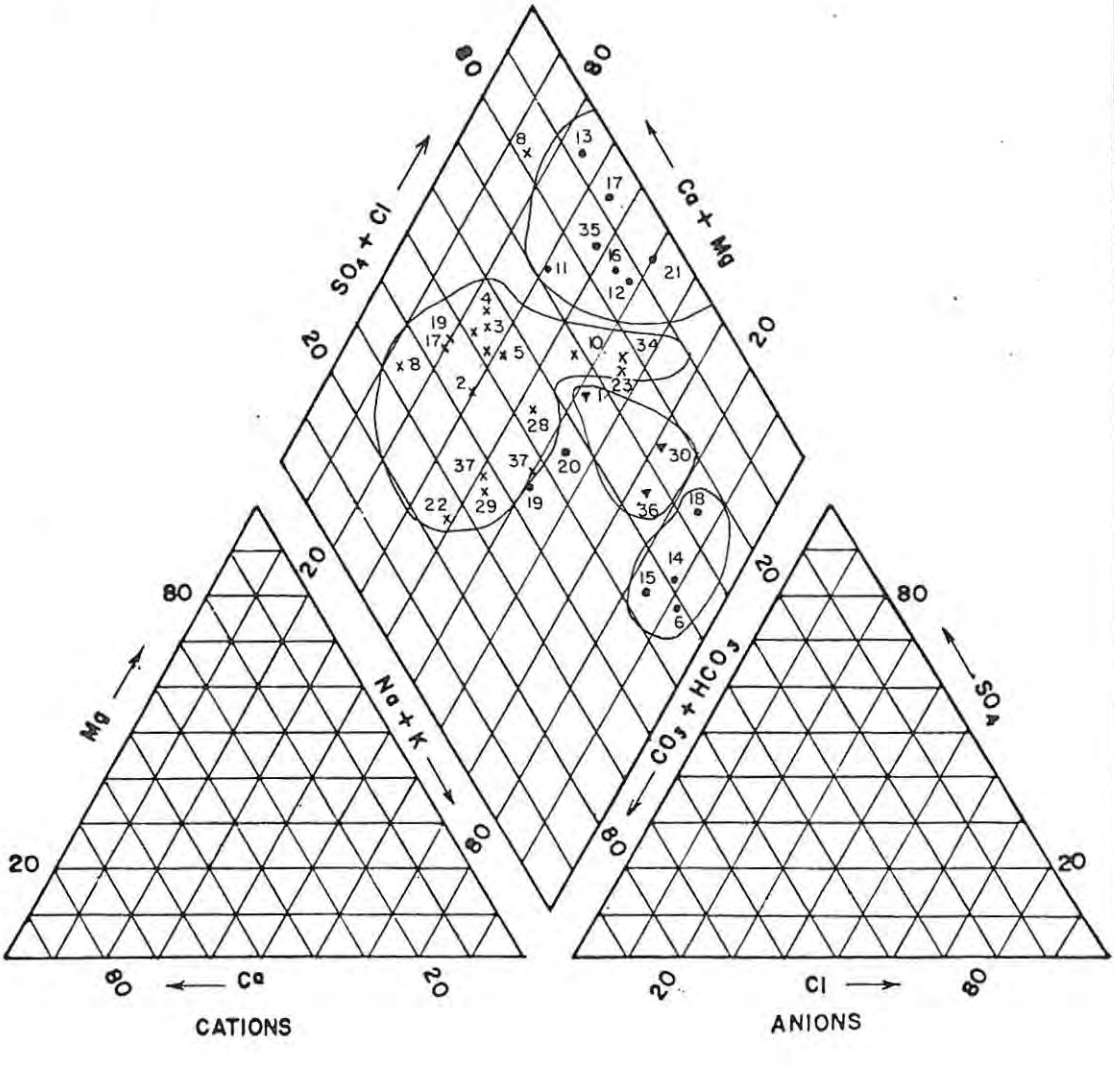
The Piper diagram indicates that groundwater from boreholes to fall into four groups. The one area is

REGIONAL SAMPLING PROGRAMME

TRILINEAR PLOT OF HYDROCHEMISTRY

BOREHOLE NO AND AQUIFER UNIT SYMBOL

- x BEAUFORT/ ECCA UNIT
- • LETABA, CLARENS REDBED UNIT
- ▾ WATERBERG UNIT



PERCENT OF TOTAL EQUIVALENTS PER MILLION

FIG. 6

characterised mostly by boreholes in the Beaufort/Ecca hydrogeological unit (south of the Daarby fault). The groundwaters from the Letaba/Clarens/Red Bed unit (north of the Daarby fault) tend to plot in two sub areas. The three samples collected from the Waterberg are not statistically significant but are representative of the aquifer and form an isolated group. In terms of the classification proposed by Bade in 1966 (in Freeze and Cherry, 1979) the groundwater from the individual units can be characterized as follows:

1) The Beaufort/Ecca aquifer unit has a calcium magnesium sulphate water.

2) The Letaba/Clarens/Red Bed unit groundwaters tend to plot in two sub-areas, one a chloride sulphate bicarbonate water and the other a sodium potassium water. The reason for the two sub-groups within the Letaba/Clarens/Red Bed unit is the probable impact of the Red Beds on the groundwater chemistry. The Clarens Formation thins to the north, and it is anticipated that a number of the boreholes further north, have intersected the Red Beds resulting in the groundwater containing more chloride than sulphate.

3) The Waterberg unit has a chloride sodium sulphate water.

A number of boreholes namely number 19, 20, 22, and 23 do not have a water chemistry indicative of the hydrogeological environment in which they are situated.

In the case of boreholes 20, 22 and 23 all are located close to the Daarby fault and varying chemistry could be due to mixing of the groundwaters from the different geological environments. The exact position of the fault away from the mine area is also not accurately known and this could result in the boreholes being classified into the incorrect geological environment.

5.3.4 Durov Diagram

Some of the shortcomings in terms of graphical plots of the trilinear plot of the type developed by Piper, are eliminated by use of a diagram introduced by S. A. Durov and described in the English language literature by Aporozec in 1972 (in Freeze and Cherry 1979). The basis of the diagram is percentage plotting of cations and anions on separate triangles similar to the Piper diagram. The plot of the anions and cations triangles are then extended to a central rectangle. The point of intersection on the rectangle represents the major ion composition of the water. A line can then be extended along the x axis to indicate the total dissolved solid content of the water.

Plots of the 1975, 1976 and 1985 sampling programmes, Figure 7, indicates that water samples from the Beaufort/Ecca unit to plot in a group. The water is characterized by moderate to high calcium and high sulphate percentages. The water samples from the Letaba/ Clarens/Red Bed unit are characterized by low calcium and sulphate percentages while high in chloride, potassium and sodium percentages (Figure 7).

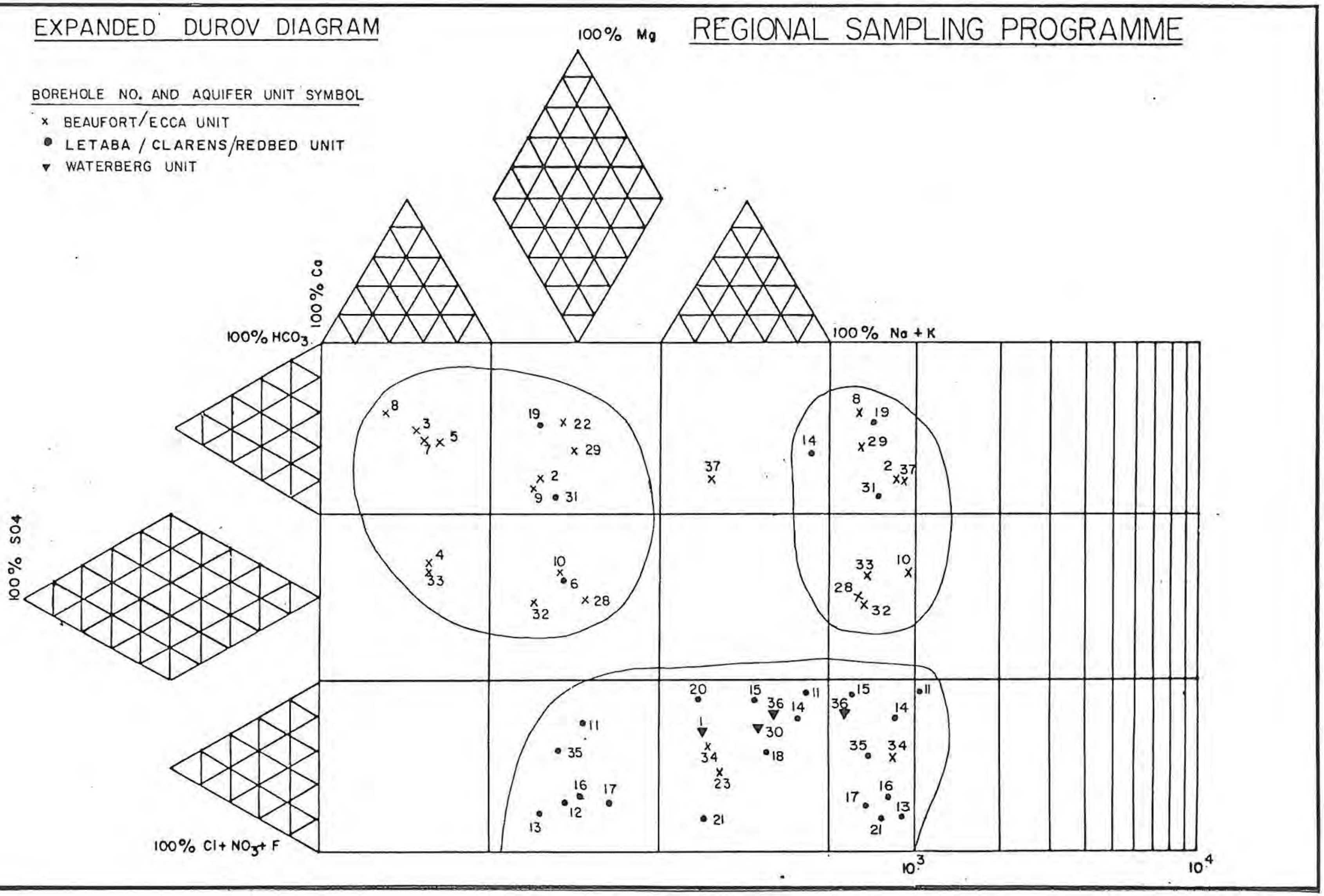

EXPANDED DUROV DIAGRAM
REGIONAL SAMPLING PROGRAMME
BOREHOLE NO. AND AQUIFER UNIT SYMBOL
× BEAUFORT/ECCA UNIT
● LETABA / CLARENS/REDBED UNIT
▼ WATERBERG UNIT
100% Mg
100% Ca
100% HCO3
100% Na + K
100% SO4
100% Cl + NO3 + F
10^3
10^4
8
3
7
5
19
22
29
2
9
31
37
14
8
19
29
2
37
31
4
33
10
6
32
28
33
10
28
32
20
15
36
11
14
36
15
11
14
1
30
34
18
23
21
11
35
16
17
12
13
35
34
16
17
13
21

FIG.7

In agreement with the Piper diagram (Figure 6) the chemical nature of the water from a number of boreholes does not correlate with their particular geological environment. Again this may be due to mixing of water from different hydrogeological environments facilitated by minor faults associated with the Daarby fault. Also, as no logs of the boreholes are available, the boreholes close to the Daarby fault could also be positioned incorrectly with respect to the individual aquifer units.

5.3.5 Areal Distribution Diagrams

From the Piper and Durov plots a number of elements and compounds were selected to be representative of the chemical composition of water from the two hydrogeological environments, namely the Beaufort/Ecca and the Letaba/Clarens/Red Bed units. The concentration of these elements or compounds are plotted on areal distribution maps at each of the borehole locations.

The Waterberg unit has not been investigated in detail in this study because the mining operations will not impact on the hydrogeological environment. The investigation focuses mainly on the Letaba/Clarens/Red Bed and the Beaufort/Ecca units as these units are in direct contact with mining operations and as a result, are more susceptible to the hydrogeological impact of the mining operations.

The areal distribution maps shown on Figures 8 to 11 fulfill the aim of the regional hydrochemical investigation by hydrochemically characterising the two individual aquifer units in the Grootegeluk area. Each of the aquifer units are discussed separately below.

5.3.6 The Letaba/Clarens/Red Bed Unit

The three geological formations of this unit all occur north of the Daarby fault. The formations have been grouped together because of the lack of geological data concerning the sampled boreholes. Also a number of the boreholes have intersected two or three of the lithological units belonging to the group.

The Letaba/Clarens/Red Bed units have a characteristic groundwater quality which distinguishes them from groundwaters south of the Daarby fault by:

i) a low calcium (Ca^{2+}) content (Range 10 - 100mg/l)

ii) a low sulphate ($SO_4{}^{2-}$) content (Range 2 - 25mg/l)

iii) a nitrate ($NO_3{}^{-}$-N) content generally greater than 1mg/l

iv) and a Silica (SiO_2) content of between 10 and 20mg/l

5.3.7 The Beaufort/Ecca Unit

Boreholes sampled south of the Daarby fault were all drilled into the Beaufort and Ecca Group sediments.

The groundwater chemistry of samples taken from boreholes in this group have the following hydrochemical characteristics.

1. a high calcium (Ca^{2+}) content (range 60 - 300mg/l)

2. a high sulphate ($SO_4{}^{2-}$) content (range 17 - 200mg/l)

3. low nitrate ($NO_3{}^{-}$-N) content (range less than 1mg/l)

4. low silica (SiO_2) content (range 5 - 15mg/l)

5.3.8 The Waterberg Unit

Insufficient data have been collected in this study from the Waterberg unit to chemically characterize the groundwater. However, the Waterberg is generally distinguished from the other groups by high fluoride contents (greater than 10mg/l).

The fluoride originates from weathering of fluoride bearing minerals the most important being apatite (Hem 1959). Thin section analysis of the Waterberg sandstone by the Grootegeluk Mine has shown the Waterberg Group to contain moderate percentages of apatite. The Apatite is contained in rear earth nodules in the Waterberg Group.

5.3.9 Statistical Analysis

The hydrochemical data from the individual aquifer units has been statistically analysed to determine range, mean and standard deviation for the selected chemical elements and compounds for the Letaba/Clarens/ Red Bed and Beaufort/Ecca aquifer units. The results are shown in Table 3. The comparison of these data indicate the chemical nature of the two aquifers either side of the Daarby fault to be markedly different, particularly in the calcium sulphate nitrate and silica concentrations of the groundwater.

LOCATION PLAN. BOREHOLE POSITIONS AND WATER QUALITY : Ca CONCENTRATIONS

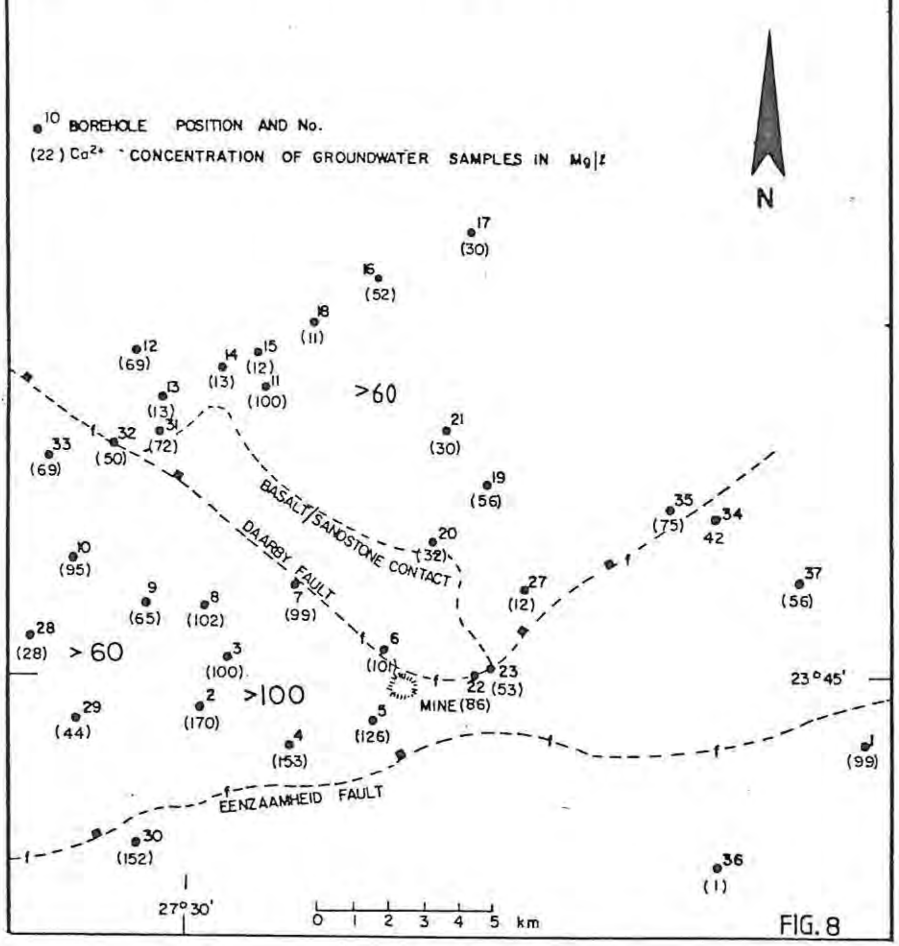


FIG. 8

LOCATION PLAN BOREHOLE POSITIONS AND WATER QUALITY : SO4 CONCENTRATIONS

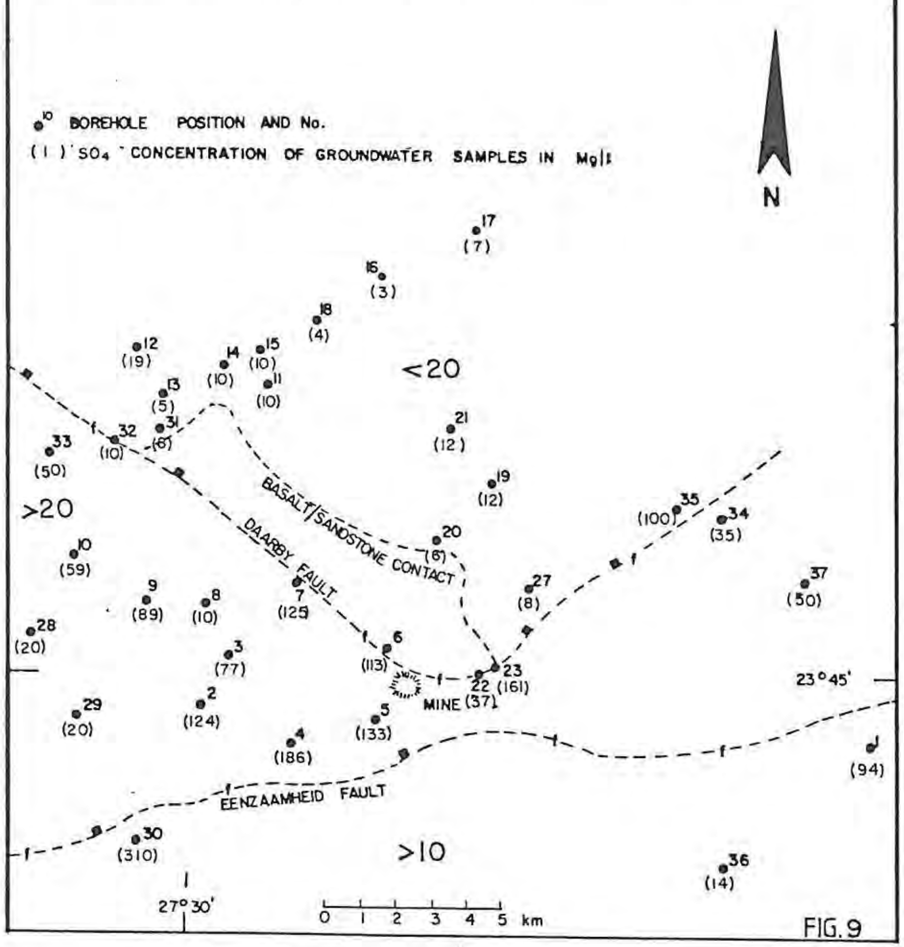


FIG. 9

LOCATION PLAN. BOREHOLE POSITIONS AND WATER QUALITY: NO_3-N CONCENTRATIONS

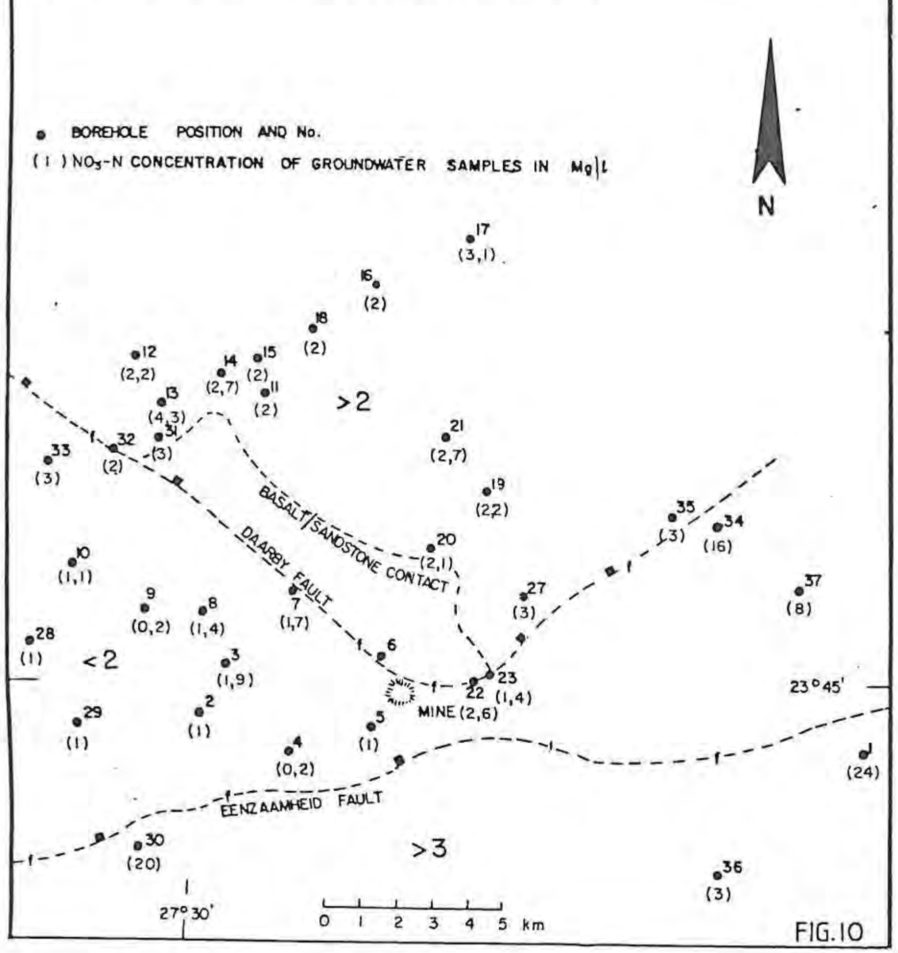


FIG.10

LOCATION PLAN. BOREHOLE POSITIONS AND WATER QUALITY: SiO_2 CONCENTRATIONS

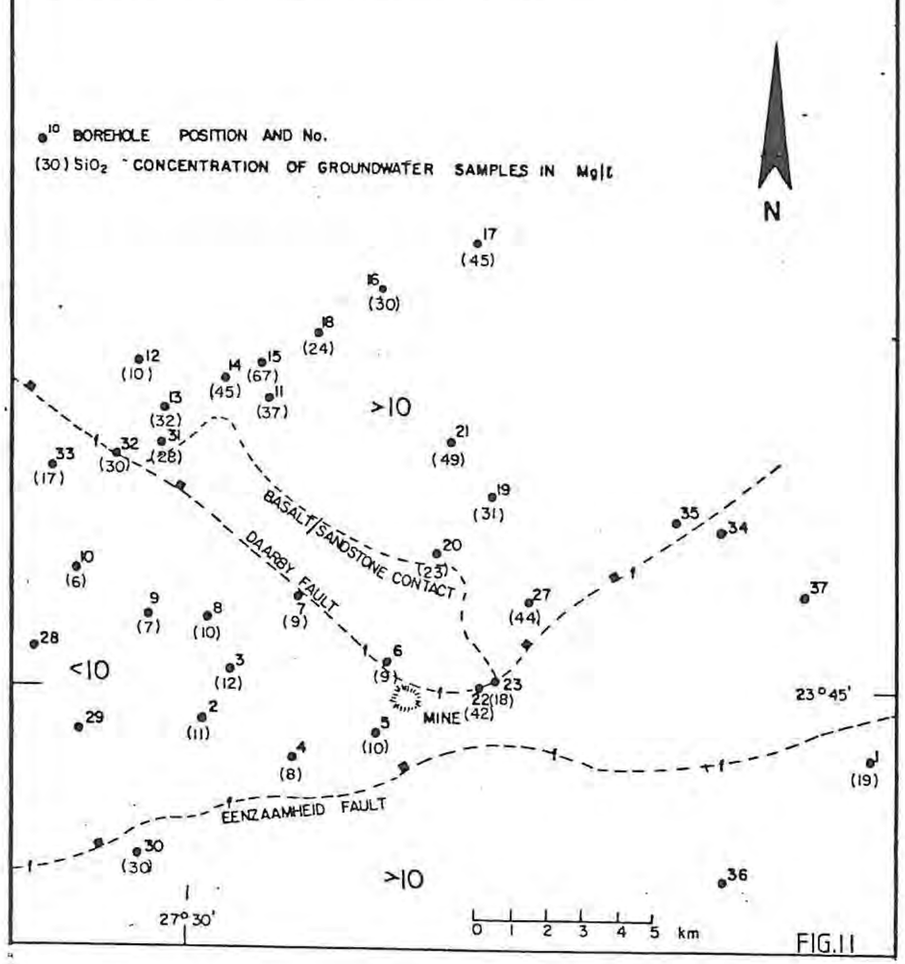


FIG.11

TABLE 3: STATISTICAL COMPARISONS OF THE HYDROCHEMISTRY OF THE INDIVIDUAL AQUIFER UNITS

	CLARENS SANDSTONE/RED BED	UNIT	1975+1985	BEAUFORT & ECCA		1975+1985
	1975	1985	$\bar{X}$	1975	1985	$\bar{X}$
Ca^{2+} distribution						
Range	30-60	10-100		60-160	20-300	
Mean	37,3	50,4	43,85	104,6	99,1	
n	9	9		7	7	101,9
σn-1	29,4	32,7		36,3	91,7	
So_4^{2-}						
Range	2-25	5-20	8,8	17-186	20-200	
Mean	7,9	9,7		82,0	62,1	
n	9	9		7	7	72,05
σn-1	4,9	4,5		70,4	64,4	
NO_3^--N						
Range	0,5-5,6	2-3		6,1-0,9	1-8	
Mean	2,9	2,2	2,6	0,4	2,7	1,6
n	9	9		7	7	
σn-1	1,4	0,4		0,35	2,4	
SiO_2						
Range	10-44	28-67		5,1-10,5	8-17	
Mean	27,9	46,9	37,4	8,2	13,2	10,7
n	9	9		7	4	
σn-1	10,1	16,3		1,9	3,7	

6.0 GROUNDWATER LEVELS ON THE ISCOR PROPERTIES SURROUNDING THE MINE

6.1 Introduction

The Grootegeluk Mine monitors water levels on a monthly basis in boreholes on the farms owned by Iscor surrounding the mine. The water levels are measured in old exploration boreholes and water level monitoring boreholes. The locations of the monitoring boreholes are indicated on Figure 12.

6.2 Nature of the Monitoring Boreholes

The boreholes in which water levels are measured are all numbered and coded according to the farm on which the borehole is located. The W B boreholes are holes especially drilled for the monitoring of, or abstraction of groundwater.

The exploration boreholes drilled on the farms Turfvlakte 463LQ and Grootegeluk 459LQ were left uncased. As a result a number of the boreholes have collapsed resulting in limited periods of water level data.

6.3 Borehole Data Selected

A total of twenty five (25) boreholes surrounding the open pit are or have been monitored since 1981. The positions of the monitoring holes are shown on Figure 12. Eleven boreholes have been selected for further study on the following criteria:

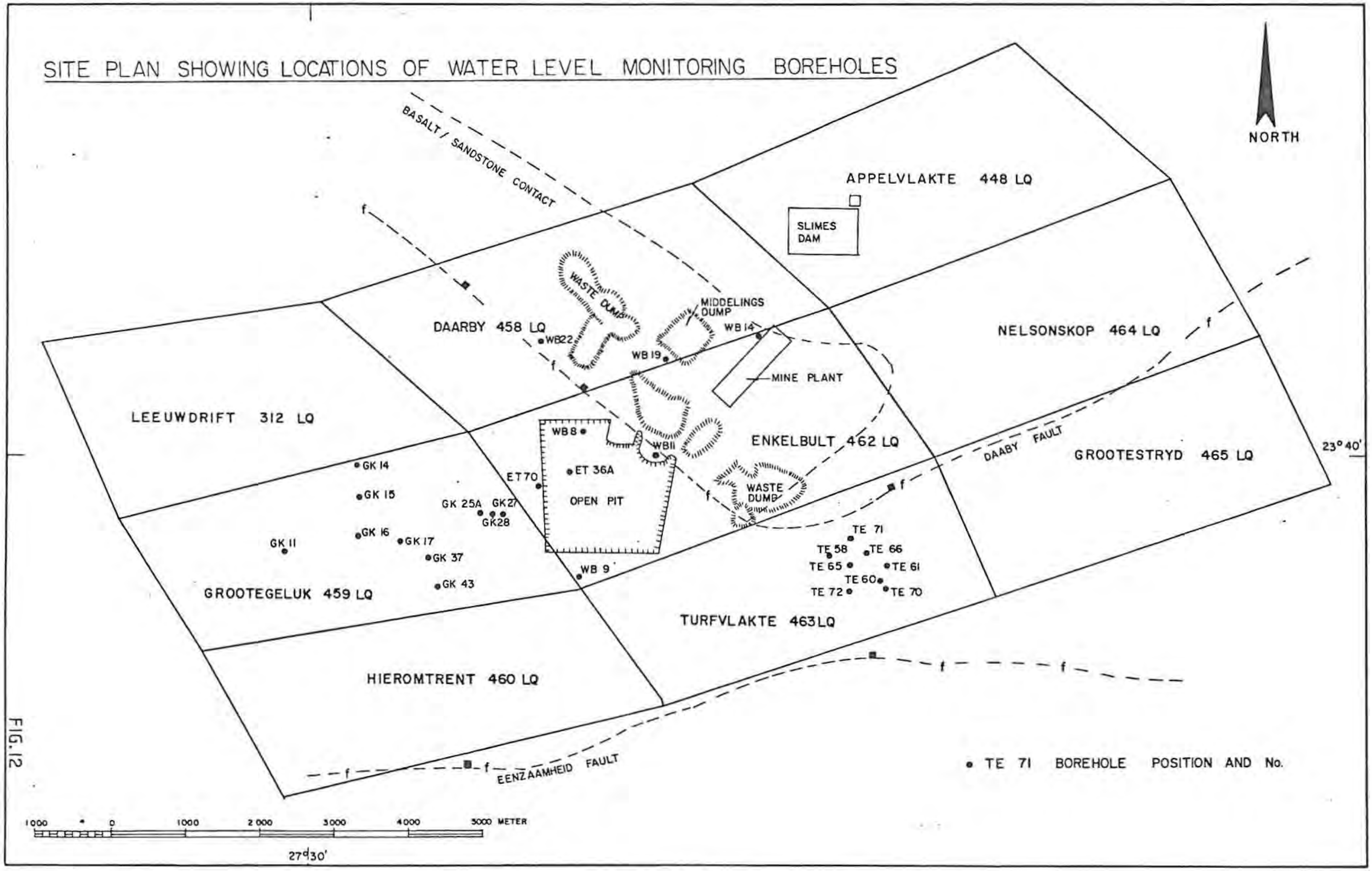

SITE PLAN SHOWING LOCATIONS OF WATER LEVEL MONITORING BOREHOLES

FIG.12

(1) Position and areal distribution

(2) Length of data record available

(3) Representativeness of the borehole position of regional groundwater level trends.

The borehole hydrographs of the selected boreholes are plotted against time with rainfall data (see Appendix 2). The time period of the data represented is from January 1981 to December 1987. On-going monitoring still takes place on a monthly basis.

6.4 Monthly Rainfall Graphs

Monthly rainfall graphs have been combined with the borehole hydrographs to enable the relationship between rainfall the recharge to be investigated. The monthly rainfall graphs (Appendix 2) show that the majority of the rainfall is experienced from October to March each year. As a result most recharge to the groundwater is expected during these months. The recharge to the groundwater is evident on the borehole hydrograph plots by a change in slope of the groundwater levels (Appendix 2).

6.5 Groundwater Levels of the Area Surrounding the Grootegeluk Mine

The groundwater levels measured in the boreholes are standing water levels. As the boreholes are not cased and do not contain any piezometers, the measured water levels, represent regional piezometric levels in the aquifer at the borehole. Boreholes both north and south of the Daarby fault have intersected different hydrogeological units and as a result the measured groundwater levels can be viewed as an average piezometric level of the hydrogeological units.

The monitoring has shown water levels south and north of the Daarby fault to be markedly different, with water levels south of the fault declining and north of the fault rising. Groundwater levels south and north of the Daarby fault are discussed individually and in more detailed below.

6.5.1 Groundwater Levels South of the Daarby Fault

The borehole data selected to examine the area south of the Daarby fault are based on length of record and position of the borehole. The data selected are from boreholes GK11 and 17 on the farm Grootegeluk, boreholes TE58, 65 and 70 on the farm Turfvlakte and boreholes WB9 and ET70 on the farm Enkelbult. Plots of borehole hydrographs and rainfall are shown in Appendix 2 and the positions of the boreholes on Figure 12 (Page 50).

In general, water levels in the boreholes surrounding the open pit, south of the Daarby fault in the Ecca Group, have shown a steady decline in regional piezometric level. The decline in levels is because of the excavation and continual dewatering of the open pit. The volume of water pumped from the open pit is discussed in Chapter 7. Water levels have declined from a calculated mean regional piezometric level of 890 m.a.m.s.l. before mining operations commenced to 840 m.a.m.s.l. at present juxtaposed to the open pit. As expected the decline in water levels is greatest at the open pit. The groundwater elevation contours south of the Daarby fault (Figure 13 Page 54) indicates a nett groundwater gradient of 1:195 or 0,3° to the open pit. The radius of drawdown due to dewatering at the open pit is conservatively estimated at 8000 metres.

As is evident from the contour map (Figure 13) the Ecca Group aquifer is anisotrophic. The decline in water level is greater in an easterly direction from the open pit. This area as discussed in Chapter 3 Section 4.3, has considerably more faulting than the rest of the Ecca Group aquifer. The hydrogeological significance of the faulting is an increase in the in-situ rock permeability and transmissivity of the Ecca Group. This increased hydraulic connection has resulted in greater drawdowns to the east of the open pit.

The borehole hydrographs, particularly WB9 (Figure 14), indicates recharge to the groundwater by the change in the piezometric trends. Recharge to groundwater in the Ecca Group is related to the summer rainfall. However a lag time between the summer rainfall events and a corresponding rise in the piezometric levels occurs, which is usually two to three months. The recharge to the groundwater usually occurs in February to April after the summer rains. The majority of summer rains occur from October to February each year. As the recharge is only evident after the summer rains it can be deduced that the majority of the water from the first summer rains that penetrates beneath the surface is taken up by the soil moisture deficit. As the rainfall season continues the soil moisture deficit is exceeded and percolating rainwater is able to recharge the groundwater.

GROUNDWATER ELEVATION CONTOURS SOUTH OF THE DAARBY FAULT 1988

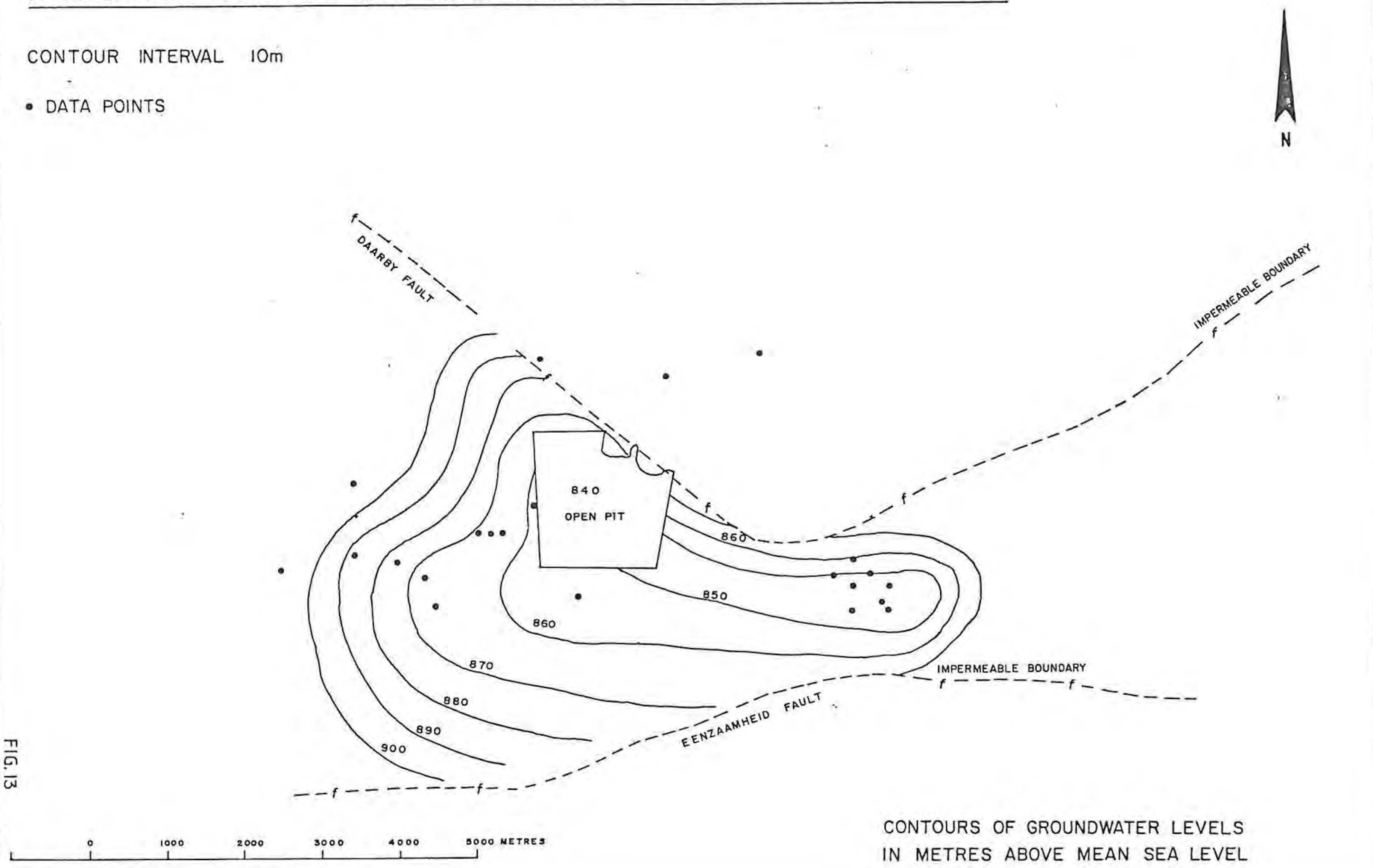


FIG.13

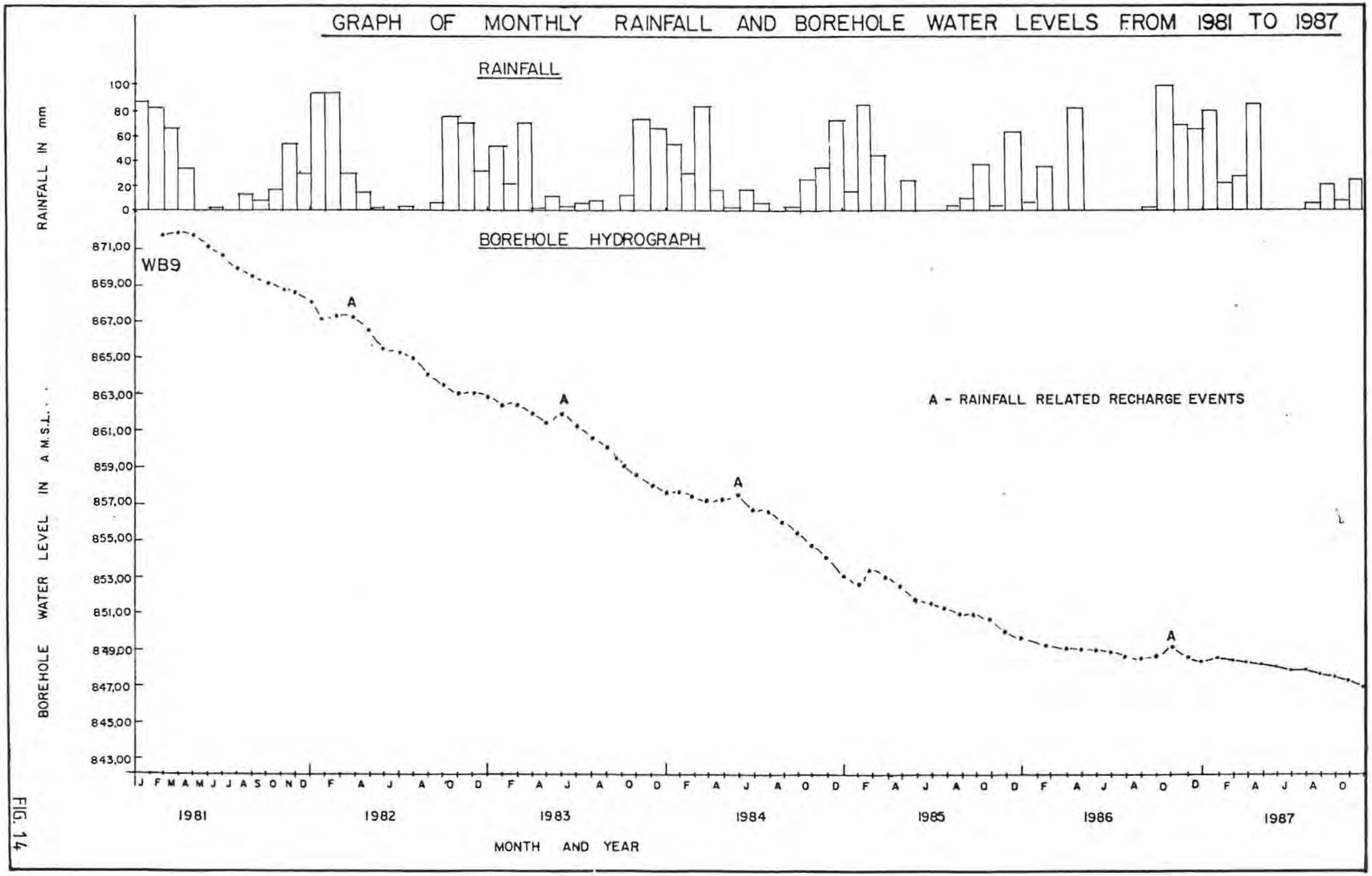

GRAPH OF MONTHLY RAINFALL AND BOREHOLE WATER LEVELS FROM 1981 TO 1987
RAINFALL
RAINFALL IN mm
100
80
60
40
20
0
BOREHOLE HYDROGRAPH
WB9
A
A - RAINFALL RELATED RECHARGE EVENTS
BOREHOLE WATER LEVEL IN A.M.S.L.
871,00
869,00
867,00
865,00
863,00
861,00
859,00
857,00
855,00
853,00
851,00
849,00
847,00
845,00
843,00
J F M A M J J A S O N D F A J A O D F A J A O D F A J A O D F A J A O D F A J A O D F A J A O
1981
1982
1983
1984
1985
1986
1987
MONTH AND YEAR

FIG. 14

Most of the recharge rainwater to the groundwater, away from the influence of the open pit, is assumed to replace groundwater lost through evapotranspiration.

6.5.2 Water Levels North of the Daarby Fault

Water levels measured in boreholes drilled into the Letaba and Clarens Formations north of the Daarby fault have shown a steady increase in piezometric level. Only three boreholes namely WB14, WB19 and WB22 are monitored by Grootegeluk. The boreholes have shown a marked increase in the regional piezometric level at an average of one to two metres per year. The borehole hydrographs of the boreholes WB14, WB19 and WB22 (Figure 15) indicates a steepening of the rise in water level after the summer rainfall events. However, there is an even rise in the regional piezometric levels throughout the year indicating continuous recharge which cannot be directly correlated to rainfall.

The continual recharge to groundwater north of the open pit can be attributed to mining operations. The waste dumps and slimes dams north of the open pit contain process water from the benefication processes undertaken by the Grootegeluk Mine plant. The process water drains, after stacking, from the waste dumps into the groundwater serving as a continual source of recharge. The Grootegeluk water balance (Figure 18) estimate 6000 m^3 is lost monthly in production. The majority of the water lost in production is contained in the wet waste material deposited on the dumps and the water based slurry pumped to the slimes dams. The exact volumes of recharge facilitated by the process water are difficult to estimate as the portion lost to evaporation is not quantifiable.

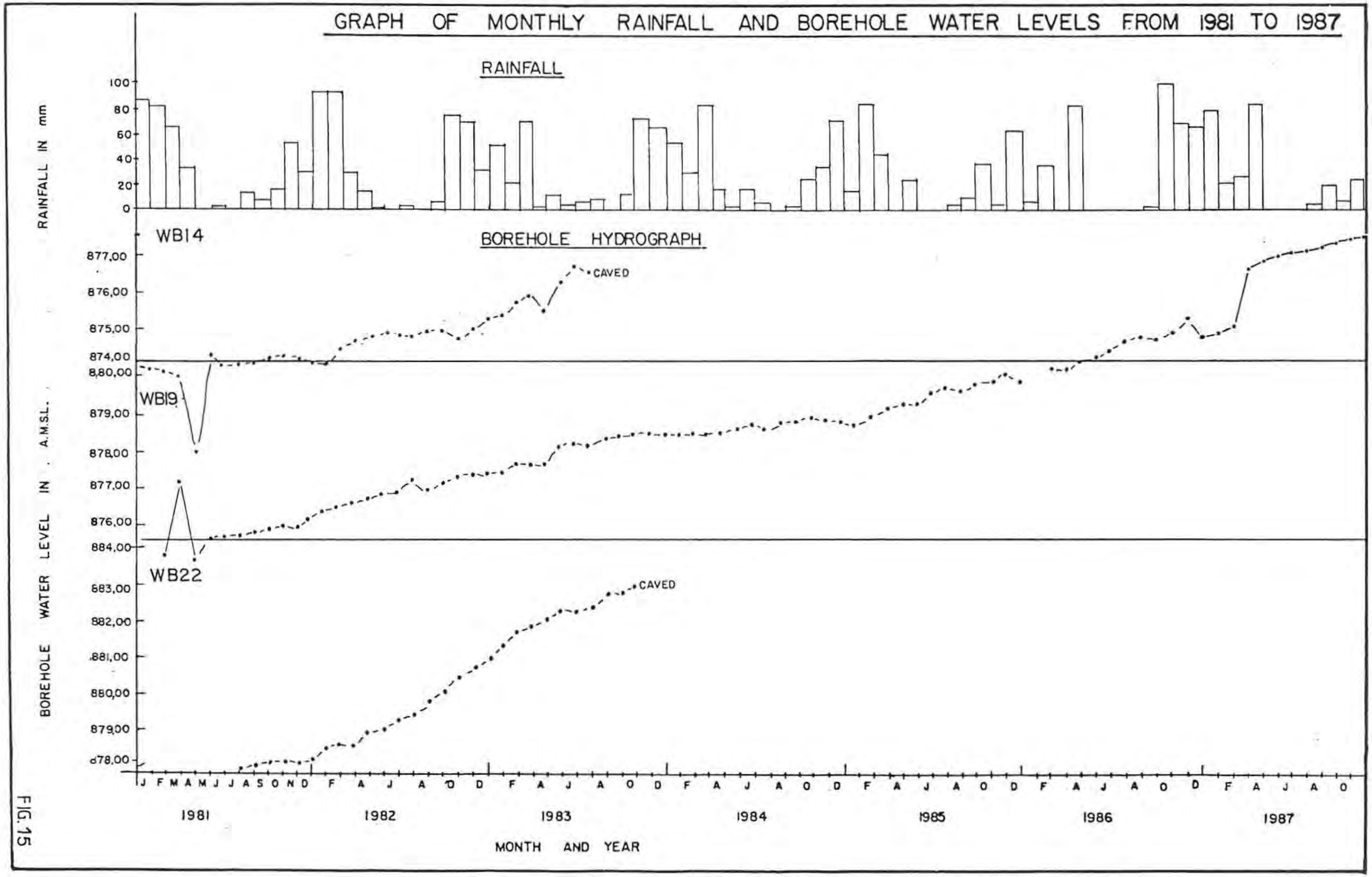

GRAPH OF MONTHLY RAINFALL AND BOREHOLE WATER LEVELS FROM 1981 TO 1987
RAINFALL
RAINFALL IN mm
100
80
60
40
20
0
BOREHOLE HYDROGRAPH
WB14
877,00
876,00
875,00
874,00
CAVED
WB19
8,80,00
879,00
878,00
877,00
876,00
WB22
884,00
883,00
882,00
881,00
880,00
879,00
878,00
CAVED
BOREHOLE WATER LEVEL IN . A.M.SL.
J F M A M J J A S O N D F A J A O D F A J A O D F A J A O D F A J A O D F A J A O D F A J A O
1981
1982
1983
1984
1985
1986
1987
MONTH AND YEAR

FIG. 15

It is estimated that (from the Grootegeluk water balance (Figure 18) and pumping from the open pit (Figure 16)), approximately 2000m^3 per day of process water and water from the open pit is introduced to the area north of the Daarby fault in the vicinity of the waste dumps. (Discussed in Chapter 8 Section 2).

Measurements of field permeabilities on the waste dumps and natural soils were completed on site using a ring infiltrometer. The results indicated the waste dump material to have a permeability in the order of 100 times that of the soils juxtaposed to the dumps. As a result it can be anticipated that the dumps will facilitate a greater portion of the rainwater falling on the dumps recharging groundwater. Also as there is continual downward percolation of process water migrating down through the dumps, the soil moisture deficit below the dumps will be near nil. This facilitates a greater portion of the rain water falling on the dumps to migrate through the dumps and recharge groundwater.

No groundwater contours are drawn for the area north of the Daarby fault (on Figure 14) due to the lack of data points. However, Figure 20 (Page 83) indicates water level contours for both sides of the Daarby fault after the installation of the monitoring network.

6.5.3 Conclusion

The groundwater level data measured by Grootegeluk personnel in the old exploratory and water boreholes indicates an alteration of the in situ hydrodynamic regime by mining operations.

The mining and associated dewatering operations in the open pit, south of the Daarby fault, have resulted in a dramatic decline in water levels in the Ecca Group. The decline of water levels is greatest at the open pit and the contour map (Figure 13) indicate the anisotropic nature of the Ecca aquifer. The majority of the permeability in the Ecca aquifer is secondary and is structurally related.

In contrast to the Ecca Group aquifer, the Letaba and Clarens aquifers north of the Daarby fault have shown a significant rise in water levels. The rise in water levels can be attributed to recharge to the groundwater by mine process and open pit water. Both areas, north and south of the Daarby fault show recharge to groundwater after the summer rains.

The contrast between water levels south and north of the Daarby fault indicate the fault to be largely impermeable. The two aquifer units each side of the fault for most purposes can be treated as two distinct aquifer units with very little or no hydraulic connection between the two. Packer testing of borehole WBR19 which intersected the fault zone indicated the fault zone to be impermeable (Chapter 9 Section 3).

Due to the poor areal distribution of the water level monitoring boreholes a number of boreholes, the WBR boreholes, were drilled specifically to upgrade the existing monitoring network (Chapter 9). Piezometers were also installed in selected WBR boreholes to determine variations in piezometer heads with depth. The results which indicate there are confining conditions in the Ecca Group are discussed in Chapter 9.

7.0 THE OPEN PIT

The mine open pit is situated south of the Daarby fault on the farm Enkelbult 462 LQ. The pit bottom is at present 80m below ground level (800 m.a.m.s.l) and has an areal extent of (July 1988) of 2020000m^2 (202ha). Mining takes place by blasting and mechanical excavation on four individual benches each of approximately 17m. The mine extracts 15 million tons of run of mine material from the pit annually, of which 3.5 million tonnes is 'middlings' (power station grade coal), 1.82 million tonnes coking coal and the remaining 9,7 million tonnes, are plant discards. The plant discards are mixed with overburden and are placed on waste dumps north of the Daarby fault.

There is a continual inflow of water into the mine throughout the year. Water enters the mine directly from rainfall and as groundwater along bedding planes and fractures. Estimates by the Grootegeluk mine personnel are that only 15% of the total water pumped from the open pit originates directly from groundwater. These estimates are based on winter pumping volumes from the open pit.

7.1 Volumes of Water Entering the Open Pit

Water is removed from the open pit by means of pumps at the pit bottom. Pumping takes place only when water collected in the open pit disrupts the mining operations. Figure 16 graphically displays the volume of water pumped from the open pit over the last six years in comparison to monthly rainfall data.

A number of points arise from Figure 16, namely:

1. More water is pumped from the open pit during the summer months corresponding to the peak rainfall periods.

2. In winter months (periods of no or very little rainfall) pumping nearly ceases.

3. The total volume of water pumped from the open pit has increased each year as the area of bench one (open pit surface area) has increased.

Visual observations during the winter months revealed that very little groundwater enters the open pit from the side walls. Calculations based on monthly winter pumping volumes show that approximately 100m^3/day of groundwater, enters the pit at localized points. These localized points are fractures or points along lithological contacts.

The water from the open pit is either pumped to the mine plant or into a soak-away trench near borehole WBR 18 (Figure 18) north of the Daarby fault. Figure 16 shows there is an increase in the volume of the water being pumped to the mine plant compared to the soak away trench. As a result, direct recharge to the sandstones and basalts north of the Daarby fault has decreased over the last years.

The relative proportions of water entering the open pit via direct rainfall or via groundwater are difficult to evaluate accurately. During the rainy months water levels in the boreholes around the open pit rise due to recharge from rainfall. This results in greater volumes of groundwater entering the open pit after the summer rains.

GRAPH OF MONTHLY RAINFALL AND VOLUMES OF WATER PUMPED FROM THE MINE OPEN PIT

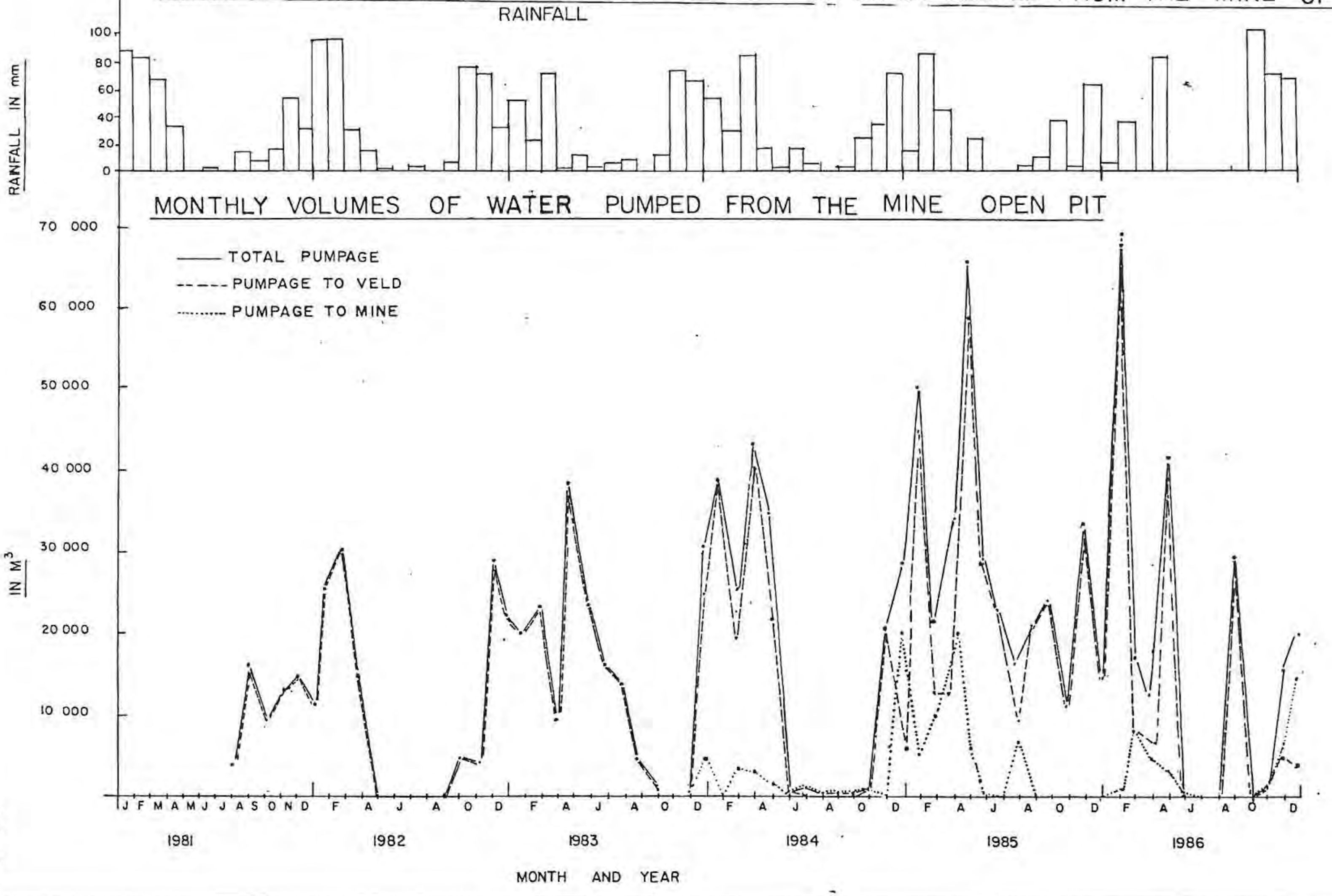
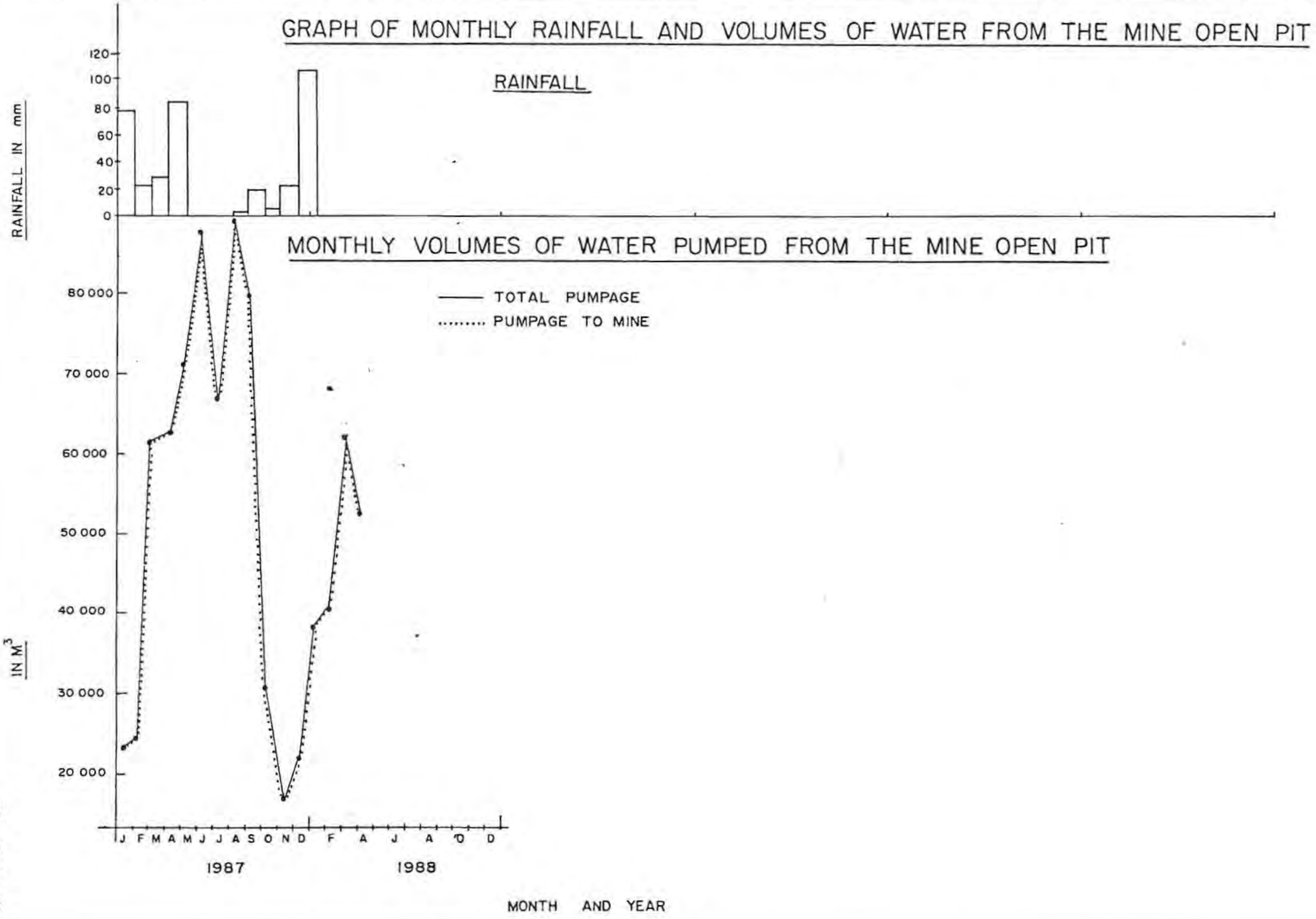


FIG.16


GRAPH OF MONTHLY RAINFALL AND VOLUMES OF WATER FROM THE MINE OPEN PIT

RAINFALL

MONTHLY VOLUMES OF WATER PUMPED FROM THE MINE OPEN PIT

FIG. 16 (cont.)

7.2 Water Chemistry

Sampling of groundwater entering the open pit was completed in February 1985 and the samples were measured in the pit for pH and conductivity. The samples were taken from localised fracture flow and flow between lithological units. The sampling positions and results of the field chemical analyses are shown in Table 4. The results of the laboratory analyses are shown in Appendix 3.

TABLE 4
LOCATIONS OF WATER SAMPLES IN THE OPEN PIT

Sample No	Locations	pH	Conductivity in Microohms/cm
A	Pond	7,75	1250
B	Eastern wall, fault zone bench 5	7,0	1450
C	Western side, bench 4, lithological contact	8,3	2000
D	Northern corner, bench 4, lithological contact	8,5	1900
E	Eastern side, bench 2, fault zone	7,6	1850
F	Western side, bench 2, lithological contact	7,10	1850
G	Eastern side, bench 3, lithological contact	7,35	1700

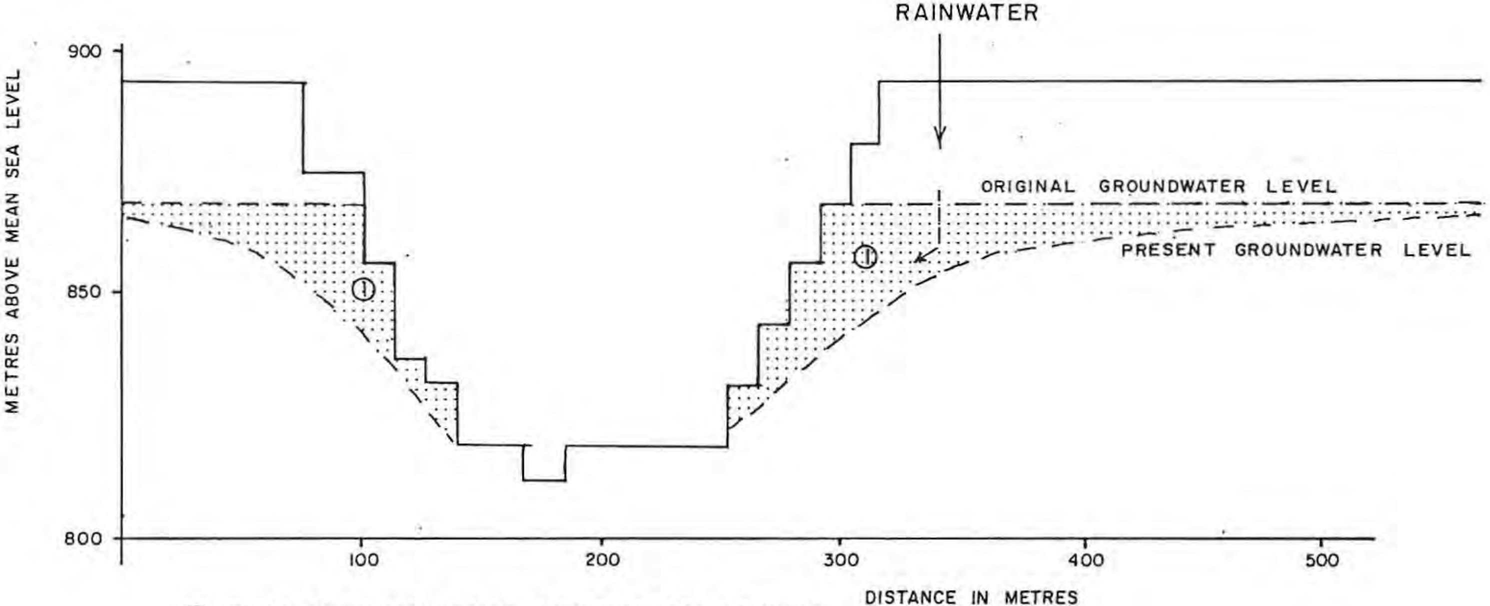
The groundwater entering the open pit is high in total dissolved solids, particularly sulphate, magnesium and calcium when compared to groundwater from boreholes in the Beaufort/Ecca aquifer unit. Piper and Durov plots (Figures 21, Page 86 and 22, Page 87) show the chemistry water entering the open pit in comparison to the groundwater chemistry measured in the WBR boreholes. The Daarby fault which is the northern limit of the open pit is largely impermeable and as a result most of the groundwater entering the open pit originates from the Beaufort and Ecca sediments. In comparison to groundwater from the Beaufort/Ecca Units the water entering the open pit is highly charged in calcium, magnesium and sulphate. The calcium, magnesium and sulphate salts are presumed to be mobilized by rain water which percolates through the soil layers dissolving salts precipitated in joints and fractures in the coal measures. The increase in the total dissolved solid content of the water entering the open pit can be attributed to periodic wetting and drying of the Ecca sediments in the vicinity of the open pit. The lowering of the groundwater level in proximity to the open pit has resulted in the exposure of previously saturated Ecca sediments to oxygen. The introduction of oxygen has resulted in an increase in the precipitation of salts in the fractures and along bedding planes. The migration of rain water to the groundwater, through the faults and fractures, results in a resolution of salts by the recharge water and an overall increase in the total dissolved solid content of the groundwater. After the recharge events, the Ecca sediments are exposed to oxygen until the next recharge event. The concept is graphically displayed in Figure 17, a generalised cross section of the open pit.

The groundwater levels in the Ecca sediments are continuously being lowered by vertical and horizontal expansion of the open pit. This results in greater volumes of Ecca sediments being exposed to oxygen and the subsequent precipitation of salts. The increased volume of salts are subject to resolutions by recharge water.

Visual identification of the salts encrusted on the sidewalls of the open pit indicate that they are mainly calcium and sulphate salts (Plates 3 and 4). During rain these salts are remobilized and migrate into the pond at the pit bottom.

In comparison, the total dissolved solids content of the pit pond is generally less than the groundwater entering the open pit. This is due to the majority of the water entering the open pit originating from rain water. During winter months the total dissolved solid content of the water in the pit pond is likely to increase due to the relative increase in volume of the groundwater contributing to the free water pond. The total dissolved solid content of the water in the pit bottom is also increased by evaporation.

GENERALIZED CROSS SECTION OF OPEN PIT SHOWING GROUNDWATER LEVELS



① ZONE CONTAINING SALTS AVAILABLE FOR SOLUTION TO PERCOLATING RAINWATER. PRESENT GROUNDWATER LEVEL WILL OSCILLATE DEPENDING ON RECHARGE EVENTS

FIG.17

(NOT TO SCALE)

PLATE 3 GROUNDWATER ENTERING THE OPEN PIT ALONG A FAULT (Note Iron Hydroxide "yellow boy" precipitation)

PLATE 4 ENCRUSTED SALTS ON THE SIDEWALLS OF THE PIT

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8.0 THE SLIMES DAMS

North of the Daarby fault and the mine are three slimes dams situated on Clarens Sandstone Formation. The dams cover an area of 109ha and are raised above ground level. The dams are constructed directly onto the Clarens sandstone with no impermeable linings or ground compaction.

Water from the Hans Strijdom Dam and the open pit is used for washing and grading the coal from the open pit. The coal fines are pumped by means of a water based slurry to the slimes dams. Here the fine coal settles out of suspension by gravity. The water (free of coal fines) is then recycled back to the mine workings. Water is lost at the slimes dams through evaporation, entrainment and downward percolation to the groundwater. Estimates of the relative volumes of water in the mine water balance (Figure 18) are made by Grootegeluk from gauging stations.

8.1 Water Chemistry

Water samples were taken to determine the chemical nature of the water in the slimes dams. Three samples were taken from various locations in the slimes dams. The chemical analyses of the samples are shown in Appendix 3 and the results are plotted on a Piper (Figure 21 Page 86) and Durov plot (Figure 22 Page 87). Both plots indicate the water to be very high in calcium and sulphate salts, similar in chemical nature to the groundwater entering the open pit. Figures 21 and 22 also show the groundwater chemistry of the WBR boreholes for comparison.

8.2 Water Balance

Figure 18 shows the total Grootegeluk daily water balance. Grootegeluk estimates 2800 m^3/day is lost in the slimes dams by entrainment, downward percolation and evaporation.

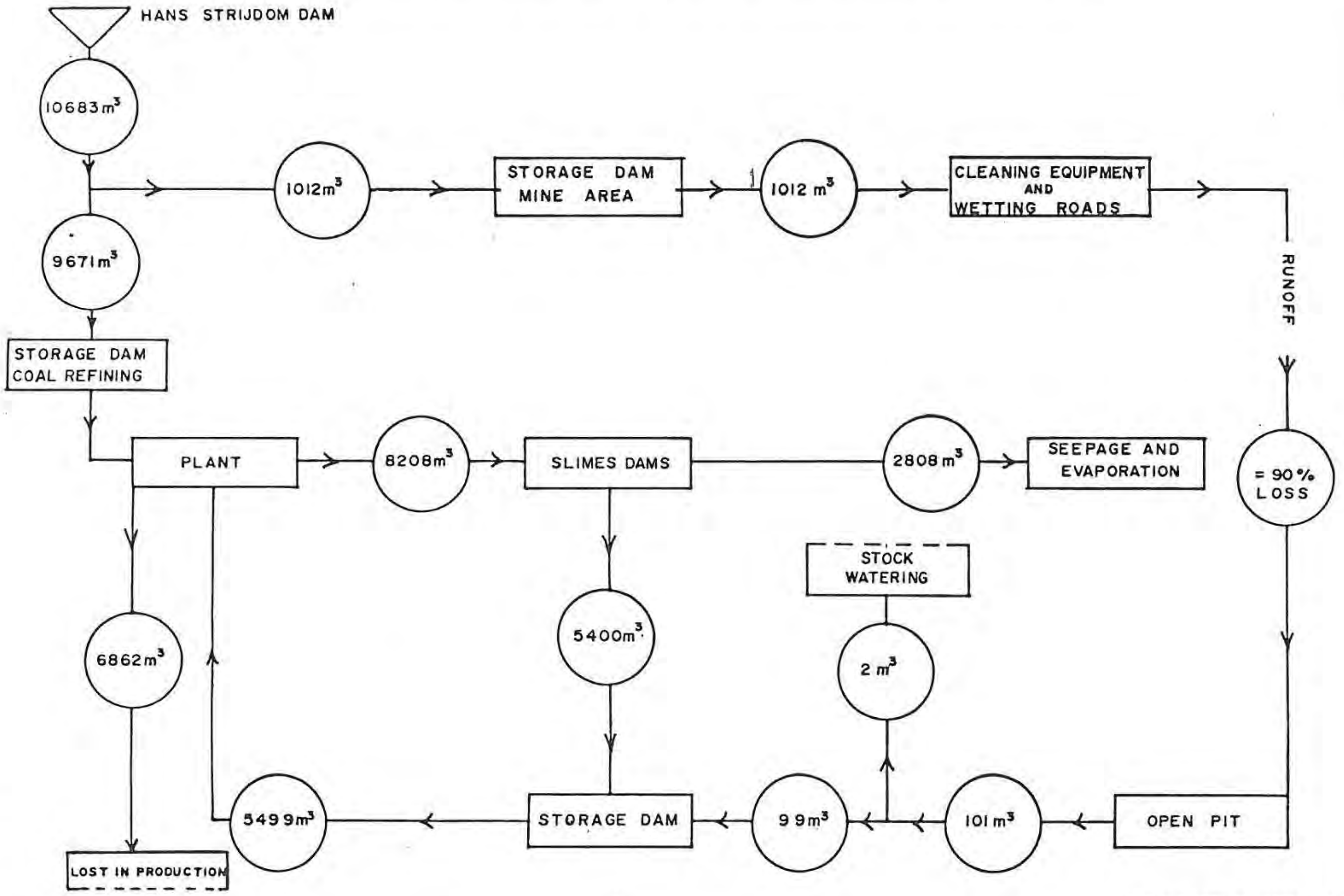
Grootegeluk water balance calculates, of the 2800m^3 lost daily in the slimes dams, 400m^3/day is lost to evaporation. Approximately 40% of the remaining 2400m^3/day is calculated to be held in entrainment and the remaining 1440m^3/day percolates into the groundwater. The water held in entrainment is slowly released to evaporation and groundwater.

The slime dams have at present (July 1988) an areal extent of some 109 hectares. Only a portion (approximately one third) of the slimes dam area is covered by free water ponds. Water is also entrained in the coal slimes below the surface of the ponds.

Soiltech (1976) undertook six in situ constant head permeability tests on areas cleared for dumping of the slimes. The average permeability of the site was 6,98 x 10^{-5}cm/sec (0,05m/day). Calculations based on the pond area and the permeability values of the soils below the slimes dams indicate that the estimated 1440m^3/day loss by Grootegeluk to groundwater is feasible.

Combining the volumes of water lost in the slimes dams (1440m^3/day) with process water and open pit water (500m^3/-day) (Chapter 6 Section 5.2), the calculated total volume of water recharging groundwater north of the Daarby fault is in the order of 2000m^3/day.

GROOTEGELUK MINE DAILY WATER BALANCE (DECEMBER 1987)



(GROOTEGELUK MINE 1987)

FIG.18

9.0 WBR BOREHOLES

In order to ascertain the hydrogeological conditions in the immediate vicinity of the mine, twenty five WBR (water boreholes rehabilitation) monitoring boreholes were drilled specifically for groundwater monitoring on Iscor's properties. These boreholes were positioned to compliment and upgrade the existing borehole monitoring network.

The boreholes sites were selected in strategic positions to enable the immediate and future impact of the mine on the ambient hydrogeological regime to be determined. Seventeen holes were sited north of the Daarby fault in the Letaba/Clarens/Red Bed aquifer unit on which the mine plant, discard dumps and slimes dams are situated. Six boreholes were drilled south of the Daarby fault into the Beaufort/Ecca sediments. The geological logs and depths of the holes are shown in Appendix 4.

The seventeen boreholes drilled north of the Daarby fault penetrated the Letaba Basalt and/or Clarens Sandstone Formation. One hole was drilled through the Daarby fault intersecting Clarens sandstone and then the Ecca Group. Six boreholes were drilled into the coal measures south of the Daarby fault. A further two boreholes were drilled south of the Eenzaamheid fault into the Waterberg Group. The positions of the boreholes and borehole numbers are shown on Figure 19.

The boreholes are used to determine groundwater levels and quality. After drilling, a number of the boreholes were pump tested for short periods of time to determine aquifer characteristics and to enable representative water samples to be taken. Multipiezometers were installed in six of the boreholes to facilitate measurement of potentiometric levels and to allow discrete water sampling from different horizons in the future. The construction details of the multipiezometers are shown on the borehole logs in Appendix 4.

9.1 Borehole Positions

The location of the WBR boreholes are shown on Figure 19. The inner ring of boreholes in the Letaba/Clarens aquifer unit are located in close proximity to the mine waste dump and slimes dams to determine the quality of leachate emanating from these structures. The outer ring of boreholes are situated in a semi circle around the mine plant, dumps and slimes dams to determine ambient groundwater quality and levels and to trace contaminant movement. The six boreholes drilled into the coal measures in the Beaufort/Ecca aquifer unit are used to determine ambient groundwater quality and more importantly to measure water levels on an ongoing basis.

Details of the borehole geological logs, construction, water intersections, final blow-out yield, and in some cases piezometer construction and packer test results are shown on the borehole logs in Appendix 4.

9.2 Aquifer Testing

Where possible each of the WBR boreholes were pump tested using an electrical submersible pump. The aim of the pump testing programme was to determine the hydraulic and chemical characteristics of the two major aquifer units each side of the Daarby fault.

SITE PLAN SHOWING LOCATION OF WBR MONITORING BOREHOLES

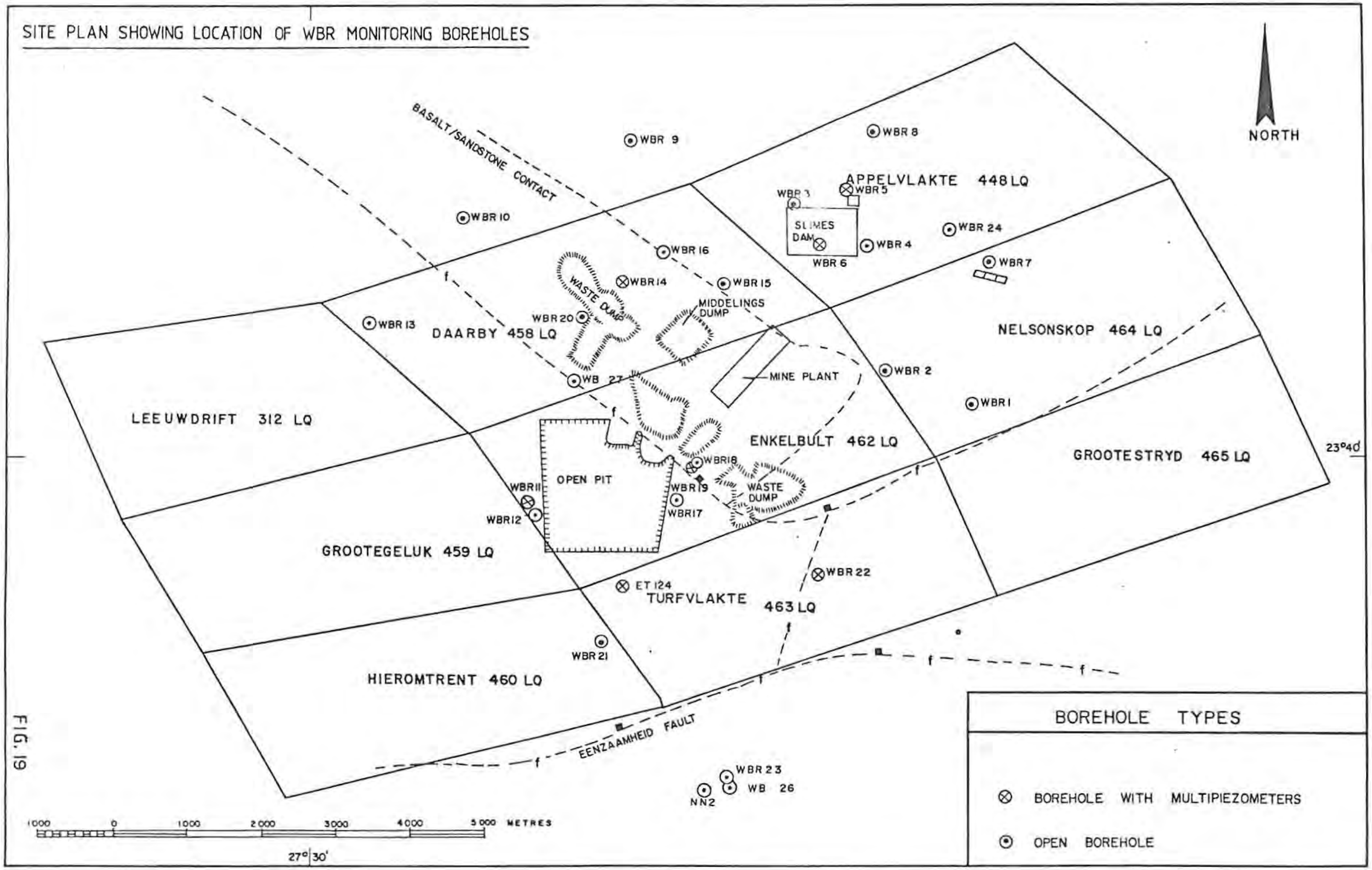


FIG. 19

The aquifer test consisted of a four hour drawdown and a two hour recovery test. A submersible pump was used because of the ease of installing the pump and the convenience of a portable generator. A submersible pump operates on the centrifugal principle, where the discharge of the pump is inversely proportional to the pumping head. This results in a decline in discharge as the drawdown increases. The steady decline in discharge rate during the pumping test was between 0% and 40% of the original pumping yield depending on the amount of drawdown in the borehole. Water samples were taken at the end of each test for chemical analysis.

The results of the drawdown and recovery measurements taken during the pump test are shown in Appendix 5.

Aquifer hydraulic properties, principally transmissivity values, were calculated from drawdown and recovery test data and plots of t/t^1 by the Cooper-Jacob method. Table 5 shows the range of transmissivity values for each borehole calculated by the three different methods. The transmissivities for each borehole were calculated from drawdown and recovery data using a method devised by Jacob (in Krusman and De Ridder, 1976). A straight line was fitted to portions of the drawdown and recovery which were most representative of the aquifers response. Another method used to calculate the transmissivity values was the recovery data plotted against total time of the test divided by the recovery time (t/t^1). The calculations of transmissivity are shown on the drawdown, recovery and t/t^1 plots for each of the boreholes in Appendix 5. The recovery data yielded more meaningful results as to the aquifer hydraulic properties, as no well losses are experienced during the recovery tests. The results are used in calculation of "average"

"average" transmissivity values for the individual aquifer units (Tables 6 and 7).

In fractured rock aquifers, transmissivity values are directly proportional to the fracture intensity of the rock and the storage characteristics of the fractured rock aquifers. As a result calculation of a transmissivity "average" value for each of the aquifer units is subjective. However because of the number of boreholes tested, a transmissivity average can be calculated. This is more applicable to the Letaba/Clarens unit where seventeen boreholes were tested compared to three in the Beaufort/Ecca unit. The results of the calculations and statistical analyses are shown in Tables 5, 6 and 7.

TABLE 5
TRANSMISSIVITY VALUES CALCULATED FOR W.B.R. BOREHOLES

WBR NO	STATIC WATER LEVEL		HOLE DEPTH m	PUMPING RATE (l/s)	DRAWDOWN $T(m^2/d)$	RECOVERY $T(m^2/d)$	t/t' $T(m^2/d)$
	m below casing top	mamsl					
1	21,76	865,89	45	1,39	93,52	115,68	94,54
2	20,07	877,92	78	1,14	10,02	8,8	11,62
3	7,27	885,91	45	0,44	9,20	10,62	13,91
4	14,91	875,53	50	0,42	9,16	5,88	7,81
5	7,36	879,21	43	0,35	5,53	5,40	5,83
6	13,78	882,45	63	0,36	30,07	11,74	9,65
7	24,54	862,40	50	0,40	1,12	1,14	1,62
8	17,42	862,13	43	0,40	0,57	0,42	0,39
9	36,50	882,74	60	0,192	5,45	4,62	3,61
10	36,35	878,70	116	0,23	1,30	0,65	0,57
11	±54	±849,51	161	Not pumped			
12			106	Not pumped			
13	31,75	874,86	112	0,235	1,11	0,16	0,201.
14	27,85	883,66	109	1,06	10,95	15,77	15,24
15	20,20	882,04	51	0,41	19,64	15,43	12,23
16	31,97	876,71	70	0,34	14,90	12,80	8,53
17	18,50	875,89	166	0,45	118,50	250,00	323,41
18	5,63	887,35	96	0,473	1,53	1,82	0,88
19	6,78	886,12	91	0,45	0,31	0,38	0,37
20	18,76	885,03	140	0,369	3,80	2,20	0,94
21	40,42	859,13	106	0,168	2,10	0,70	0,31
22	34,04	852,61	166	0,34	4,90	2,00	0,84
23			166	Not pumped			
24	19,60	867,67	43	0,25	0,35	0,87	0,33
25			115,5	Not pumped			
26			110	Not pumped			
27	13,83	888,45	140	1,53	124,06	169,52	182,58
NN2	19,65			0,03		0,42	0,18

T = transmissivity
mamsl = metres above mean sea level
l/s = litres per second
m = metres
m^2/d = metres squared per day

TABLE 6
CALCULATED TRANSMISSIVITY "AVERAGES" FOR THE MAJOR AQUIFER UNITS IN M^2/DAY

AQUIFER UNIT	MEAN $\overline{x}$	STANDARD DEVIATION $\sigma n-1$	RANGE	NUMBER n
Letaba/ Clarens	21,72	46,8	182,21	17
Ecca/Beaufort	0,45	0,34	0,64	3

(Calculated from t/t^1 results)

TABLE 7
CALCULATED PERMEABILITY "AVERAGES" VALUES FOR MAJOR AQUIFER UNITS IN M/DAY

AQUIFER UNIT	MEAN $\overline{x}$	STANDARD DEVIATION $\sigma n-1$	RANGE	NUMBER n
Letaba/ Clarens	0,47	0,98	4,01	17
Ecca/Beaufort	0,006	0,0029	0,003	3

($K = \frac{\text{Transmissivity}}{\text{Saturated depth in borehole}}$)

The difference between the "average" transmissivity values for the Letaba/Clarens and Beaufort/Ecca units are two orders of magnitude, as are the permeability values. The average T and K values (Tables 6 and 7) for the different aquifer units give an indication of the rate of movement of groundwater in the individual aquifer units. From these values the rate of movement of leachate in the Letaba/ Clarens aquifer unit is calculated in Chapter 9 Section 7.

9.3 Packer Testing

The identification of detailed flow patterns within the aquifers surrounding Grootegeluk is vital for studies relating to contaminant migration and water quality. Although useful information was achieved from drilling, the geological logs and records of water intersections, these do not provide details of fissure permeability and depth. The pumping tests provided an overall response over the portion of aquifer penetrated by the borehole to the withdrawal of groundwater.

Packer tests were carried out in a number of selected holes to help determine the depth at which fractures occurred and the relative permeability of the fractures. The packer tests allowed detailed information to be obtained about actual fracture flow in different sections adjacent to the borehole.

Three boreholes were selected for packer testing namely, WBR 11, WBR 14 and WBR 19. WBR 14 is a high yielding hole in the basalts 200m north of the waste dumps. WBR 11 is situated east of the open pit and intersects the Ecca Group and WBR 19 is drilled into the Clarens Formation through the Daarby fault into the Ecca Group (Figure 19).

The results of the packer testing are shown on the borehole logs for boreholes WBR 11, 14 and 19 in Appendix 4. The criteria used for the selection of the boreholes was based on the hydrogeological environment and proximity to the mine structures impacting on the hydrogeological regime.

Before commencing with the packer tests detailed caliper logs of the boreholes were run. Results from the caliper logs were compared to the geological logs and recorded water strikes. By this accurate identification of fracture zones was possible. The field caliper log of borehole WBR14 is shown after the borehole log in appendix 4. Fracture zones on the caliper logs are indicated by a variation in the borehole diameter measured by the caliper tool. Fracture zones and casing depths are indicated on the caliper log of WBR 14 in Appendix 4.

The packer testing showed the basalt and sandstone in borehole WBR 14 to be highly permeable at certain horizons. These horizons are conduit zones for the movement of water and possible seepage from the waste dumps. Multipiezometers were installed opposite the highly permeable zones to allow discrete sampling.

9.4 Installation of Piezometers

From the packer testing zones of high permeability in the borehole were selected. Open Casagrande type piezometers were then installed in the boreholes with the slotted and sections opposite the selected fracture zones. The open section was gravel packed then grouted to seal the horizon. The piezometers in the holes are isolated from each other by thick grout layers. The piezometers facilitate the measuring of potentiometric levels from different elevations in the borehole and also allow discrete water sampling from different horizons. The construction of the piezometers are shown on the relevant borehole logs in appendix 4.

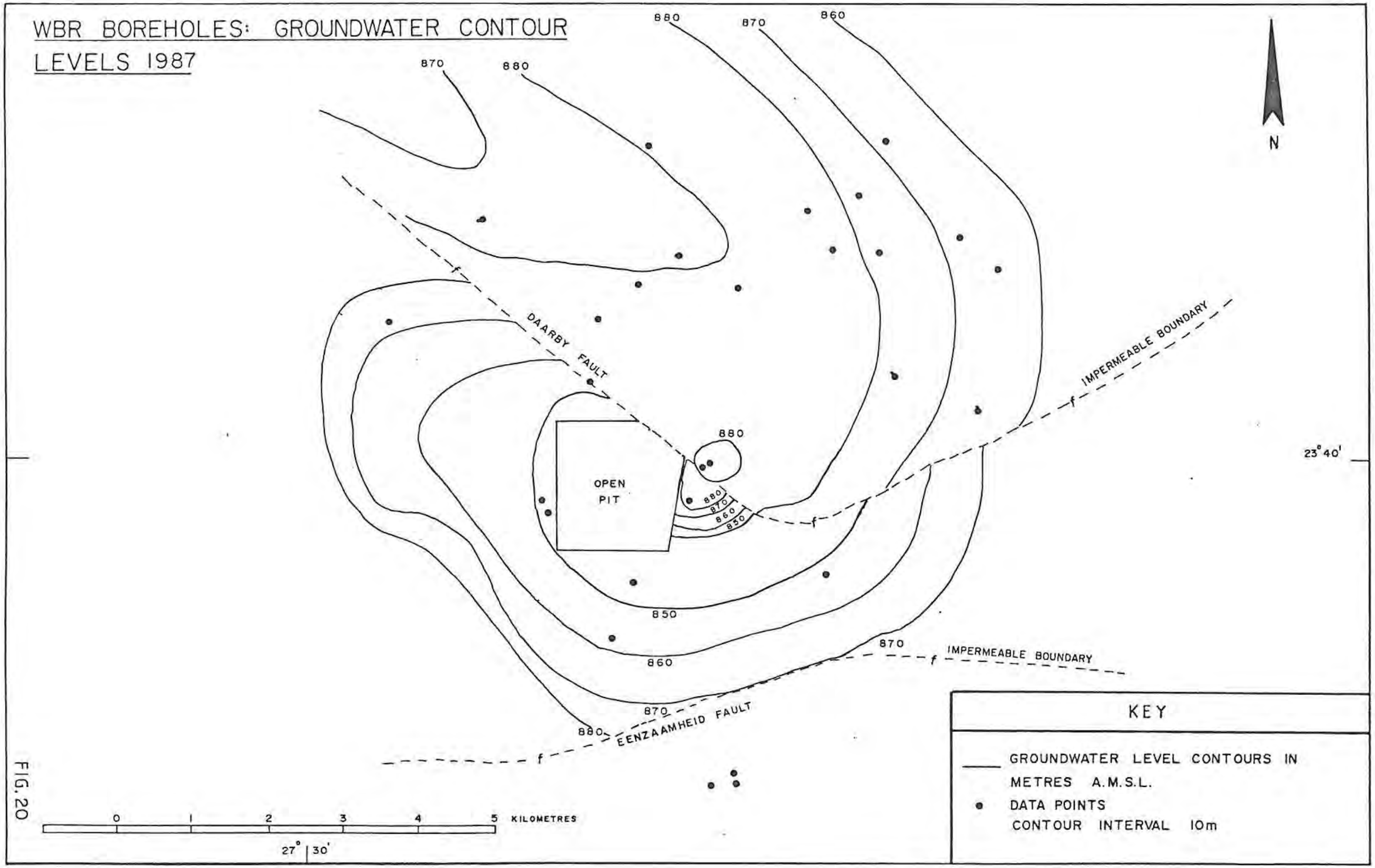
The side walls of the boreholes drilled into the Ecca Group tend to be unstable (Chapter 6 Section 2) and as a result the piezometers were installed in boreholes in the Ecca Group to stabilize the hole and to allow differences in piezometric water levels to be measured over extended periods of time.

Piezometers were installed in boreholes WBR 5, 6, 11, 14, 19, 22 and ET 124. The details of the piezometer constructions are shown on the borehole logs for each of the boreholes (Appendix 4).

9.5 Water Levels

The water levels were measured in open WBR holes before the installation of piezometers. As a result the water levels measured can be viewed as averages of piezometric levels of the aquifer units either side of the Daarby fault. North of the Daarby fault piezometric levels show a groundwater gradient away from the mine plant, waste dumps and slimes dams. South of the Daarby fault piezometric levels show a nett groundwater gradient into the open pit. The contour levels either side of the Daarby fault are shown in figure 20. The contours indicate a difference in piezometric levels of some 20 metres either side of the Daarby fault.

With the installation of discrete piezometers in the boreholes the piezometric levels in the boreholes varied indicating confined conditions.



WBR BOREHOLES: GROUNDWATER CONTOUR LEVELS 1987

FIG. 20

Table 8 shows the comparisons of water levels in the multipiezometer holes. Water levels were measured in the piezometer boreholes in May 1988, six months after installation. In all the multipiezometer holes water levels in the piezometers were not equal indicating different piezometric pressures at various depths in the lithological units.

TABLE 8
WATER LEVELS IN WBR PIEZOMETERS

BOREHOLE NO.	PIEZOMETER 1 (Upper)	PIEZOMETER 2 (Middle)	PIEZOMETER 3 (Lower)
		in metres above mean sea level	
WBR 5	879,425		
WBR 6	864,285	882,735	
WBR 11	844,664	844,574	861,084
WBR 14	884,454	884,507	891,857
WBR 19	884,251	887,523	
WBR 22	838,502	852,017	
ET 124	842,11		

(measured 5 May 1988)

In general, the Red Beds (Elliot Formation) had higher water levels than the overlying Clarens Formation in the slimes dams area. The two Formations have different permeabilities resulting in water mounding in the lower impermeable confined Red Beds. The lower water levels in the Clarens Formation sandstone suggest that the sandstone is relatively permeable and is able to transmit water seeping from the slimes dams laterally.

In the Letaba Formation below the waste dumps potentiometric levels increased with depth indicating confined aquifer conditions with depth. This indicates that the majority of the fractures in the basalts to be horizontal and very little vertical permeability being present.

In the Ecca Group potentiometric levels increased with depth and in some cases as much as twenty metres difference in heads was measured. This confirms observations that there is very little vertical permeability in the Ecca aquifer and the majority of groundwater movement is along bedding planes and lithological contacts. Water levels indicate a lowering of water levels in the Upper Ecca which is at present being mined. However, water levels in the Middle and Lower Ecca have largely been unaffected by mining operations. From this it can be concluded that the majority of the Ecca is confined by the individual stratigraphic horizons except where the Ecca has been faulted. It is anticipated that relatively large volumes of water may be intersected with the future mining of zone 2. Exploration boreholes drilled in the open pit into the Middle Ecca have all been artesian indicating confined aquifer conditions and appreciable volumes of water in storage.

9.6 Groundwater Chemistry

Water samples for chemical analysis were taken at the end of each pump test. The water samples taken from each of the holes are therefore assumed to be representative of the groundwater chemistry of the aquifer in the vicinity of the borehole.

The water samples were taken at the end of the pump tests after approximately 5000 litres of groundwater had been abstracted from the borehole. As there are approximately 26 litres of water per metre in a 165mm diameter borehole, all water stored in the hole would have been abstracted during the pump test, inducing flow into the hole from the surrounding aquifer. The samples were analyzed at Iscor's Laboratory in Pretoria. Full details of the groundwater chemistry for each for the water samples are shown in Appendix 6.

In order to evaluate groundwater chemistry, graphical trilinear Piper and expanded Durov diagrams are used to plot major cation and anion compositions. The Piper and Durov diagrams, Figure 21 and 22 indicate differing chemistries for boreholes in the Letaba/Clarens, Beaufort/Ecca and Waterberg aquifer units. When comparing the groundwater chemistry of the WBR boreholes to the norms of the individual aquifer units calculated from the regional sampling programme contrasts are evident (Figures 6 and 7, Chapter 5). These are especially evident in the WBR boreholes in the Letaba/Clarens/Red Bed aquifer unit in close proximity to the waste dumps and slimes dams. The variation from the ambient groundwater chemistry for the aquifer unit indicates the introduction of recharge water containing relatively high concentrations of total dissolved solids. The source of the majority of the recharge water north of the Daarby fault is from the waste dumps, slimes dams and process water (Chapter 8). However as no clear pattern is evident when compared to the regional sampling programme (Chapter 5) a degree of mixing of the groundwater chemistry is inferred. To study the variation in the groundwater chemistry north of the Daarby fault, single element areal concentration plots for the WBR boreholes are used to plot the areal distribution of specific chemical elements in more detail.

WBR BOREHOLES OPEN PIT & SLIMES DAMS

TRILINEAR PLOT OF HYDROCHEMISTRY

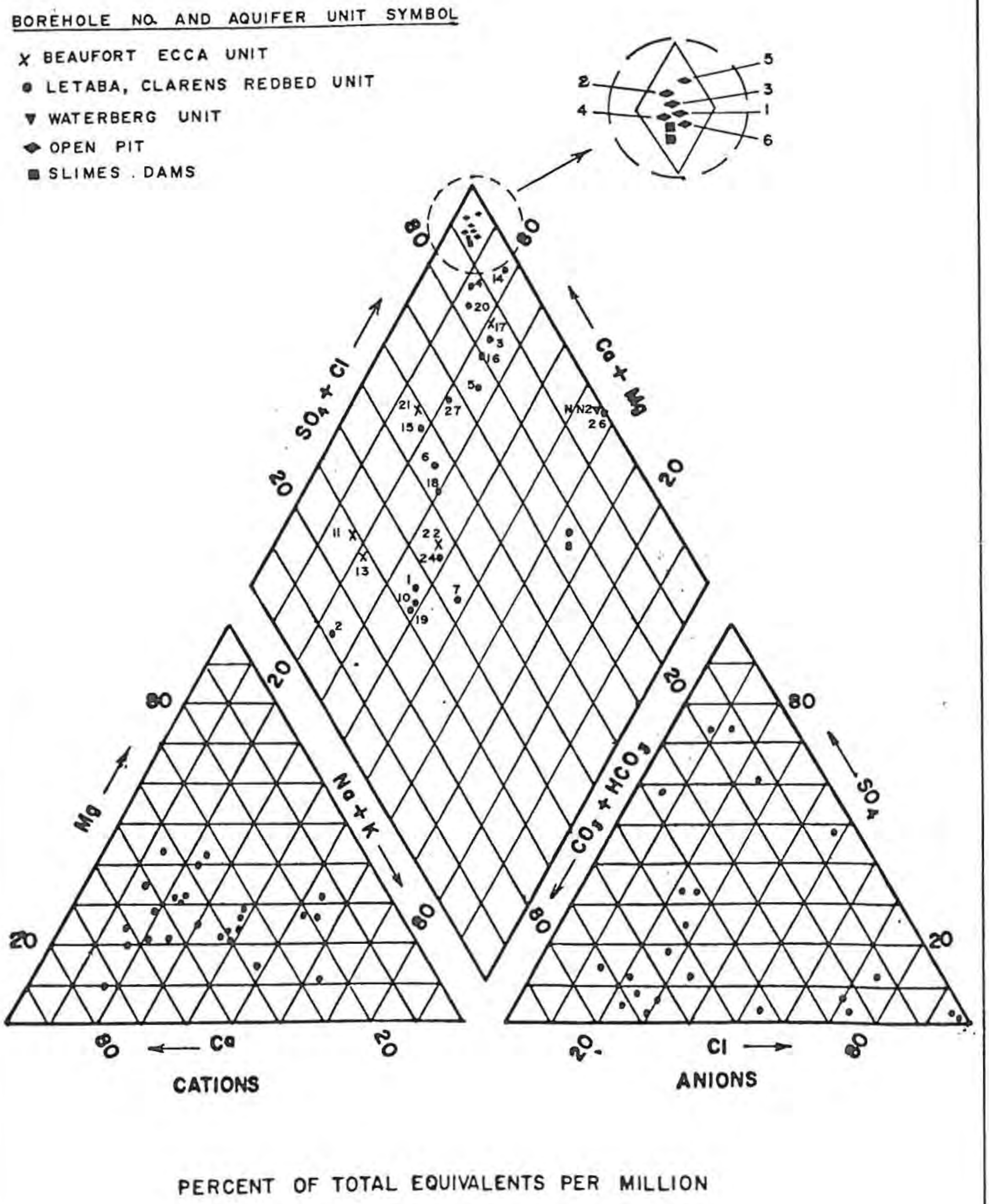
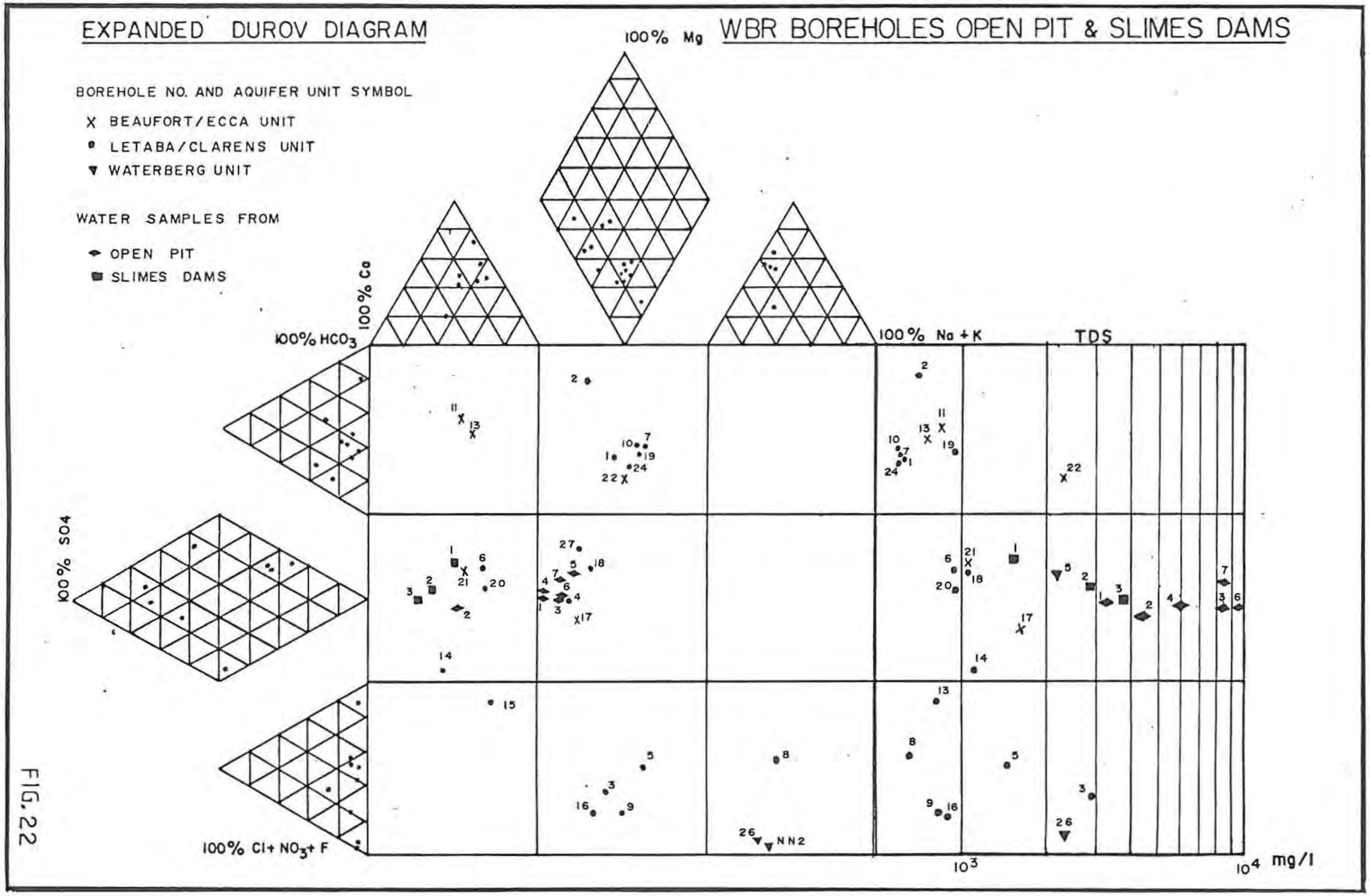


FIG. 21



EXPANDED DUROV DIAGRAM

WBR BOREHOLES OPEN PIT & SLIMES DAMS

FIG. 22

Figures 23 to 27 show the positions of the boreholes and concentrations of each of the chemical elements/components selected for in depth study. The elements/components selected for further in depth investigation were namely sulphate (SO_4^{2-}), fluoride (F), nitrate (NO_3^{-}-N), calcium (Ca), chloride (Cl), and cadmium (Cd). These were selected on the basis of an increase in the element concentrations compared to the mean values obtained from the individual aquifers during the regional sample programme (Chapter 5). The selection was also in the light of leachability groups suggested by Libicki (1983).

Sulphate (SO_4^{2-})

The regional sampling programme showed the SO_4^{2-} concentration of the groundwater to range between 2 - 25 mg/l for the Letaba/Clarens aquifer unit and 12 to 200 mg/l for the Beaufort/Ecca unit. Figure 23 shows the location of the sampled WBR boreholes, and SO_4^{2-} concentrations. There are clearly above normal concentrations of SO_4^{2-} in the boreholes in close proximity with the waste dumps and slimes dams on the Letaba/Clarens/ Red Bed aquifer unit. Sulphates leached from these structures are actively being introduced into the groundwater. The sulphates are released by weathering of pyrite and solution of sulphate salts in the waste dumps and slimes dams. This can be attributed to both the short and longer term impacts of the mining operations on the groundwater.

High sulphates are seen around the open pit result from the solution of precipitated salts in the dewatered Ecca group (Chapter 7). There is a direct correlation between the level of dewatering and the groundwater sulphate

SITE PLAN SHOWING LOCATION OF WBR MONITORING BOREHOLES AND GROUNDWATER SULPHATE CONCENTRATIONS

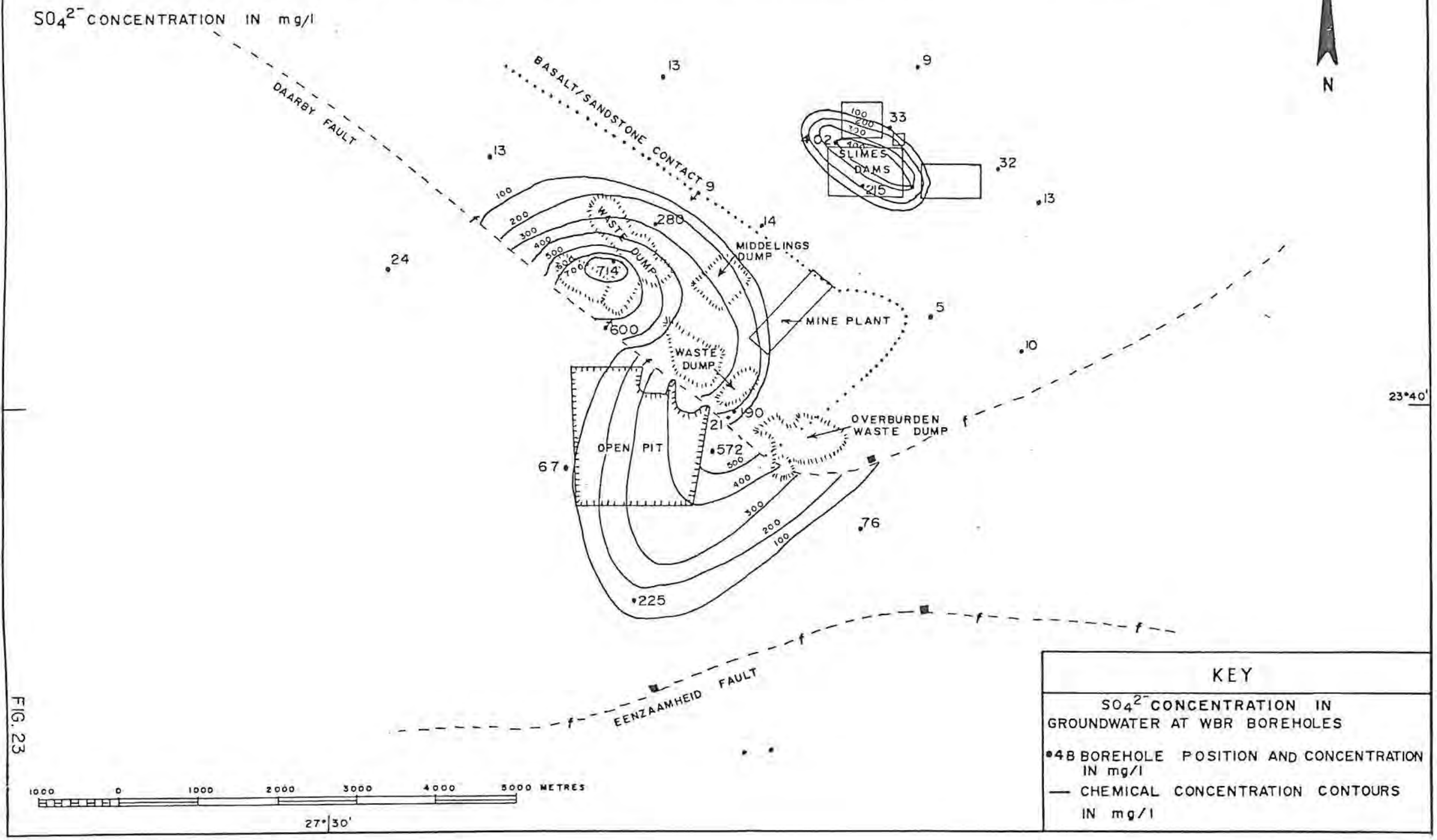


FIG. 23

concentration. The greater the level of dewatering the higher the sulphate concentrations of the groundwater.

Calcium (Ca^{2+})

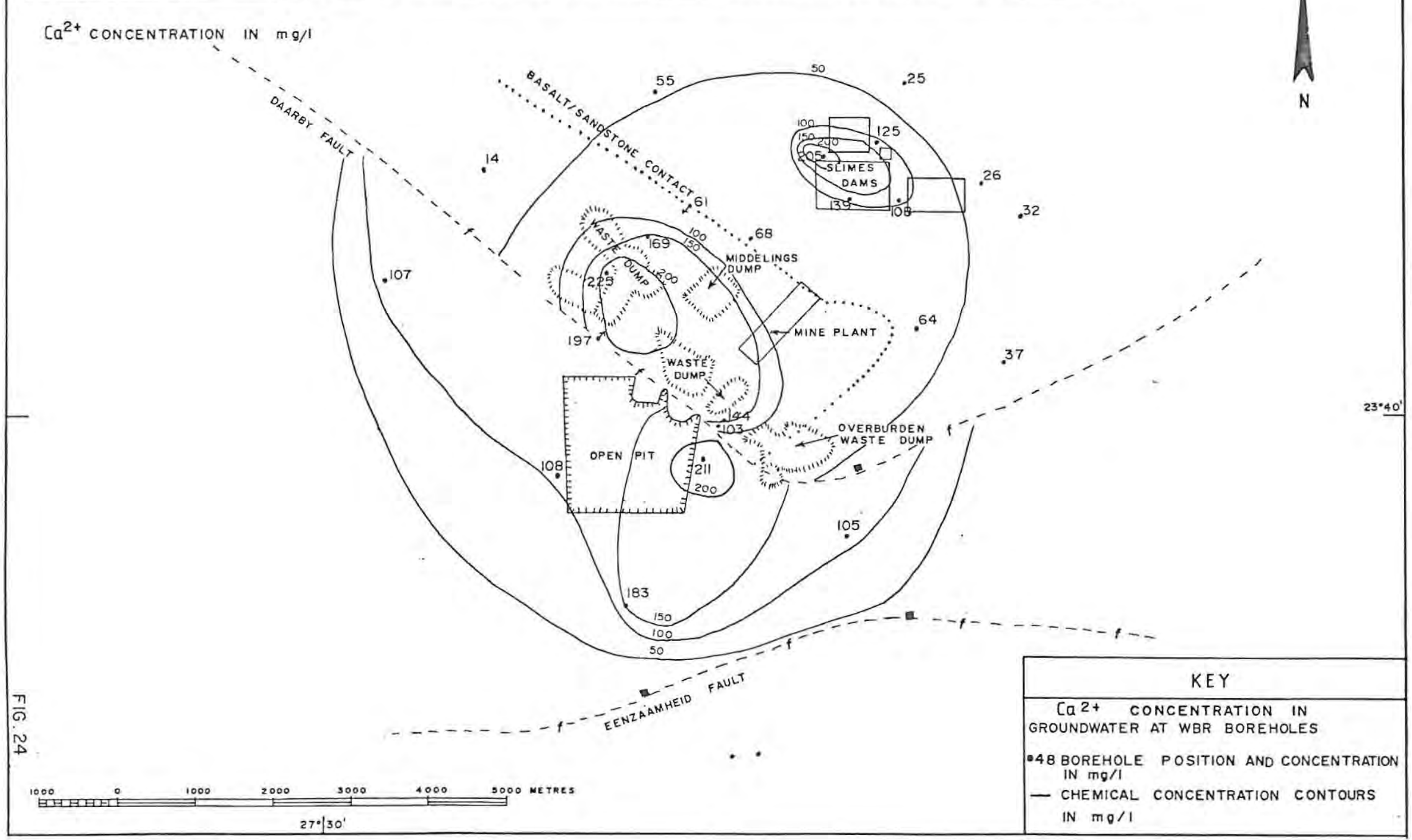
The regional sampling programme indicated the calcium content of the groundwater to range between 10 and 100 mg/l in the Letaba/Clarens/Red Bed aquifer unit and between 60 and 300 mg/l in the Beaufort/Ecca unit. Concentrations around the slimes dams vary between 109 and 205 mg/l and at the waste dumps 170 - 225 mg/l against an ambient mean in the Letaba/Clarens/Red Bed unit of 50 mg/l. Again there are indications of calcium salts being actively leached from the waste dumps and slimes dams and migrating into the groundwater in the vicinity of the slimes dams and waste dumps (Figure 24). Although calcium was indicated by Libicki (1983) to belong to the third leachability group (lowest) it is very evident in the Grootegeluk situation. South of the Daarby fault the calcium content of the groundwater indicates greater concentrations of calcium corresponding to the dewatered areas.

Chloride (Cl)

The chloride concentrations serve to emphasize results obtained from the sulphate and calcium distribution plots The main source of Cl is from the leaching of the Ecca and Beaufort sediments dumped north of the Daarby fault on the Letaba/Clarens/Red Bed aquifer unit by mining operations (Figure 25).

FIG. 24

SITE PLAN SHOWING LOCATION OF WBR MONITORING BOREHOLES AND GROUNDWATER CALCIUM CONCENTRATIONS



SITE PLAN SHOWING LOCATION OF WBR MONITORING BOREHOLES AND GROUNDWATER CHLORIDE CONCENTRATIONS

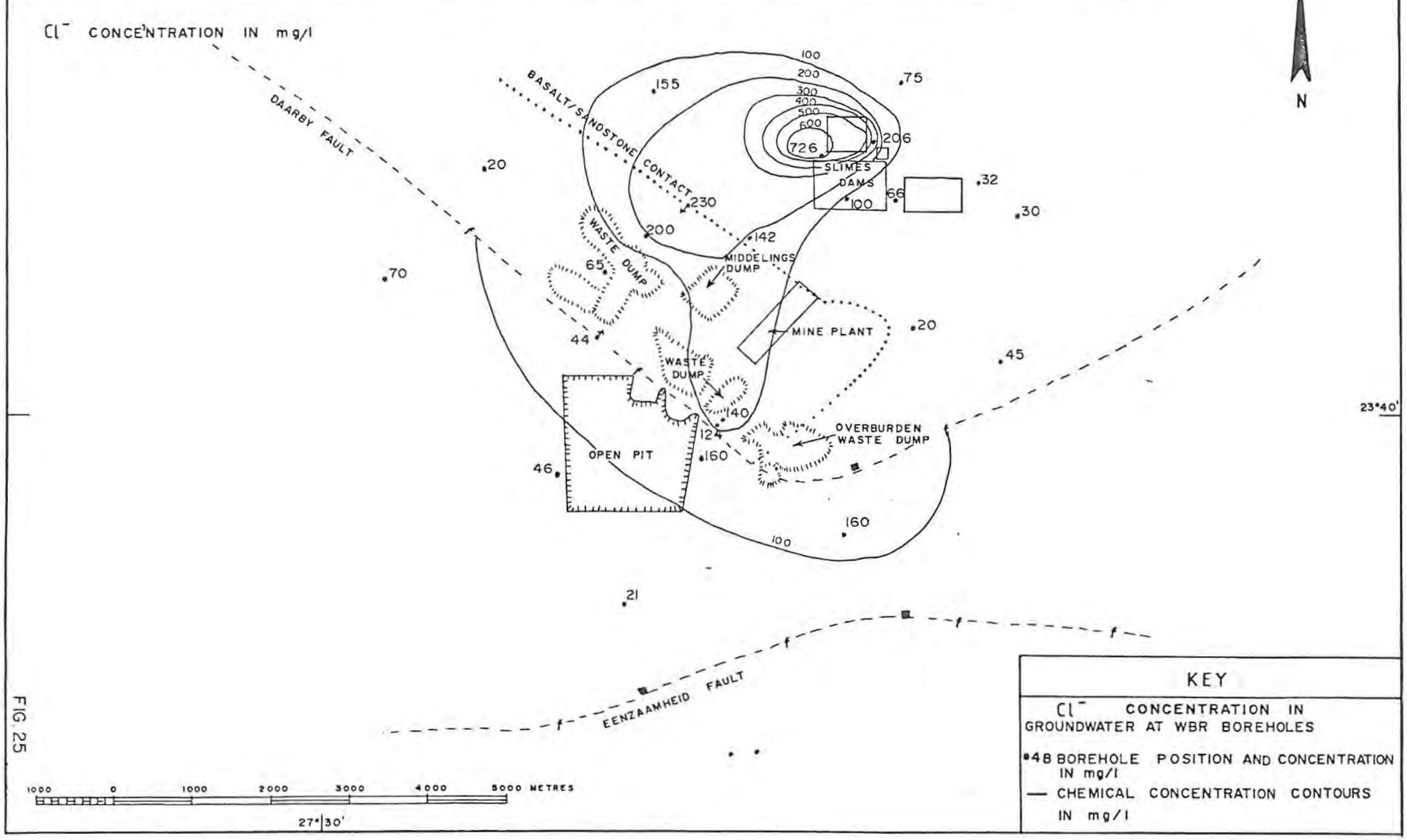


FIG. 25

Nitrate (NO_3^--N)

The major source of nitrates in the mined material are probably from nitrate type explosives used in the open pit. Material transported from the open pit to the waste dumps contains reasonable concentrations of nitrates which are evident in the groundwater beneath the waste dumps and slimes dams (Figure 26). Higher nitrate levels than those experienced in the Beaufort/Ecca aquifer unit have been detected indicating an alternative source, possibly from the explosives.

Cadmium (Cd) and Fluoride (F)

Fluorides and Cadmium (Figure 27) compositions serve to emphasize the higher mineral concentrations of the groundwater below the slimes dams and dumps in the Letaba/Clarens/Red Bed aquifer unit (Figure 29). The groundwater in the Ecca Group was found during the regional sampling programme to have similar values to the groundwater found beneath the waste dumps and slimes dams situated on the Letaba/Clarens/Red Bed aquifer unit.

Iron (Fe^{2+})

The iron concentrations analyzed from the acidicized (i.e. preserved) samples taken do not seem to have any fixed pattern as do the other elements investigated. This is largely due to the complex solubility and stability equilibrium of Fe^{2+} and Fe^{3+}.

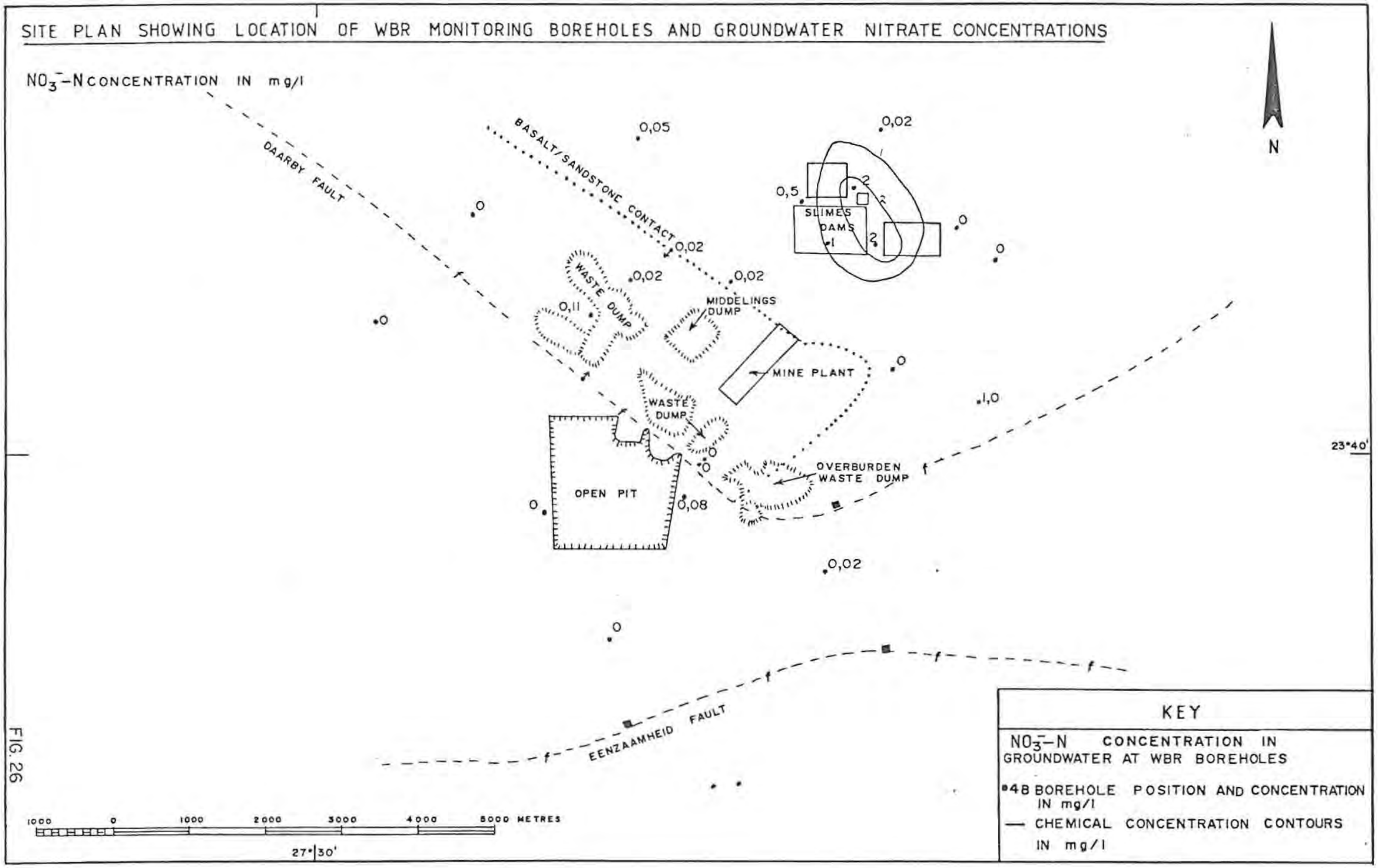


FIG. 26

SITE PLAN SHOWING LOCATION OF WBR MONITORING BOREHOLES AND GROUNDWATER NITRATE CONCENTRATIONS

SITE PLAN SHOWING LOCATION OF WBR MONITORING BOREHOLES AND GROUNDWATER CADMIUM CONCENTRATIONS

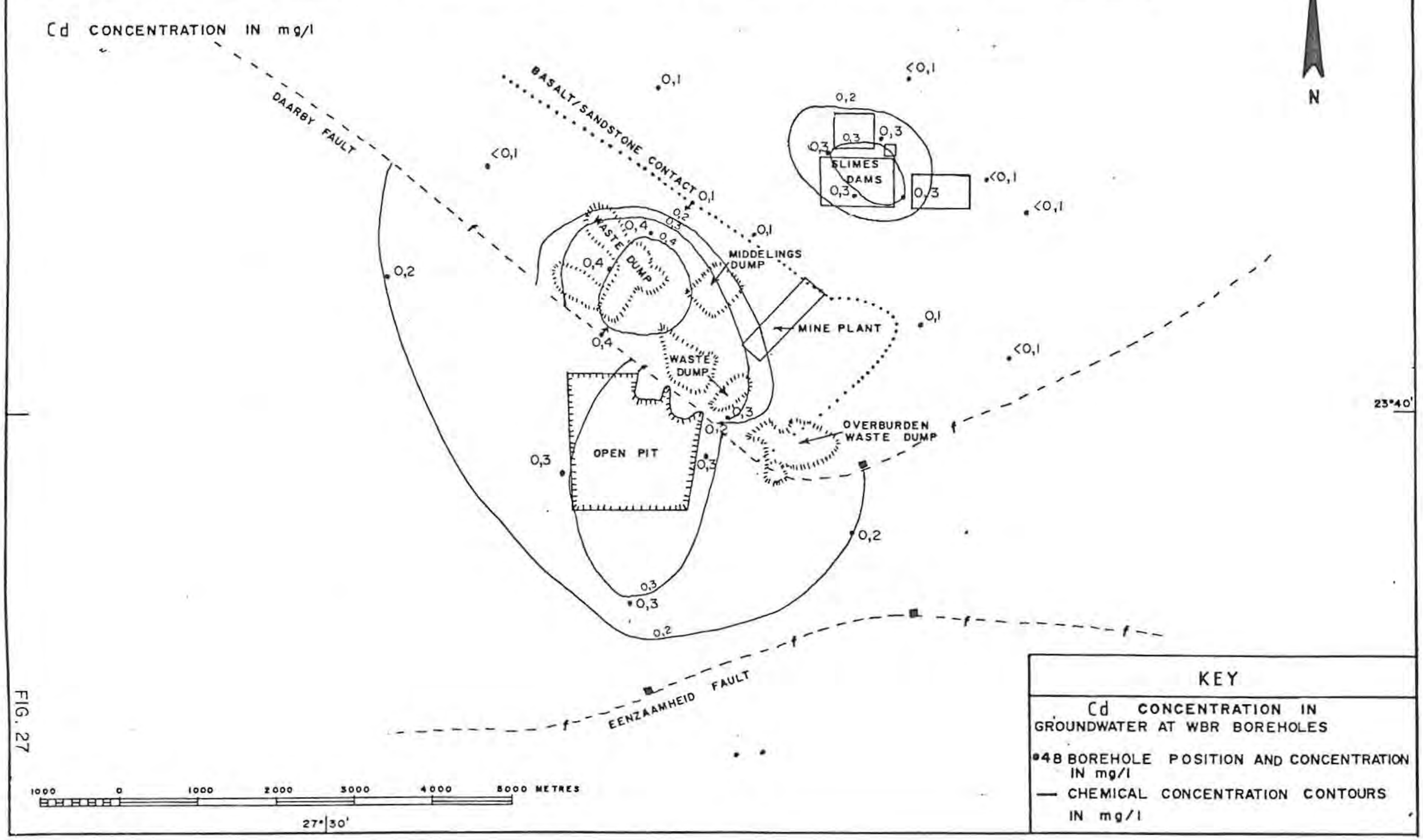


FIG. 27

The increase in the total dissolved content of the groundwaters in the Letaba/Clarens/Red Bed aquifer unit below the slimes dams and waste dumps can be attributed to increased recharge facilitated by these structures and the loss of mine process water into the groundwater. The alteration of the ambient hydrochemistry results from salts leached from these structures by rain and mine process water. The specific element concentrations of the leachate and process water are very similar to the groundwaters found in the Beaufort/Ecca aquifer unit.

The increase in total dissolved solid content of the ambient groundwater in the Letaba/Clarens/Red Bed aquifer unit is due to the base and ion exchange reactions resulting in the short term contamination of the ambient groundwater. The longer term impact of "acid mine drainage" is not fully evident. Although there is an increase in the sulphate and iron contents of the ambient groundwater, pH's are relatively neutral. This can be attributed to the buffering effect of the groundwater and alkali ash residue in the dumps.

The impact of dewatering in the Ecca/Beaufort Group south of the Daarby fault has resulted in the introduction of oxygen and precipitation of salts in joints and fractures of the previously saturated Ecca/Beaufort sediments. These salts are subject to resolution with migrating recharge water and result in an increase in the total dissolved solid content of the water.

9.7 Groundwater Quality Standards

In attempting to establish an acceptable chemical standard of the groundwater in the individual aquifer units and to assess the impact of leachate from the mine waste disposal facilities, it is most feasible to compare the water quality to a standard. The selected standard is the South African Bureau of Standards drinking water criteria listed in SABS-241 (Kempster and Smith 1984). By comparing the water quality from the Letaba/Clarens/Red Bed and Beaufort/Ecca aquifer units to groundwater from boreholes in the vicinity of the slimes dams and waste dumps the relative impact of the leachate on the regional groundwater chemistry can be assessed. The standards for drinking water (SABS 241) also allows a comparison of the regional aquifer hydrochemistry to acceptable standards for drinking water. Conclusions are drawn as to the quality of leachate from the slimes dams and waste dumps and the relative impact on the regional hydrochemistry.

Table 9 shows the comparisons of the individual aquifers hydrochemistry, the groundwater influence by leachate and the recommended minimum allowable standards in terms of SABS-241. Table 9 clearly indicates the alteration of groundwater chemistry beneath the slimes dams and waste dumps due to the introduction of mineral salts leached from these structures. The leachate entering the groundwater has resulted in the groundwater beneath the dumps and slimes dams to largely exceed recommended limits for drinking water and some trace elements to exceed the maximum permissible limits.

TABLE 9
COMPARISONS OF GROUNDWATER CHEMISTRY FROM THE MAJOR AQUIFER UNITS, BELOW WASTE DUMPS AND SLIMES DAMS COMPARED TO STANDARDS FOR DRINKING WATER SABS-241

Chemical Elements/ Compounds	Ambient Groundwater Aquifer Units		Contaminated Groundwater Below		SABS-241	
	Letaba/ Clarens	Beaufort/ Ecca	Dumps	Slimes Dams	Recom- mended	Max Allowable
T.D.S.	669	720	859	1580	1000	2000
pH	6,85	6,9	6,8	6,7	6,0-9,0	5,5-9,5
Major Cations						
Ca	44	105	99	145	150	200
Mg	20	34	59	79	70	100
Na	74	58	41	123	100	400
K	12	16	10	17	200	400
Major Anions						
CO_3	83	174	68	119	NS	
SO_4	8	95	95	274	200	600
NO_3-N	2,5	1,1	2,5	2	6	10
CL	151	124	171	351	250	610
Trace Elements						
S_1O_2	30	9	24	37,5	No limit	
F	0,1	0,7	0,2	0,25	1	1,5
Mn	0,12	0,4	0,12	0,75	0,05	1,0
Pb	0,1	0,08	0,1	0,1	0,05	0,1
Zn	0,09	0,42	0,1	0,1	1	5
Cd	0,01	0,2	**0,25**	**0,3**	0,01	0,02
Fe	0,2	**1,3**	**1,2**	**3,8**	0,1	1,0

Values in excess of recommended limits are underlined

Values exceeding the maximum allowable limits are **bold** and **underlined**

All values expressed in mg/l except for pH

9.8 Summary

The analysis of samples from boreholes in the vicinity of the slimes dams and discard piles shows a change in the groundwater chemistry by the introduction of salts leached by process water from the dams and piles.

The ambient groundwater in the Letaba/Clarens/Red Bed aquifer unit is altered by the introduction of leachate water containing sulphates, calcium, chlorides, nitrates, fluorides and cadmium. Some of these chemical elements belong to the most easily leached group of salts identified by Libicki (1983). The impact of mining operations at present can be regarded as short term contamination effects of the mine slimes dams and dumps. The short term impacts result in an increase in the total dissolved solid content of the ambient groundwater (Chapter 4). There is also an increase in the trace elements particularly cadmium, iron, manganese and fluoride.

The longer term effect, acid mine drainage is not evident at present. This is assumed to be largely due to the buffering effect of the natural groundwater and alkali salts in the mine waste. In the discard dumps, spontaneous combustion results in an alkali ash residue which is easily leached and will have an added buffering effect.

The severity of acid mine drainage will only become evident when the neutralizing capacity of the ambient groundwater and leachable salts is overcome. It is difficult to estimate an exact time period but research by Walsh (1982) and Kim et al (1982) indicates it will become evident within the next ten years.

In comparing the Grootegeluk situation to the work by Bosch and Loos (1987), oxidation of pyrite is already active in the dumps at Grootegeluk. The process of oxidation (natural and bacteriological) is proved by Walsh (1982) to accelerate geometrically with time.

Water levels in the multipiezometer holes indicated different water levels with depth. Water level monitoring around the slimes dams indicates the Red Beds are largely confined. South of the Daarby fault in the Ecca Group there are indications of very little vertical permeability with water levels in the Middle and Lower Ecca being substantially higher than in the Upper Ecca which is at present being mined.

Calculations based on the hydraulic gradient and permeability values calculated from the pump and packer tests indicate the contaminant plume will move away from the dumps at a rate of $4,7x10^{-3}$m/day (0,4cm/day or 1,7m per year). The groundwater level contours indicate the contaminant plume will move away from the slimes dams and dump in a north easterly and north westerly direction. The plume is however expected to move at a greater rate to the north east because of the higher groundwater gradients.

The contaminant plume will not migrate in the form of a wide front but will migrate in the form of narrow veins along fractures. This is due to the anisotropic nature of the Letaba/Clarens aquifer unit with the majority of the permeability being associated with fractures. The most important consideration is that the local differences in permeability will determine the leachate concentration. It can be expected that higher the permeability the higher the concentration of leachate.

Dewatering of the Upper Ecca and Beaufort Groups has resulted in the introduction of oxygen and the precipitation of salts. These salts are subject to resolution with migrating recharge water resulting in an increase in the total dissolved solid content of the groundwater. Contours of calcium and sulphate concentrations can be directly correlated to lower groundwater evaluation contours around the open pit.

10.0 THE PRESENT AND FUTURE IMPACT OF MINING OPERATIONS ON THE REGIONAL HYDROGEOLOGY

In order to assess the present and future impact of mining operations of the Grootegeluk Mine on the regional hydrogeology, a time scale has to be taken into consideration. The conceptual model of the impact of mining operations over the life of the mine is divided into stages 1 to 6 and depicted graphically in figures 28 to 33. The stages discuss the impact of the mine on the regional hydrogeology ignoring any remedial measures implemented to control the impact of mining.

Stage 1. Prior to Mining

The regional hydrogeology is in a state of equilibrium with water levels either side of the Daarby fault being equal. Hydrochemically groundwaters either side of the Daarby fault would be typical of each of the aquifer units. Very little mixing across the Daarby fault is expected to be occurring.

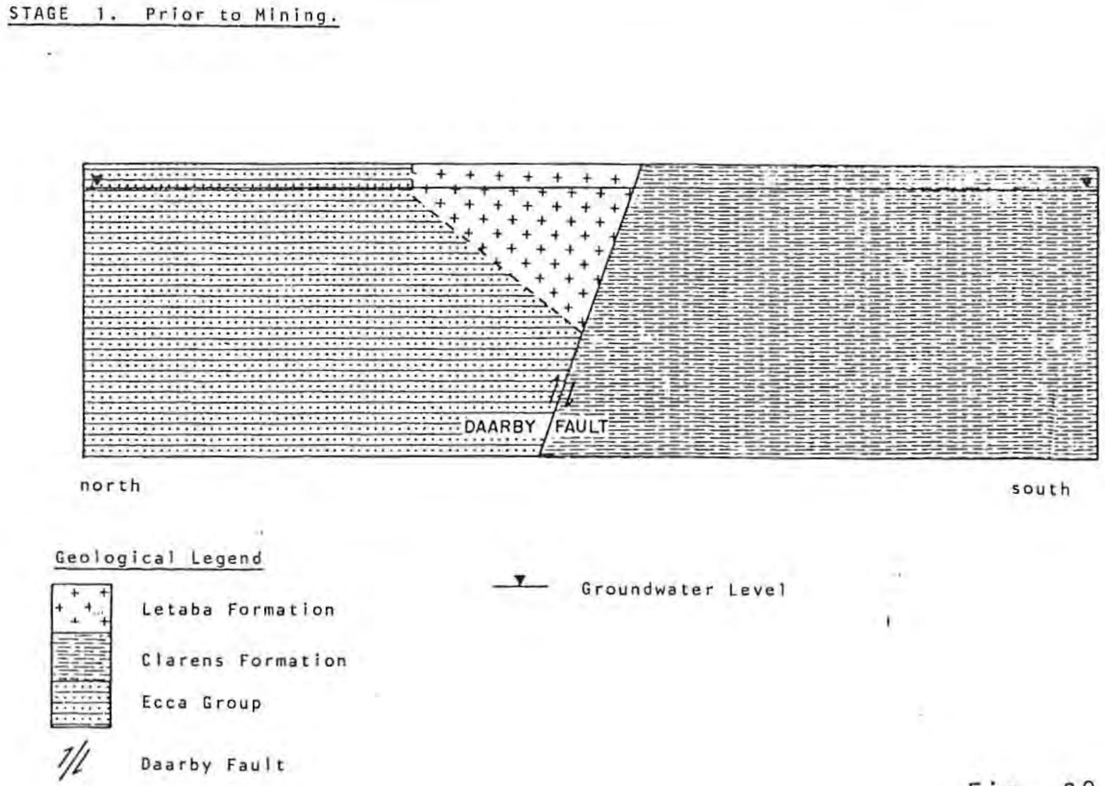
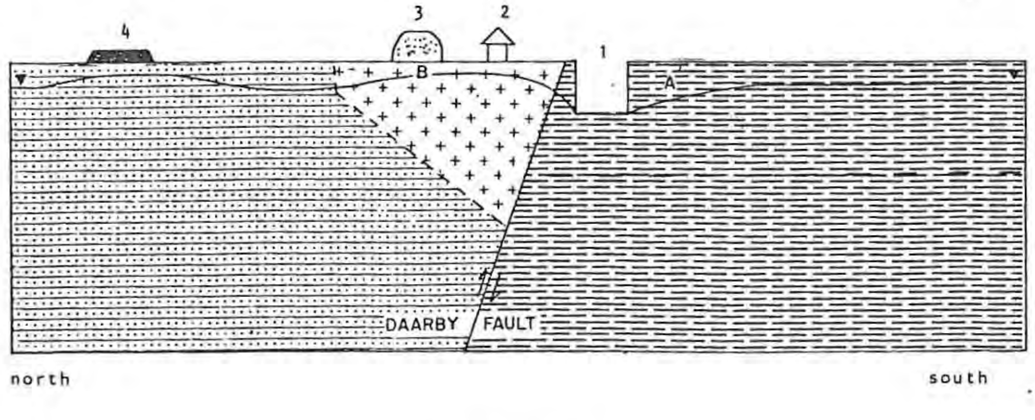


Fig. 28

Stage 2. Five Years after Mining

Mine operations result in a disruption of the hydrogeological equilibrium both hydrochemically and hydrodynamically. Hydrodynamically water levels north of the Daarby fault are lowered by dewatering in the open pit. In contrast aquifers north of the Daarby fault experience a rise in the regional groundwater level due to the increased recharge facilitated by the introduction of mine process water and water pumped from the open pit. Hydrochemically the area surrounding the open pit is dewatered leaving previously saturated geological units exposed to oxygen. North of the Daarby fault, mine process water leaking from the mine waste dumps and slimes dams and water from the open pit is highly charged with total dissolved solids. The leachate enters the groundwater north of the Daarby fault resulting in the introduction of foreign salts into the Letaba/Clarens aquifer unit.

STAGE 2. Five Years After Mining.



Key

1. Open Pit
2. Mine Structures
3. Waste Dumps
4. Slimes Dams

Explanation

A. Lowering of regional groundwater level in the vicinity of the open pit.

B. Recharge to groundwater by high TDS water from the waste dumps and slimes dams.

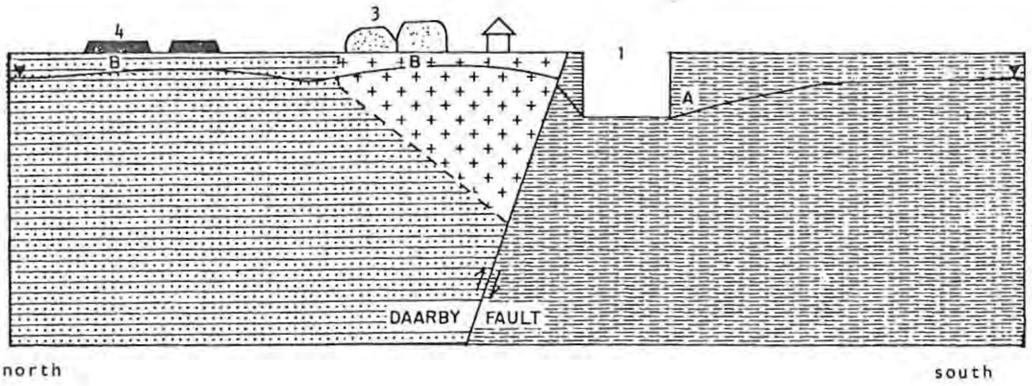
Fig. 29

Stage 3. Fifteen Years after Mining

The groundwater level south of the Daarby fault is further lowered by expansion of the open pit and simultaneous dewatering. Water levels north of the Daarby fault rise further resulting in an increased hydraulic gradient and the spread of leachate away from beneath the mine waste dumps and slimes dams into the surrounding aquifer.

Hydrochemically, water entering the open pit increases in dissolved solids due to solution of encrusted salts in the dewatered area by percolating rainwater. The process giving rise to acid mine drainage are advanced in the mine waste dumps and slimes dams north of the Daarby fault resulting in the release of highly mineralized low pH water into the aquifer. The buffering capacity of the aquifer and alkaline waste dumps is slowly exceeded.

STAGE 3. Fifteen Years After Mining.



Explanation

A. Further lowering of the groundwater level with expansion of the open pit.

B. Recharge to groundwater by low pH high TDS water.

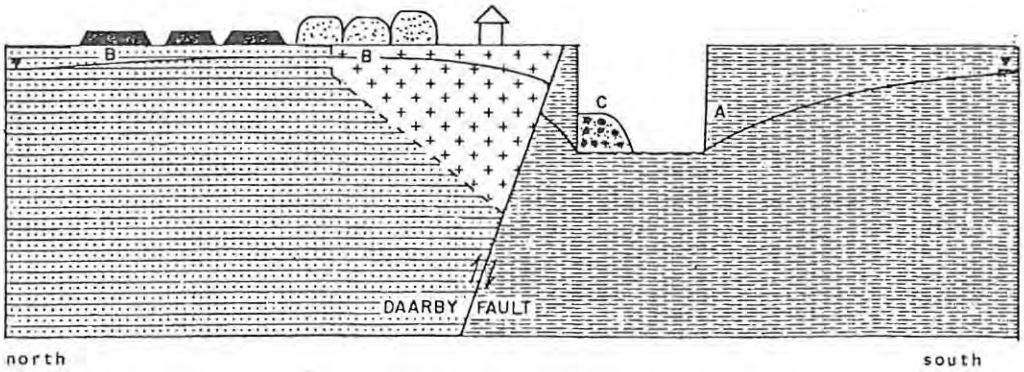
Fig. 30

Stage 4. Twenty Five Years after Mining

The groundwater levels in the Ecca Group is further lowered by the deepening and expansion of the open pit. The pit is partially backfilled with waste material and the pit is continuously dewatered to enable mining operations in the void to continue. Water levels in the Letaba/Clarens formations have reached an hydraulic equilibrium and recharge water from the mine structures is transmitted laterally to the surrounding aquifer.

Hydrochemically, the back filled material in the open pit begins to oxidize resulting in the break down of pyrite and the release of low pH high TDS water. In the waste dumps north of the Daarby fault, the neutralizing capacity of the dumps and the aquifer are exceeded. Slugs of high TDS low pH water enter the aquifer during the summer rains.

STAGE 4. Twenty Five Years After Mining.



Explanation

A. Further lowering of the groundwater level.

B. Introduction of high TDS and Acid mine drainage into the groundwater and lateral migration of pollution plume.

C. Back filling of open pit.

Fig. 31

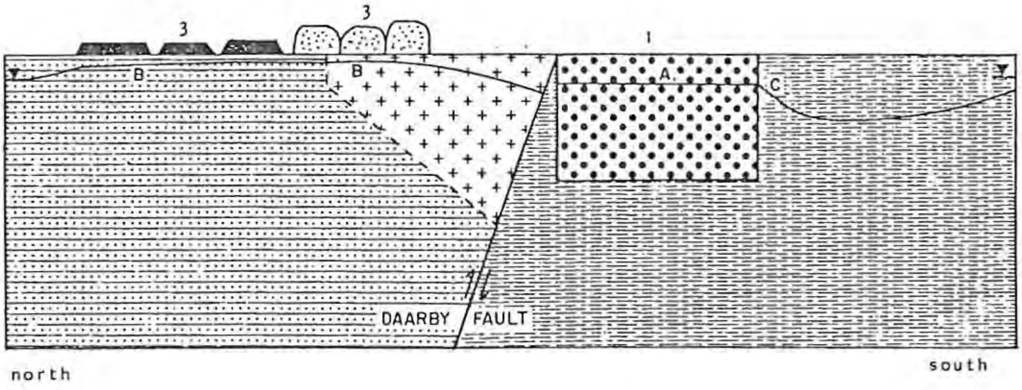
Stage 5. End of Mining

The open pit is completely backfilled and water levels rise rapidly in the highly permeable backfilled material resulting in a nett outflow into the Ecca Group Aquifer. North of the Daarby fault water levels remain essentially constant.

The backfilled material being highly permeable and porous becomes an optimum environment for the generating of acid mine drainage. Water from the open pit enters the surrounding aquifer and is transmitted laterally. The rise in water level in the Ecca Group results in the saturation of previously dewatered rock and the resolution of precipitated salts.

North of the Daarby fault acid mine drainage enters the Letaba/Clarens aquifer and the leachate plume migrates further into the aquifer.

STAGE 5. End of Mining.



Legend

1. Backfilled Open Pit.
3. Vegetated Waste Dumps and Slimes Dams.

Explanation

A. Rapid rise in water level in highly permeable backfilled material.

B. Groundwater below waste dumps and slimes dams low in pH and very high in TDS. Lateral migration of pollution plume.

C. Migration of highly mineralized low pH from the open pit into the surrounding Ecca aquifer.

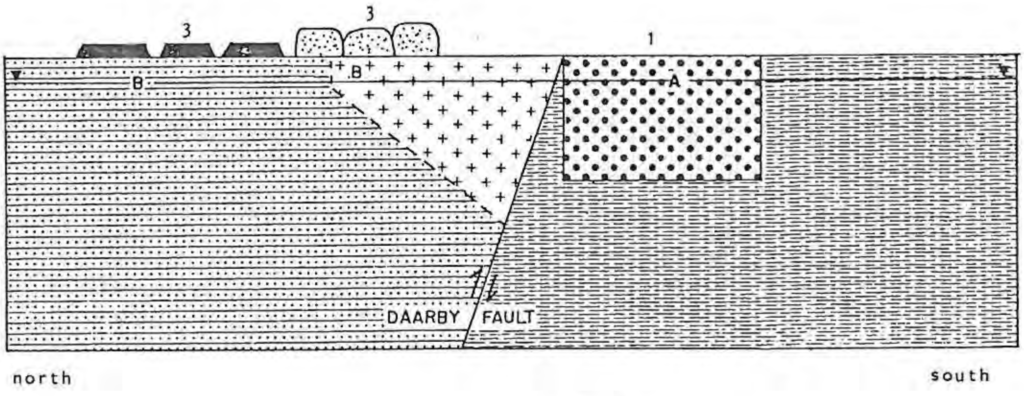
Fig. 32

Stage 6. Ten Years after the end of Mining

Water levels on either side of the Daarby fault have reached equilibrium and are equal to the original groundwater level before mining commenced. Very little flow occurs naturally in the aquifers. However, recharge is increased locally by the waste dumps and the backfilled open pit resulting in movement of groundwater away from the structures after rainfall related recharge events.

Hydrochemically, the increase recharge facilitated by the more permeable waste dumps, slimes dames and backfilled open pit causes migration of water away from the structures. Water contained in the structures, particularly the more permeable backfilled material, becomes high in total dissolved solid and low in pH. Recharge to the structures induces flow into the neighbouring aquifer and as a result slugs of highly mineralized low pH water are introduced into the aquifer.

STAGE 6. Ten Years After the End of Mining.



Legend

1. Backfilled Open Pit.
3. Vegetated Waste Dumps and Slimes Dams.

Explanation

A. Rapid rise in water level in highly permeable backfilled material.

B. Groundwater below waste dumps and slimes dams low in pH and very high in TDS. Lateral migration of pollution plume.

C. Migration of highly mineralized low pH from the open pit into the surrounding Ecca aquifer.

Fig. 33

11.0 HYPOTHESES TESTING

The hypotheses originally formulated on pages XIV and XV are discussed individually below.

Hydrodynamics

i. Water levels in the Ecca Group in the vicinity of the mine will be lowered by mine dewatering.

   Discussed in Chapter 6, Section 5 and Chapter 9, Section 5.

   Water levels in the Ecca group are lowered by continual dewatering of the open pit.

   The hypothesis is accepted.

ii. Lowering of the groundwater levels will not occur homogeneously around the open pit due to the fractured nature of the aquifer.

   Discussed in Chapter 6, Section 5.

   The groundwater contours in observation holes south of the Daarby fault indicated a greater decline in groundwater levels in a trend similar to the main structural trends.

   The hypothesis is accepted.

iii. Recharge to the Letaba Basalt and Clarens Sandstone Formations will be increased locally because of the mine plant, slimes dams and waste dumps.

   Discussed in Chapter 8, Section 2.

The increased recharge to the area north of the Daarby fault is the Letaba and Clarens Formations facilitated by the mine plant, slimes dams and waste dumps is in the order of $2000m^3$/day.

The hypothesis is accepted.

iv. The permeability across the Daarby fault is low and forms a leaky boundary between the Clarens and Letaba Formations and the Ecca Group.

Discussed in Chapter 6, Section 5 and Chapter 9, Section 3.

Packer testing through the Daarby fault showed the fault to be impermeable. Contouring of water levels showed a difference in groundwater levels of some 20m either side of the fault.

The hypothesis is accepted.

Hydrochemistry

i. The hydrochemistry of the groundwaters in the Clarens Formation will differ from those in the Ecca Group.

Discussed in Chapter 5, Section 3.

Due to the nature of the aquifers and logistics, individual aquifer units were not sampled. However groundwaters north and south of the Daarby fault were chemically characterised and found to be markedly different.

The hypothesis is neither accepted nor rejected due to insufficient data.

ii. The hydrochemistry of the aquifers surrounding the mine will be altered by mining operations, particularly in terms of an increase in the total dissolved solid content and a decrease in the pH north of the Daarby fault.

Discussed in Chapter 7, Section 2 and Chapter 9, Section 6.

Mining operations have resulted in an increase in the total dissolved solid content of the groundwater north of the Daarby fault particularly in sulphate calcium, chloride, nitrate, cadmium, fluoride and iron. However the pH of the groundwater is essentially neutral.

Mining has also resulted in an increase in total dissolved solid content of the groundwater in the area immediately around the open pit.

The hypothesis is partially accepted. The decrease in pH of the groundwater in the Clarens Formation is not evident at present.

12.0 CONCLUSION

The investigation has determined that the Grootegeluk Coal Mine and mining operations impact on the regional hydrogeology of the area surrounding the mine in terms of the hydrodynamics and hydrochemistry.

South of the Daarby fault mining operations have resulted in a steady decline in water levels from a calculated original groundwater level of 890 m (a.m.s.l.) to 840m (a.m.s.l.) at the pit. The decline in water levels is most evident at the open pit where dewatering of workings takes place. The cone of depression is calculated to have a radius of influence of 8000m around the pit in the Ecca Group. No major changes in groundwater chemistry in the Ecca group occur except in the immediate vicinity of the pit where dewatering of the Ecca has resulted in precipitation of salts. These salts are subject to resolution and migration with the percolation of recharge rain water. Groundwater levels in the Middle and Lower Ecca are substantially higher that those in the Upper Ecca.

North of the Daarby fault the mining operations have resulted in a rise in water levels and an alteration of the ambient groundwater chemistry by the introduction of salts. The rise in water levels in the Letaba and Clarens Formations can be attributed to leakage and increased recharge from the mine waste dumps, slimes dams and pumping from the open pit into a soak-away trench north of the Daarby fault. To a lesser extent the rise in groundwater levels can be attributed to the 45 million tons of middlings and waste material dumped onto the basalt and sandstone. The weight of the discard pile could have the effect of decreasing void space and storage capacities in the basalt and sandstone and leading to a rise in water levels.

This is perhaps largely as a result of the reduction in secondary permeability and porosity of the basalt and a reduction in the primary permeability and porosity of the sandstone.

Water seeping from the waste dumps and the slimes dams has resulted in an increase in the mineral content of the ambient groundwater beneath the structures. Soluble mineral salts in the waste dump are mobilized by percolating rainwater and process water and migrate into the groundwater. Chemical analysis of groundwater from boreholes around the discard piles and slimes dams have shown a significant increase in the calcium, sulphate, nitrate, chloride, fluoride and cadmium concentrations in the groundwater below the structures. The increase in these elements is the primary phase and short term impact of the mining operations and is due to base exchange and direct solution of salts in the discard material.

The longer term impact, acid mine drainage, is not evident in the groundwater at present. This is probably due to the neutralizing capability of natural groundwater. Only when the neutralizing capacity of the environment is exceeded will the pH of the groundwater decrease.

Stage one of the process of the formation of acid mine drainage is taking place in the discard piles. This involves the oxidation of pyrite by water and oxygen resulting in the formation of sulphuric acid and ferrous sulphate. The sulphuric acid is neutralized by the alkalinity of the coal and groundwater and as a result the pH of the groundwater is between 7 and 8. However, there is evidence of high concentrations of sulphate and iron in the groundwater.

Stages two, three and four are likely to be taking place in the waste dumps (unable to sample). As the waste dumps are above ground and the volume of water held in the dumps is low, the products of the weathering of the pyrite will only be leached into the groundwater during periods of rainfall. This will result in slugs of concentrated salts being introduced to the groundwater.

The continual monitoring of groundwater levels and chemistry in the future is crucial in determining the ongoing impact of the mine on the regional groundwater regime. By continual monitoring, additional information and the severity of the mine's impact on the regional aquifers can be assessed. This will also allow the timely implementation of measures to control the impact of the mining on the hydrochemistry before it reaches unmanageable proportions.

The impact of the mining operations on the regional hydrochemistry is likely to increase in the future. Acid mine drainage is likely to become evident and the impact is likely to increase geometrically with time.

In retrospect, on completion of the study two additional tasks would have been beneficial to the study. The first would be the drilling of boreholes in the waste dumps to facilitate the measurement of water quality and levels in and beneath the dumps. This would enable water quality in the dumps to be assessed and the relative importance of the buffering affects of the ambient groundwater to be quantified.

Secondly, a laboratory experiment simulating the field conditions of the waste dumps and the slimes dams would have provided detailed information as to the nature of the salts leached, from the dumps and the time period for acid mine drainage to become evident.

13.0 RECOMMENDED CONTINGENCY PLANS TO CONTROL THE SPREAD OF LEACHATE AT GROOTEGELUK

Coal mines contaminate the groundwater both in the short and long terms. Short term pollution results in the increase in total dissolved solids of the groundwater. Long term pollution is termed acid mine drainage and results in the decrease in the pH of the groundwater and increase in the iron and sulphate content of the groundwater.

Control of short term pollution of groundwater from coal mine workings or spoils is near impossible. The effect of short term pollution is however not of serious hydrogeological or environmental consequences, due to the processes involved. Short term pollution results in an increase in the TDS of the groundwater with the addition of salts. If the material causing the short term pollution originates from the same hydrogeological environment major problems are not usually envisaged. However, in the case of Grootegeluk the material is transported onto another hydrogeological regime resulting in the introduction of foreign salts.

Long term pollution however is of more serious environmental consequences. Objectives of controlling the formation of acid mine drainage is at its source by limiting pyrite oxidation. Research by Walsh et al (1982), Dugan and Apel (1983), and Watson (1983) indicate that methods of slowing reaction rates are by limiting oxygen, inhibiting iron oxidizing bacteria or otherwise influencing reaction chemistry.

Other methods of treating acid mine drainage is the actual treatment of the waste water once acid generation has taken place. These processes usually involve time neutralization, aeration, and settling suspended solids.

In evolving contingency plans for Grootegeluk, differing time scales have to be taken into consideration. Short term pollution involves an increase in TDS of the groundwater and initial breakdown of iron-sulphides. The treatment of short term pollution should involve a series of scavenger wells to minimize the spread of highly mineralized leachate from the mine spoils.

13.1 Waste Dumps and Slimes Dams

The scavenger wells installed in strategic positions around the discard dumps and slime dams, should be designed to permanently lower water levels in the vicinity of the structures from where the contamination is emanating. This will result in a nett groundwater gradient to the wells preventing the contaminant plume moving from the mine properties. The water pumped from the wells can be used in the mine as process or dust control water.

In the long term, acid mine drainage is likely to be evident in the following 20 years. Leachate or acid mine drainage from the discard dumps and slimes dams will be very high in dissolved solids and low in pH.

The prevention of the formation of acid mine drainage hinges on the success of inhibiting the oxidation of pyrite. Numerous methods of inhibiting oxidation of pyrite have been investigated. Perhaps the most successful is by treatment of coal dumps with sodium layryte sulphate (S.L.S.) and sodium benzoate (Dugan and Apel 1982). The treatment is aimed at the inhibition of bacterial oxidation of pyrite which cause the accelerated breakdown of iron sulphides and concomitant acid mine drainage.

Work on the control of the generation of acid mine drainage is at present being undertaken by Bosch and Loos (1987) for the Water Research Commission. Bosch and Loos found that the amount of acid generated in coal waste dumps increases during the rainy season and decreases during the dry season. This is not only due to the amount of water present to leach the salts from the dumps but also due to the increased activity of the bacterium Thiobacillus ferrooxidans. The cost implications of treating whole dumps with solutions to inhibit bacteria oxidation of pyrite is not known at this stage.

Loos (1988, personal communication) found that S.L.S. was not as effective as most of the S.L.S. was absorbed by the coal. As a result concentrations of up to 70ppm were required to reduce bacterial oxidation. Experiments by Bosch and Loos (1987) show that benzoate and sorbic acid may be more effective as inhibitors of bacterial oxidation than S.L.S. because of the lower concentrations (15-20ppm) required. The absorption of benzoate and sorbic acid by coal is also minimal. Unfortunately the research by Bosch and Loos is still in its early stages and no cost implications of treatment of dumps could be supplied.

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APPENDIX 1

THE RESULTS OF THE CHEMICAL ANALYSIS OF GROUNDWATER SAMPLES TAKEN DURING THE REGIONAL SAMPLING PROGRAMMES

1) 1975
2) 1976
3) 1984/1985

CHEMICAL ANALYSES OF GROUNDWATER SAMPLES TAKEN DURING FEBRUARY 1975

BOREHOLE NO.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
TDS Evap mg/l	1368	764	482	1004	802	902	624	600	314	884	176	972	1232	884	1424	944	586	258	404	386	658	474	2754
Cond ms/m	180	90	58	110	100	110	80	70	70	40	20	100	100	110	53	86	56	31	58	59	65	65	350
pH Lab	6,90	6,70	7,10	6,60	6,70	7,40	7,10	6,70	7,40	7,10	8,00	6,60	6,50	6,40	6,80	6,50	6,40	6,50	7,30	8,90	6,10	8,20	6,90
Major Cations in meq/l																							
Ca^{2+}	4,97	4,95	4,21	7,63	6,97	5,06	5,56	6,39	3,24	3,16	0,12	3,46	4,46	0,68	1,32	2,71	1,14	0,52	2,92	1,60	1,44	3,02	5,00
Mg^{2+}	4,53	2,77	1,74	3,70	3,86	3,54	2,80	1,36	2,54	2,56	0,04	3,06	3,02	0,70	0,52	2,22	1,72	0,56	2,32	1,10	1,34	2,20	7,80
Na^+	10,52	2,69	0,96	2,70	2,39	4,09	1,48	0,96	1,53	4,04	1,78	2,70	3,39	10,52	4,48	3,09	2,13	7,00	1,52	3,13	2,70	2,39	17,46
K^+	0,38	0,46	0,38	0,54	0,72	0,38	0,51	0,31	0,18	0,31	0,10	0,49	0,49	0,49	0,74	0,38	0,41	0,31	0,10	0,15	0,41	0,10	0,18
Major Anions in meq/l																							
$CO_3{}^-{}_2{}^-$	5,24	5,94	5,16	6,72	8,00	6,06	6,20	6,38	4,90	3,22	0,80	1,22	1,06	5,20	2,72	1,30	0,68	0,98	5,72	3,12	0,56	6,28	9,10
CL	12,20	4,11	1,61	4,11	2,39	5,10	1,89	1,01	3,75	6,56	1,04	8,70	8,90	7,49	3,30	7,29	4,79	2,39	1,49	3,61	5,60	1,49	28,30
$SO^2{}_4{}^-$	1,96	1,19	0,85	3,87	3,54	2,35	2,62	1,85	0,29	0,35	0,04	0,40	0,10	0,21	0,52	0,04	0,19	0,17	0,15	0,12	0,10	0,54	0,69
$NO_3{}^-$-N	1,68	0,02	0,06	0,01	0,00	0,04	0,04	0,06	0,00	0,01	0,00	0,16	0,40	0,24	0,07	0,15	0,29	0,04	0,13	0,15	0,24	0,12	0,16
Trace Element mg/l																							
S_1O_2	1,96	9,20	9,70	8,30	10,20	9,40	7,50	7,20	4,00	5,10	5,40	0,00	23,20	26,40	33,20	35,60	32,40	24,20	20,40	23,20	35,60	26,40	36,001
F^-	3,20	0,70	0,50	0,90	0,70	1,00	0,70	0,50	0,80	0,70	0,50	0,50	0,50	0,50	0,50	0,50	0,50	0,50	0,50	0,50	0,50	0,50	2,00
$PO_4{}^{3-}$																							
NH_2-N^-	0,00	0,00	0,00	3,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	4,50	0,00	4,50	3,50	5,00	3,00
Mn																							
Pb																							
Zn																							
Cd																							
Fe	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	4,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00

CHEMICAL ANALYSIS OF GROUNDWATER SAMPLES TAKEN IN JUNE 1976

BOREHOLE NO.	3	5	7	19	22	23	27
TDS Evap mg/l	700	750	620	480	475	1335	185
Cond ms/m	123	145	123	102	100	282	32
pH lab	7,50	8,00	7,30	7,60	7,60	8,40	6,70
Major Cations							
in meq/l Ca^{2+}	5,79	5,60	4,40	3,20	3,60	2,20	0,60
Mg^{2+}	2,20	3,28	3,20	1,00	2,32	0,92	0,88
Na^+	2,39	3,30	2,70	3,22	2,61	19,10	0,96
K^+	0,33	0,49	0,28	0,17	0,10	0,23	0,10
Major Anions in meq/l							
CO_3^{2-}	4,80	7,00	5,56	4,20	6,20	4,00	1,12
Cl^-	3,83	4,20	3,49	3,89	1,69	11,83	1,24
SO_4^{2-}	2,33	1,98	2,56	0,33	0,86	6,16	0,17
NO_3-N	0,21	0,21	0,21	0,29	0,21	0,07	0,21
Trace Elements in mg/l							
SiO_2	14,30	10,80	10,00	33,20	42,00	18,40	44,00
F^-							
NH_3-N^-	3,00	3,00	5,00	4,00	4,00	4,00	3,00
Fe							

CHEMICAL ANALYSIS OF GROUNDWATER SAMPLES TAKEN IN JUNE 1985

BOREHOLE NO.	2	8	10	11	13	14	15	16	17	19	21	28	29	30	31	32	33	34	35	36	37
TDS Evap mg/l	795	325	980	1050	810	765	210	575	440	490	495	260	255	3262	525	380	430	660	5,80	5,80	8,50
Cond ms/m																		94	67	14	124
pH lab	7,40	7,10	6,80	6,60	7,10	7,30	7,60	6,60	6,30	7,00	6,30	6,60	6,50	7,00	7,20	7,30	7,70	6,20	485	100	6,90
Major Cations in meq/l																					
Ca^{2+}	5,90	3,80	6,30	5,00	4,80	0,60	0,60	2,50	1,80	2,19	1,60	1,40	2,20	7,59	3,40	2,50	3,44	2,10	3,74	0,06	2,80
Mg^{2+}	2,80	1,20	3,90	3,30	2,80	0,60	0,40	1,90	1,60	1,90	1,50	1,40	0,80	12,79	2,20	1,70	1,50	1,70	1,52	0,30	3,20
Na^{1+}	1,96	0,13	4,26	7,39	2,17	16,79	1,96	3,26	1,94	4,17	2,91	1,65	1,13	27,83	1,83	1,09	1,00	5,13	3,48	0,87	6,09
K^{+}	0,28	0,23	0,56	0,33	0,39	0,90	0,18	0,36	0,36	0,23	0,28	0,10	1,10	26,92	0,31	0,21	0,21	0,10	0,08	0,13	0,23
Major Anions in meq/l																					
CO_3^{+2-}	5,10	4,00	7,00	4,60	0,90	11,40	0,90	1,00	0,30	4,40	0,40	1,80	2,96	14,00	4,00	2,40	3,00	2,00	0,90	6,50	6,80
Cl^{-}	1,97	0,99	6,06	10,71	8,45	6,06	1,27	6,34	4,23	3,38	4,79	1,92	1,21	29,61	3,66	2,54	1,97	6,20	3,67	0,71	4,65
SO_4^{2-}	3,96	0,10	2,08	0,21	0,13	0,21	0,21	0,10	0,13	0,25	0,42	0,42	0,42	6,46	0,19	0,21	1,04	0,73	2,08	0,20	1,04
NO_3^{-}-N	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,02	0,02	0,32	0,05	0,03	0,05	0,26	0,05	0,05	0,13
Trace Elements (in mg/l)																					
SiO_2	14	14	8	57	41	64	67	25	59	38	63	N.A	N.A	N.A	28	30	17	N.A	N.A	N.A	
F	0,26	0,27	0,45	0,12	0,17	0,32	0,13	0,07	0,09	0,13	0,09	1,00	1,00	2,90	0,11	0,09	2,04	N.A	N.A	N.A	
Fe	0,10	0,10	0,10	0,10	0,10	0,20	0,40	1,30	0,10	0,20	0,10	0,25	7,08	-	0,10	0,10	0,10	N.A	N.A	N.A	
Mn	0,60	0,60	0,40	0,10	0,10	0,10	0,10	0,30	0,10	0,10	0,10	0,09	0,75	0,09	0,10	0,10	0,10	N.A	N.A	N.A	
Pb	0,10	0,10	0,10	0,10	0,10	0,10	0,10	0,10	0,10	0,10	0,10	0,02	0,01	0,06	0,10	0,10	0,10	N.A	N.A	N.A	
Zn	0,50	0,50	0,60	2,00	1,30	0,10	0,10	0,30	0,80	1,40	0,10	0,03	0,80	0,50	1,00	0,10	0,10	N.A	N.A	N.A	
Cd	N.A	N.A	N.A	N.A	N.A	N.A	N.A	N.A	N.A	N.A	N.A	0,20	0,20	0,20	N.A	N.A	N.A	N.A	N.A	N.A	

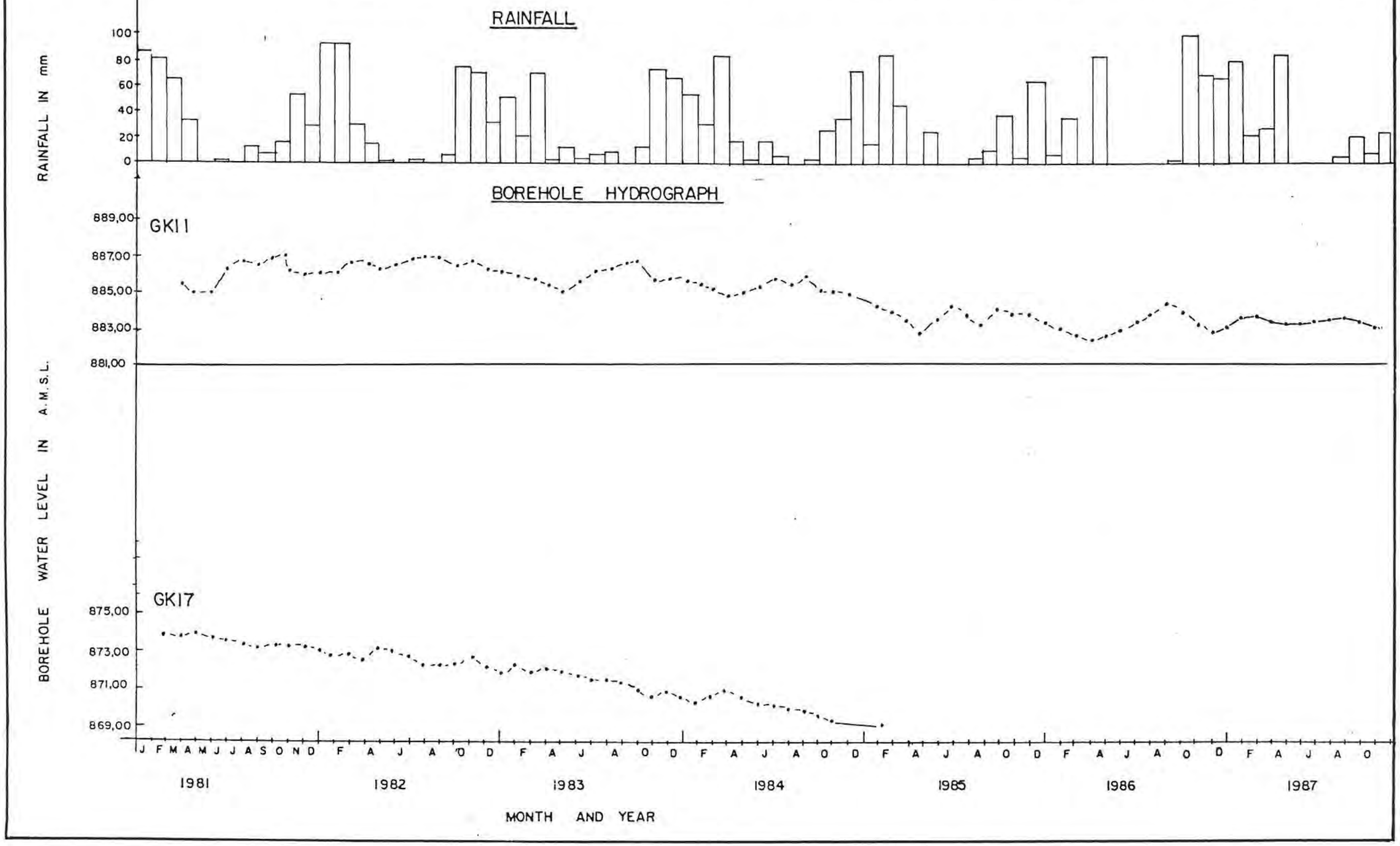
NOTE: N.A. = Not analysed

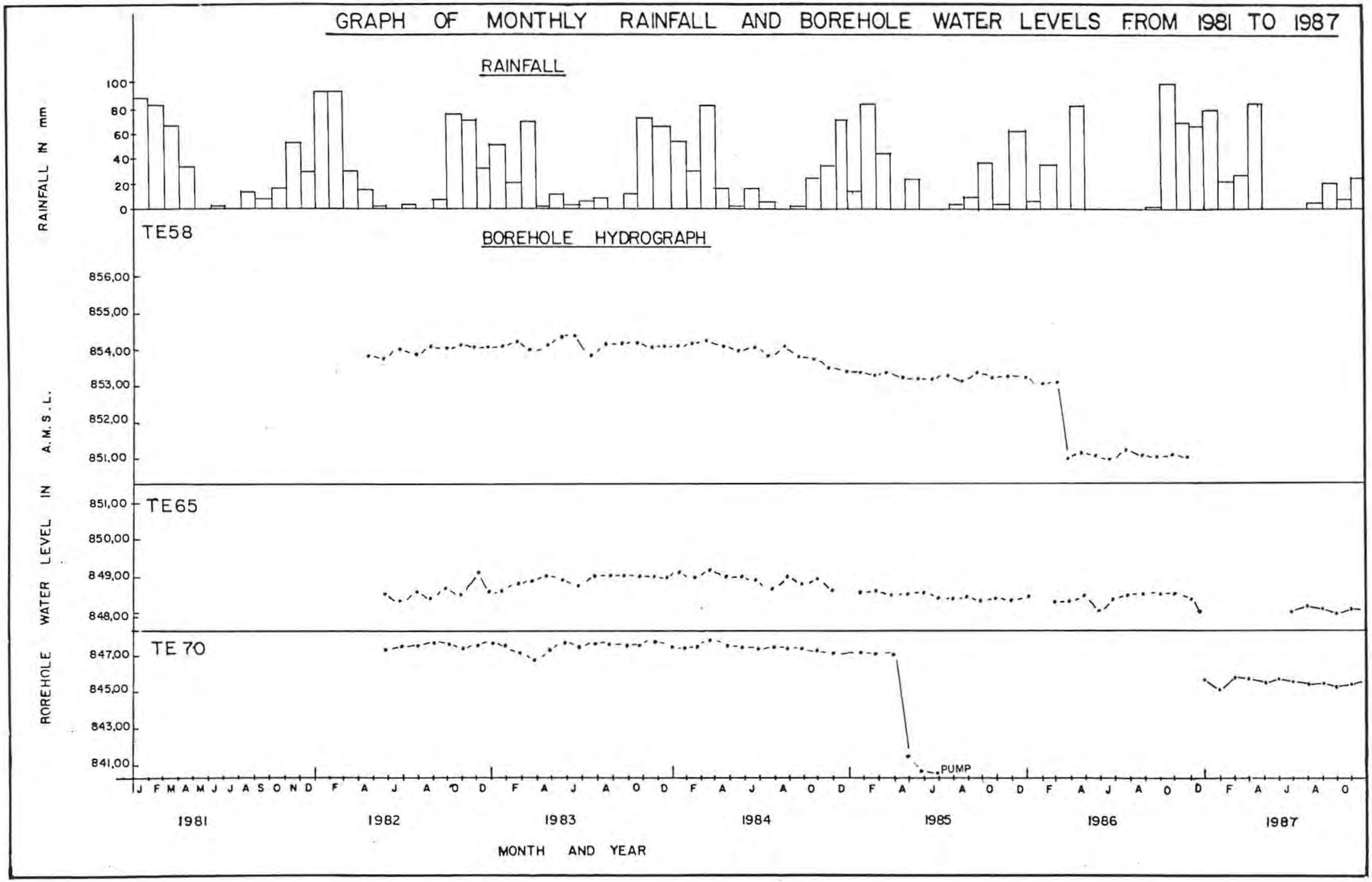
APPENDIX 2

GRAPHS OF MONTHLY RAINFALL AND BOREHOLE HYDROGRAPHS FROM 1981 TO 1987 FOR BOREHOLES

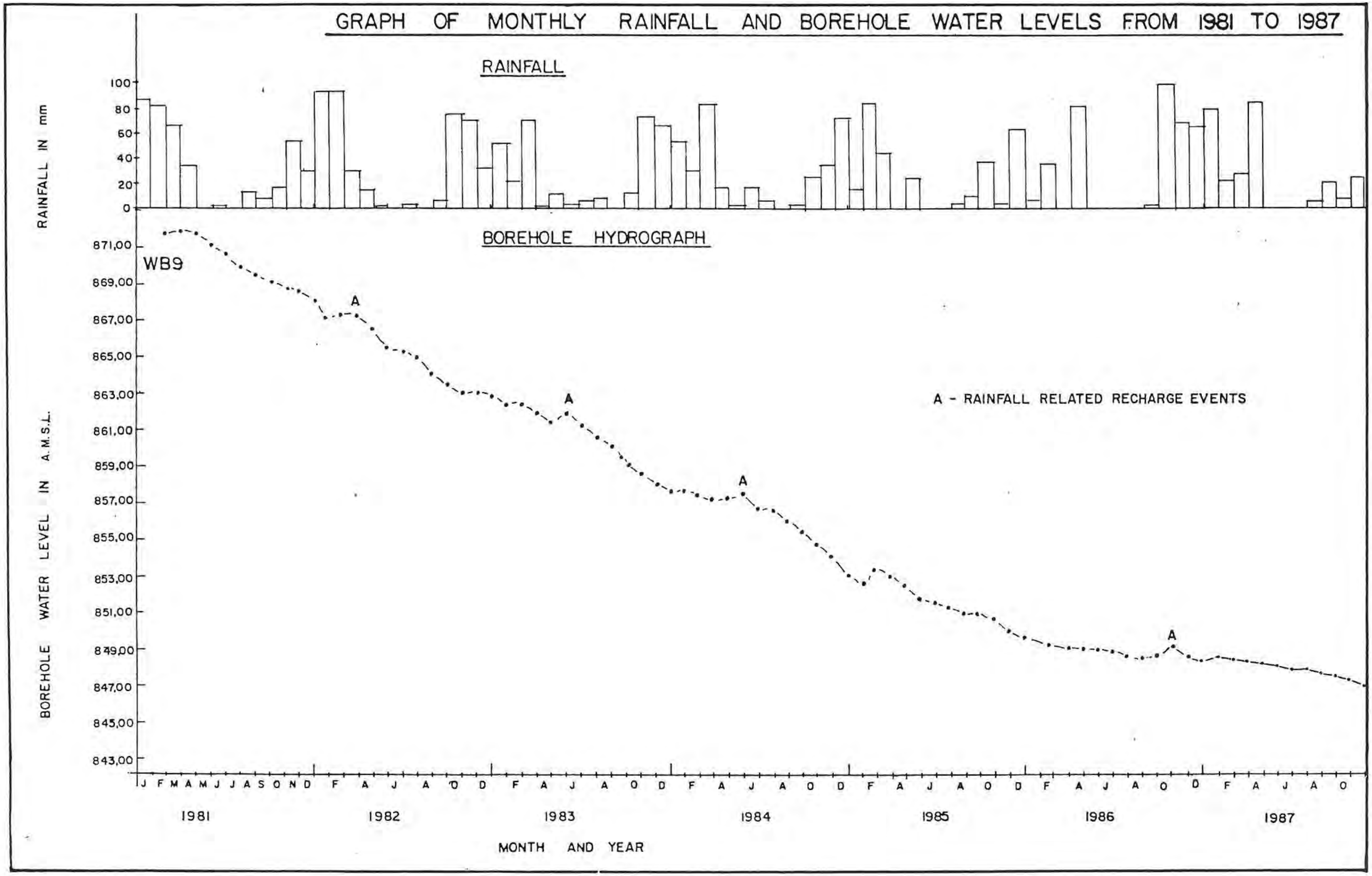
1) GK11 AND GK17
2) TE 58, TE 65 AND TE 70
3) WB9
4) ET 70
5) WB 14, WB 19 AND WB 22

GRAPH OF MONTHLY RAINFALL AND BOREHOLE WATER LEVELS FROM 1981 TO 1987

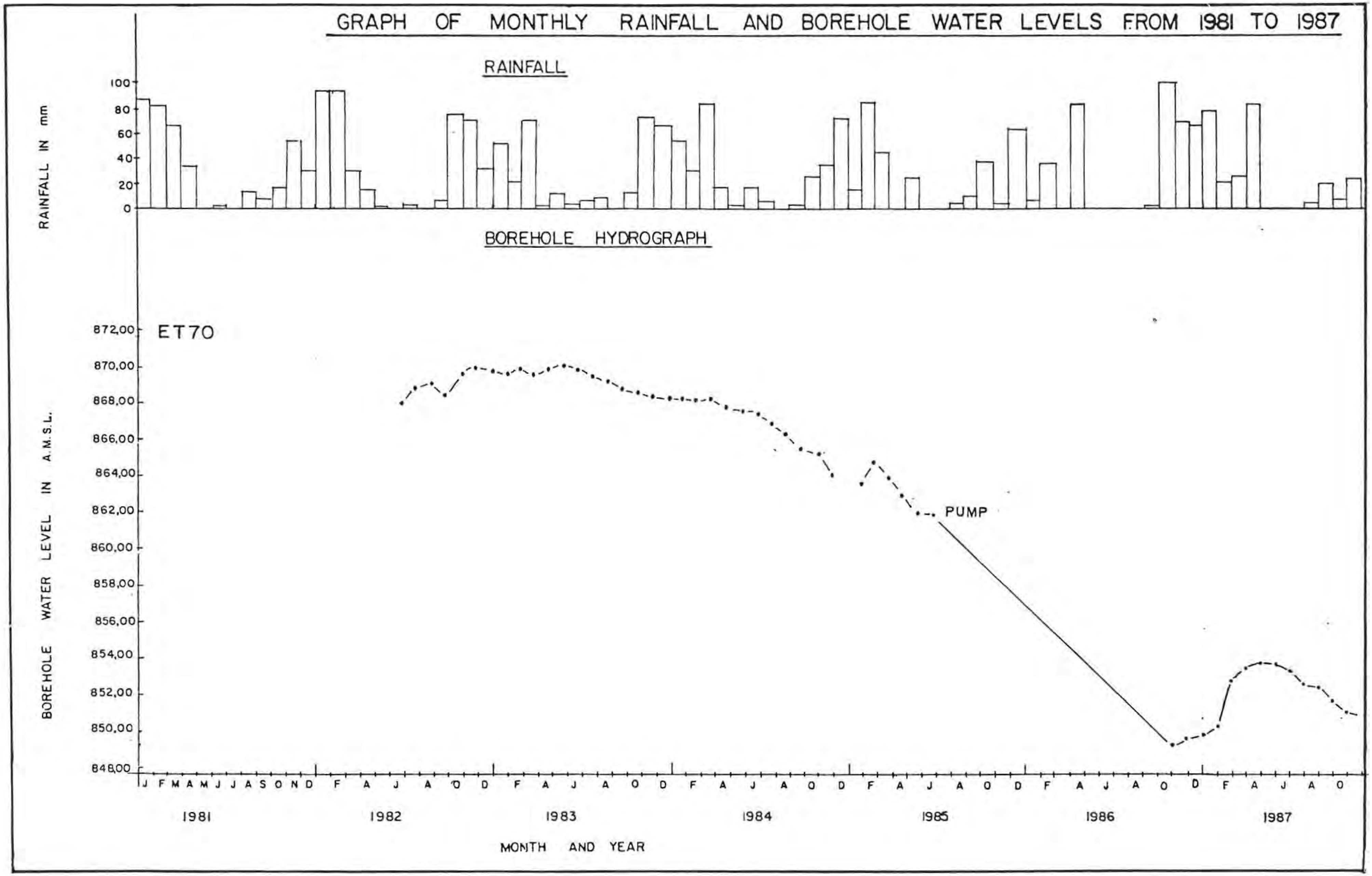




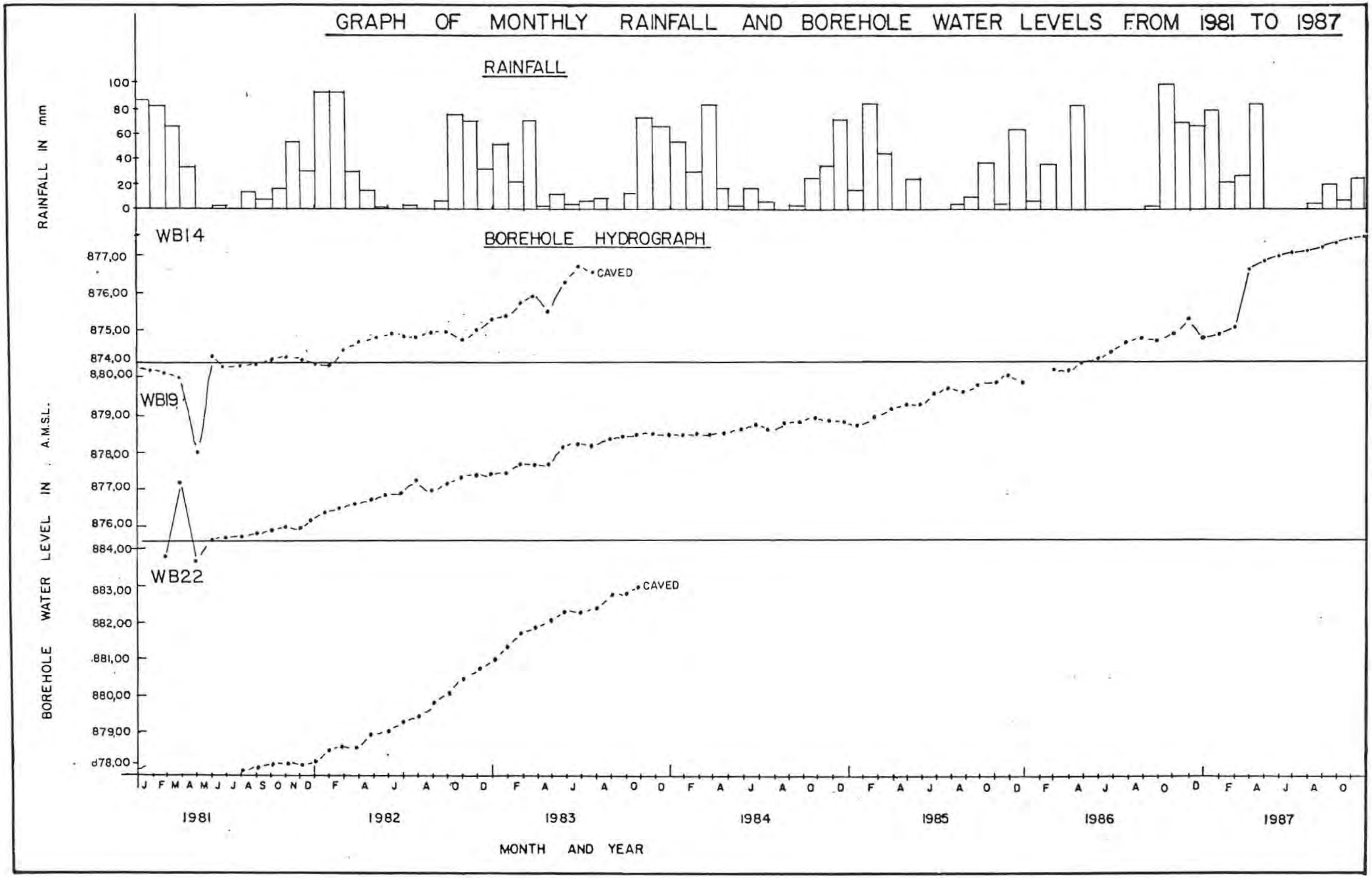
GRAPH OF MONTHLY RAINFALL AND BOREHOLE WATER LEVELS FROM 1981 TO 1987



GRAPH OF MONTHLY RAINFALL AND BOREHOLE WATER LEVELS FROM 1981 TO 1987



GRAPH OF MONTHLY RAINFALL AND BOREHOLE WATER LEVELS FROM 1981 TO 1987



GRAPH OF MONTHLY RAINFALL AND BOREHOLE WATER LEVELS FROM 1981 TO 1987

APPENDIX 3

THE RESULTS OF THE CHEMICAL ANALYSIS OF WATER SAMPLES TAKEN IN THE OPEN PIT AND SLIMES DAMS

CHEMICAL ANALYSIS OF GROUNDWATER SAMPLES TAKEN IN THE OPEN PIT AND SLIMES DAMS

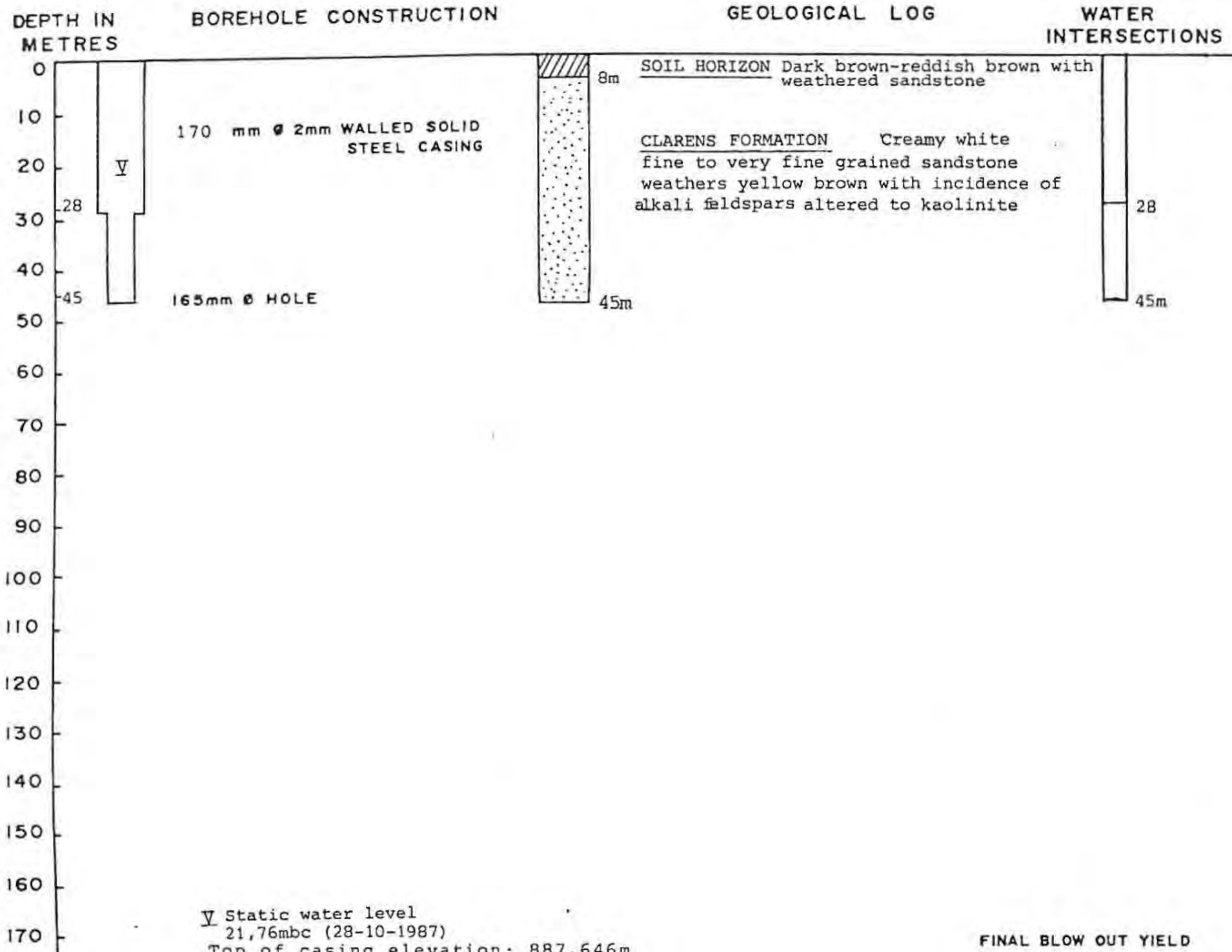
		OPEN PIT										SLIMES DAMS		
BOREHOLE NO.		1	2	3	4	5	6	7	8	9	10	1	2	3
TDS Evap mg/l		3110	4360	8275	5915	2100	9030	8525	1775	2945	3170	1620	2440	3440
Solids suspension		6	6	12	10	14	87	29	14	6	4	181	235	283
pH lab														
field		7,75	7,00	8,30	8,50	7,60	7,10	7,35	5,70	7,80	8,15	7,70	7,50	7,90
EH mv		+180	+105	+205	+195	+210	-65	+5	+95	+190	+230			
Major Cations	Ca^{2+}	16,40	25,00	40,20	31,00	11,60	40,00	36,10	11,50	23,00	24,00	10,97	15,57	23,95
in meq/l	Mg^{2+}	14,70	20,70	43,50	28,00	9,00	50,30	49.00	8,50	6,50	8,00	2,96	6,39	11,31
	Na^+	1,40	0,80	2,00	1,80	3,40	3,10	2,40	1,20	1,10	0,90	2,13	4,35	18,27
	K^+	0,50	0,70	1,20	0,90	0,30	1,20	0,90	0,60	0,40	0,50	0,13	0,38	0,17
Major Anions	CO_{3-}^{2-}	1,76	4,46	2,24	1,76	3,50	3,20	1,30	6,60	1,20	2,60	2,88	4,12	2,40
in mcqr/l	CL	1,50	1,10	0,40	0,70	0,50	2,10	0,70	0,80	0,60	0,60	2,65	6,37	2,88
	SO_{42}^{-}	30,00	41,00	82,30	59,40	19,80	90,00	86,00	14,60	29,20	31,20	8,62	16,66	31,33
	NO_4-N	0	0,10	0,10	0,10	0,60	0,10	0	0,10	0,1-	0,40	0,98	0,15	0,03
Trace Element														
mg/l	SiO_2													
	F^-	1,80	1,50	1,00	1,00	1,00	2,20	2,30	1,40	1,40	1,50	0,10	0,10	0,10
	Fe	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,10	1,80	0,70
	Mn	1,00	3,00	2,00	0,50	0,00	4,00	25,00	0,30	0,20	1,00	0,10	0,40	2,50
	Pb	0,04	0,03	0,05	0,07	0,02	0,04	0,05	0,00	0,00	0,00	0,10	0,10	0,10
	Z_1	0,10	0,10	0,10	0,10	0,10	0,10	0,10	0,10	0,10	0,10	0,10	0,10	0,10
	Cd											0,40	0,60	0,70
	SE											0,10	0,10	0,10
	AS											1,00	1,00	1,00
Fe Acidified												0,50	3,00	5,50

APPENDIX 4

WBR BOREHOLE LOGS

(Logged by personnel of the Grootegeluk Geology Department)

WBR 1 BOREHOLE LOG



SOIL HORIZON Dark brown-reddish brown with weathered sandstone

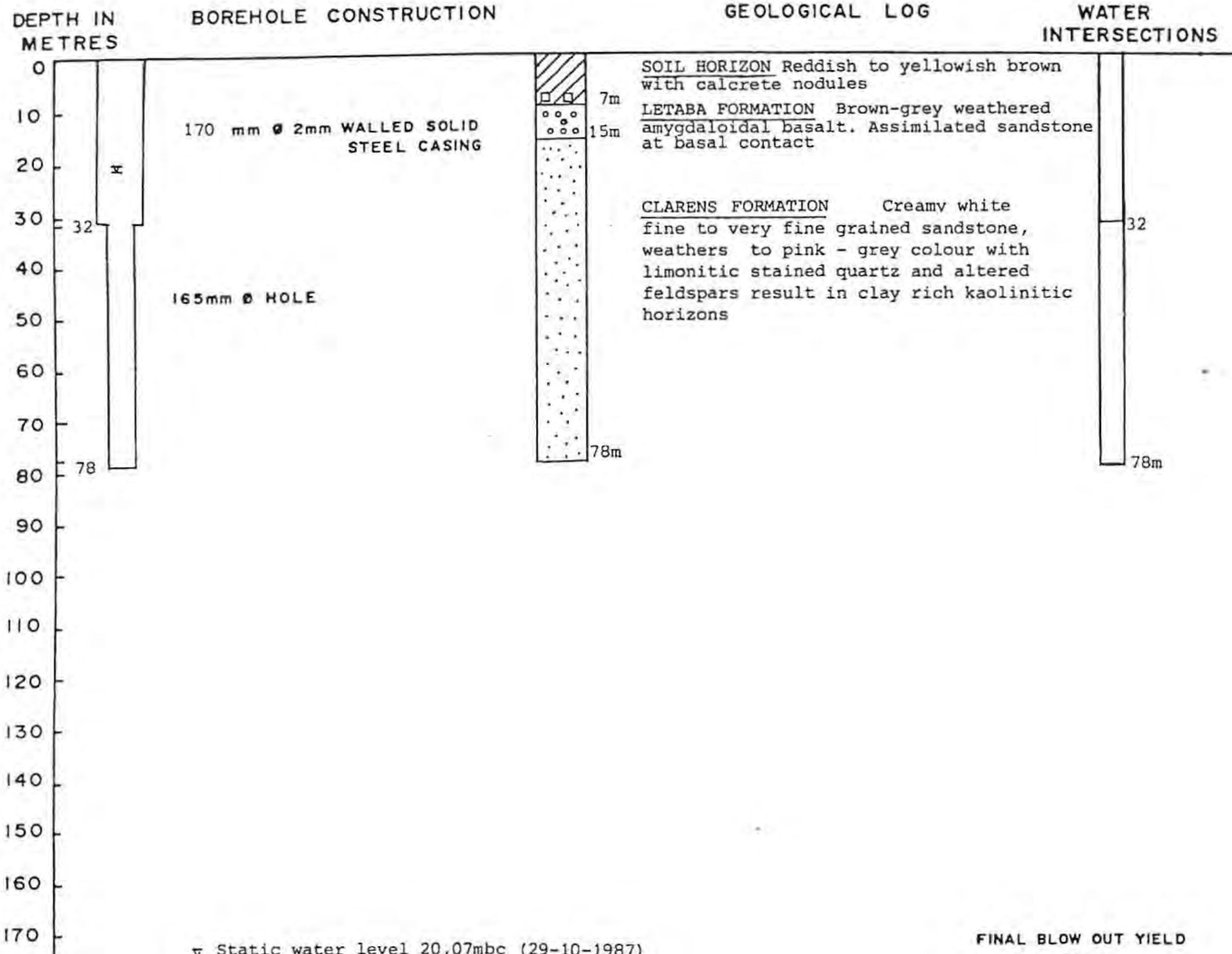
CLARENS FORMATION Creamy white fine to very fine grained sandstone weathers yellow brown with incidence of alkali feldspars altered to kaolinite

Ṿ Static water level
21,76mbc (28-10-1987)
Top of casing elevation: 887.646m

FINAL BLOW OUT YIELD
3,0 l/sec

DATE OF DRILLING 09-02-1987

WBR 2 BOREHOLE LOG



SOIL HORIZON Reddish to yellowish brown with calcrete nodules

LETABA FORMATION Brown-grey weathered amygdaloidal basalt. Assimilated sandstone at basal contact

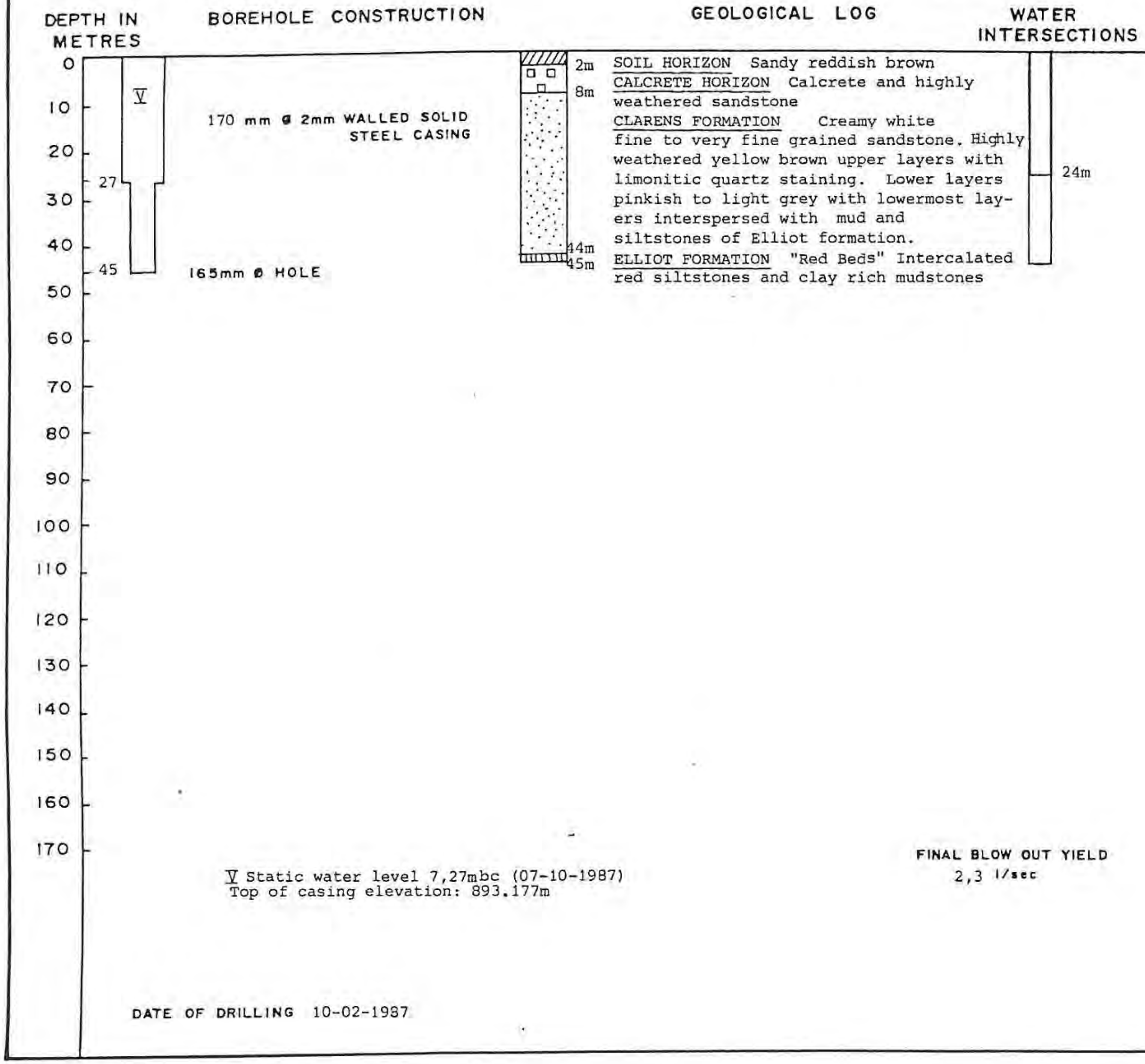
CLARENS FORMATION Creamy white fine to very fine grained sandstone, weathers to pink - grey colour with limonitic stained quartz and altered feldspars result in clay rich kaolinitic horizons

⊻ Static water level 20,07mbc (29-10-1987)
Top of casing elevation: 897.991m

FINAL BLOW OUT YIELD
2,0 l/sec

DATE OF DRILLING 09/02/1987

WBR 3 BOREHOLE LOG



<u>SOIL HORIZON</u> Sandy reddish brown

<u>CALCRETE HORIZON</u> Calcrete and highly weathered sandstone

<u>CLARENS FORMATION</u> Creamy white fine to very fine grained sandstone. Highly weathered yellow brown upper layers with limonitic quartz staining. Lower layers pinkish to light grey with lowermost layers interspersed with mud and siltstones of Elliot formation.

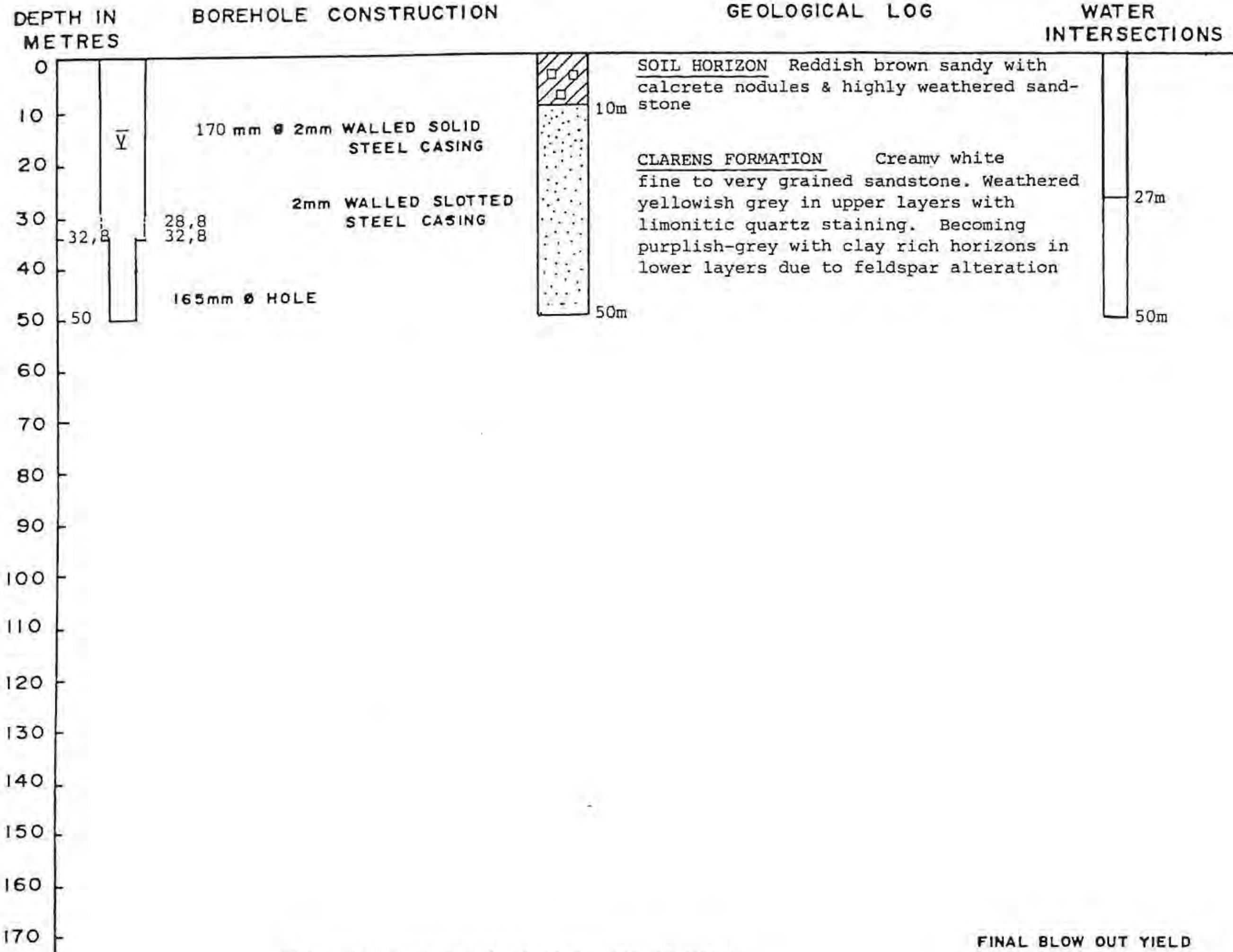
<u>ELLIOT FORMATION</u> "Red Beds" Intercalated red siltstones and clay rich mudstones

⊻ Static water level 7,27mbc (07-10-1987)
Top of casing elevation: 893.177m

FINAL BLOW OUT YIELD
2,3 l/sec

DATE OF DRILLING 10-02-1987

WBR4 BOREHOLE LOG



170 mm ø 2mm WALLED SOLID STEEL CASING

2mm WALLED SLOTTED STEEL CASING

165mm ø HOLE

SOIL HORIZON Reddish brown sandy with calcrete nodules & highly weathered sandstone

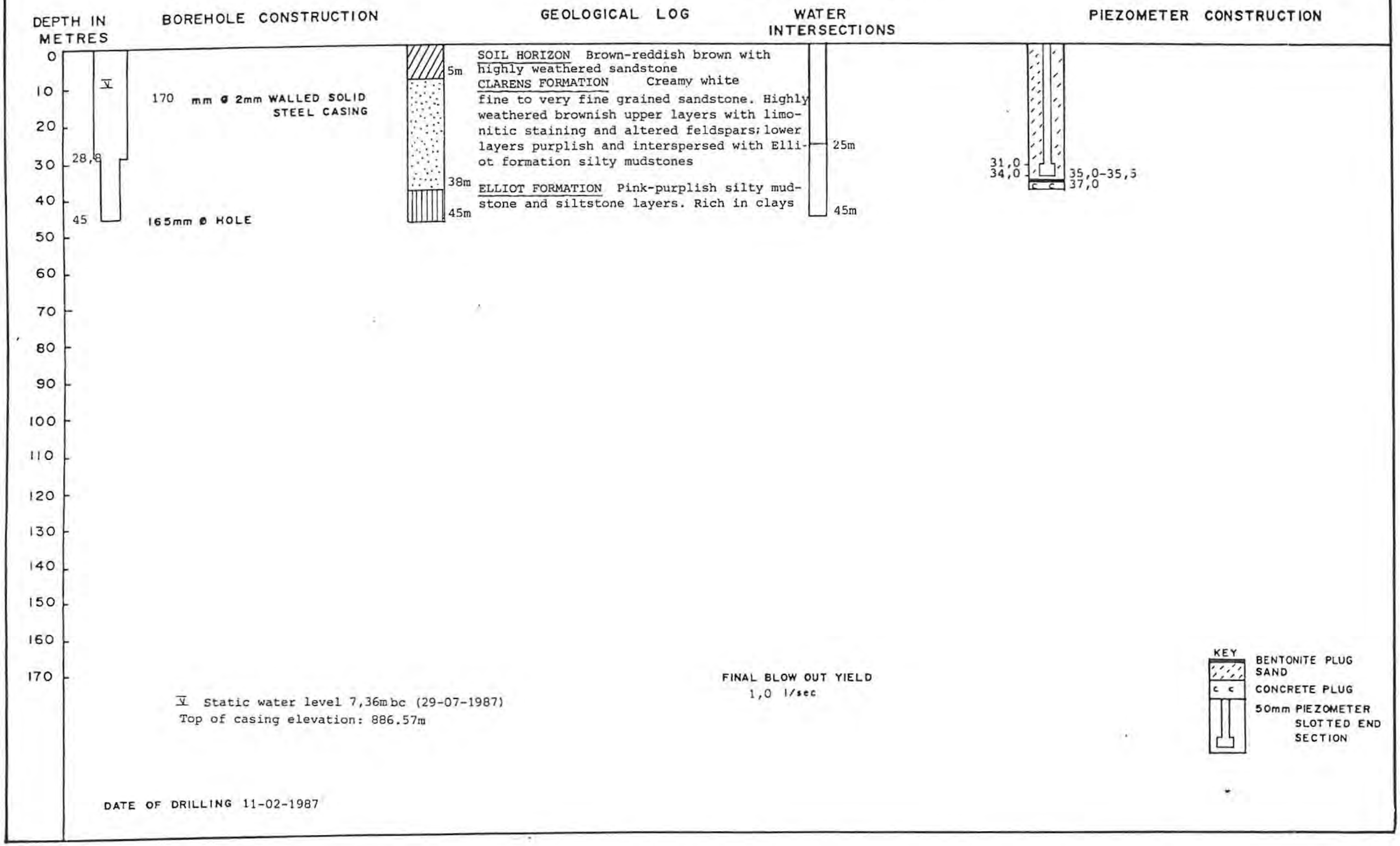
CLARENS FORMATION Creamy white fine to very grained sandstone. Weathered yellowish grey in upper layers with limonitic quartz staining. Becoming purplish-grey with clay rich horizons in lower layers due to feldspar alteration

V̲ Static water level 14,91mbc (31-07-1987)
Top of casing elevation: 890.440m

FINAL BLOW OUT YIELD
1,2 l/sec

DATE OF DRILLING 10-02-1987

WBR 5 BOREHOLE LOG



SOIL HORIZON Brown-reddish brown with highly weathered sandstone

CLARENS FORMATION Creamy white fine to very fine grained sandstone. Highly weathered brownish upper layers with limonitic staining and altered feldspars; lower layers purplish and interspersed with Elliot formation silty mudstones

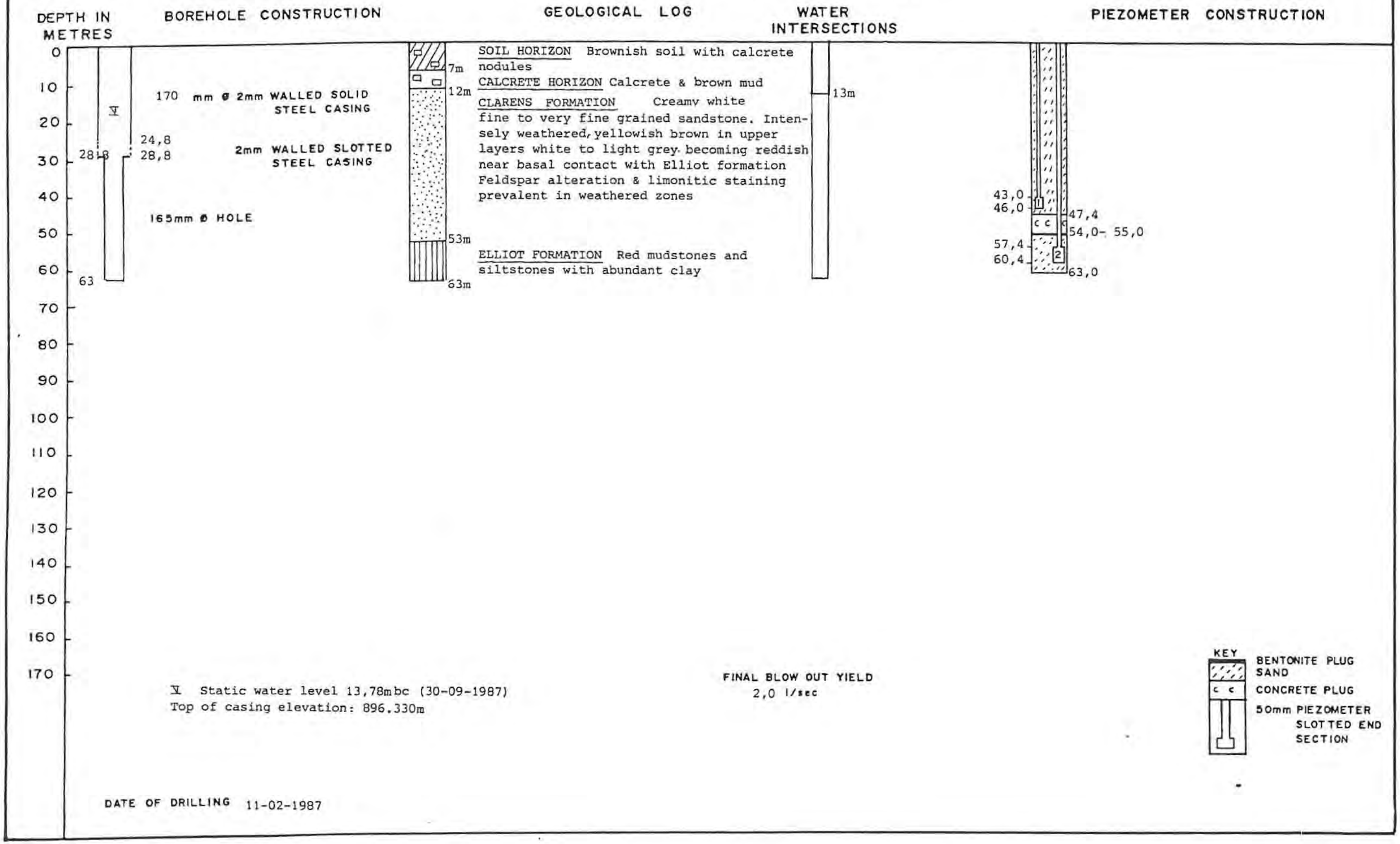
ELLIOT FORMATION Pink-purplish silty mudstone and siltstone layers. Rich in clays

FINAL BLOW OUT YIELD
1,0 l/sec

⊻ Static water level 7,36m bc (29-07-1987)
Top of casing elevation: 886.57m

DATE OF DRILLING 11-02-1987

WBR 6 BOREHOLE LOG



SOIL HORIZON Brownish soil with calcrete nodules

CALCRETE HORIZON Calcrete & brown mud

CLARENS FORMATION Creamy white fine to very fine grained sandstone. Intensely weathered, yellowish brown in upper layers white to light grey becoming reddish near basal contact with Elliot formation Feldspar alteration & limonitic staining prevalent in weathered zones

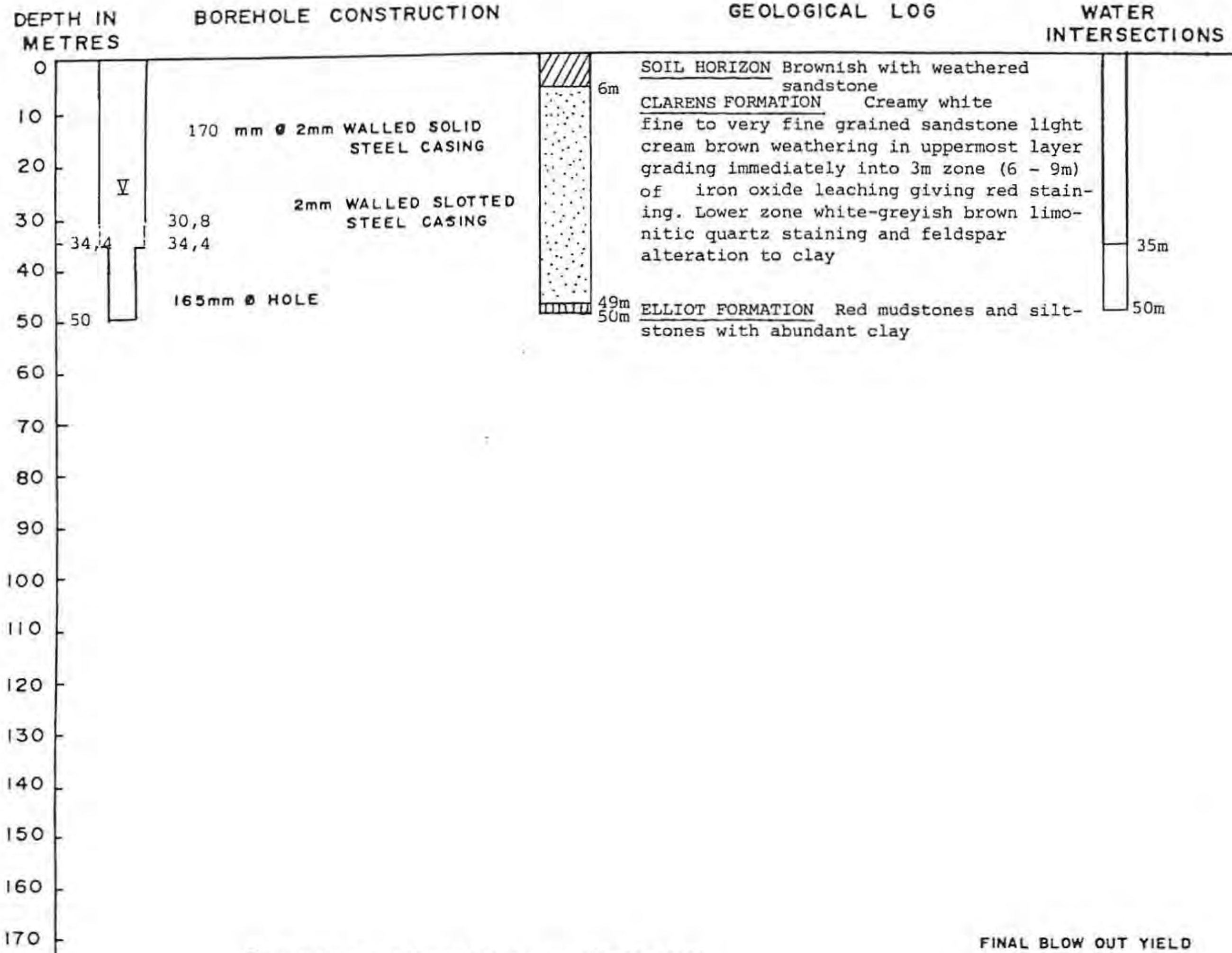
ELLIOT FORMATION Red mudstones and siltstones with abundant clay

Ⅴ Static water level 13,78mbc (30-09-1987)
Top of casing elevation: 896.330m

FINAL BLOW OUT YIELD
2,0 l/sec

DATE OF DRILLING 11-02-1987

WBR 7 BOREHOLE LOG



SOIL HORIZON Brownish with weathered sandstone

CLARENS FORMATION Creamy white fine to very fine grained sandstone light cream brown weathering in uppermost layer grading immediately into 3m zone (6 - 9m) of iron oxide leaching giving red staining. Lower zone white-greyish brown limonitic quartz staining and feldspar alteration to clay

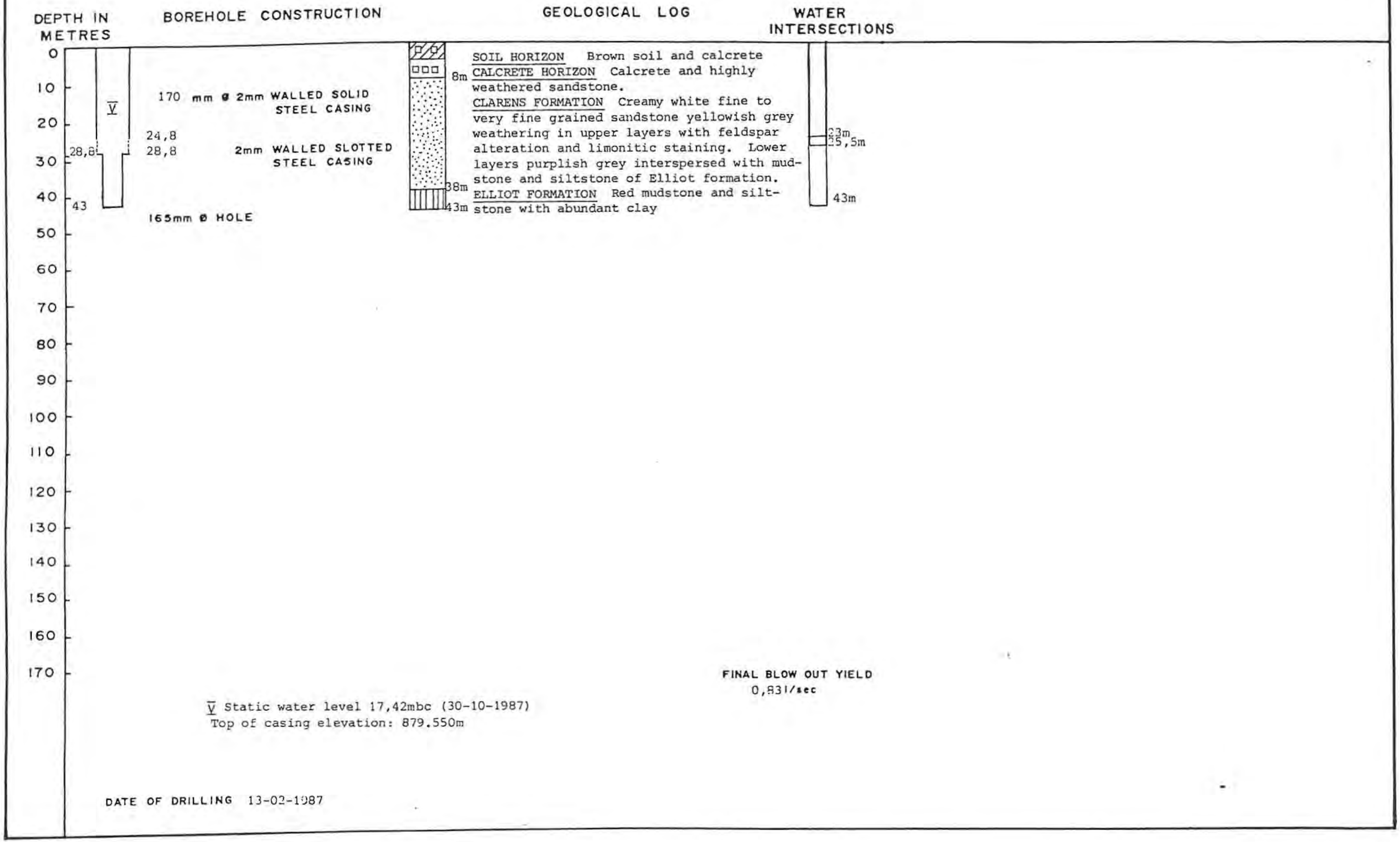
ELLIOT FORMATION Red mudstones and siltstones with abundant clay

∇ Static water level 24,54mbc (27-10-1987)
Top of casing elevation: 886.940m

FINAL BLOW OUT YIELD
0,27 l/sec

DATE OF DRILLING 12-02-1987

WBR 8 BOREHOLE LOG



SOIL HORIZON Brown soil and calcrete

CALCRETE HORIZON Calcrete and highly weathered sandstone.

CLARENS FORMATION Creamy white fine to very fine grained sandstone yellowish grey weathering in upper layers with feldspar alteration and limonitic staining. Lower layers purplish grey interspersed with mudstone and siltstone of Elliot formation.

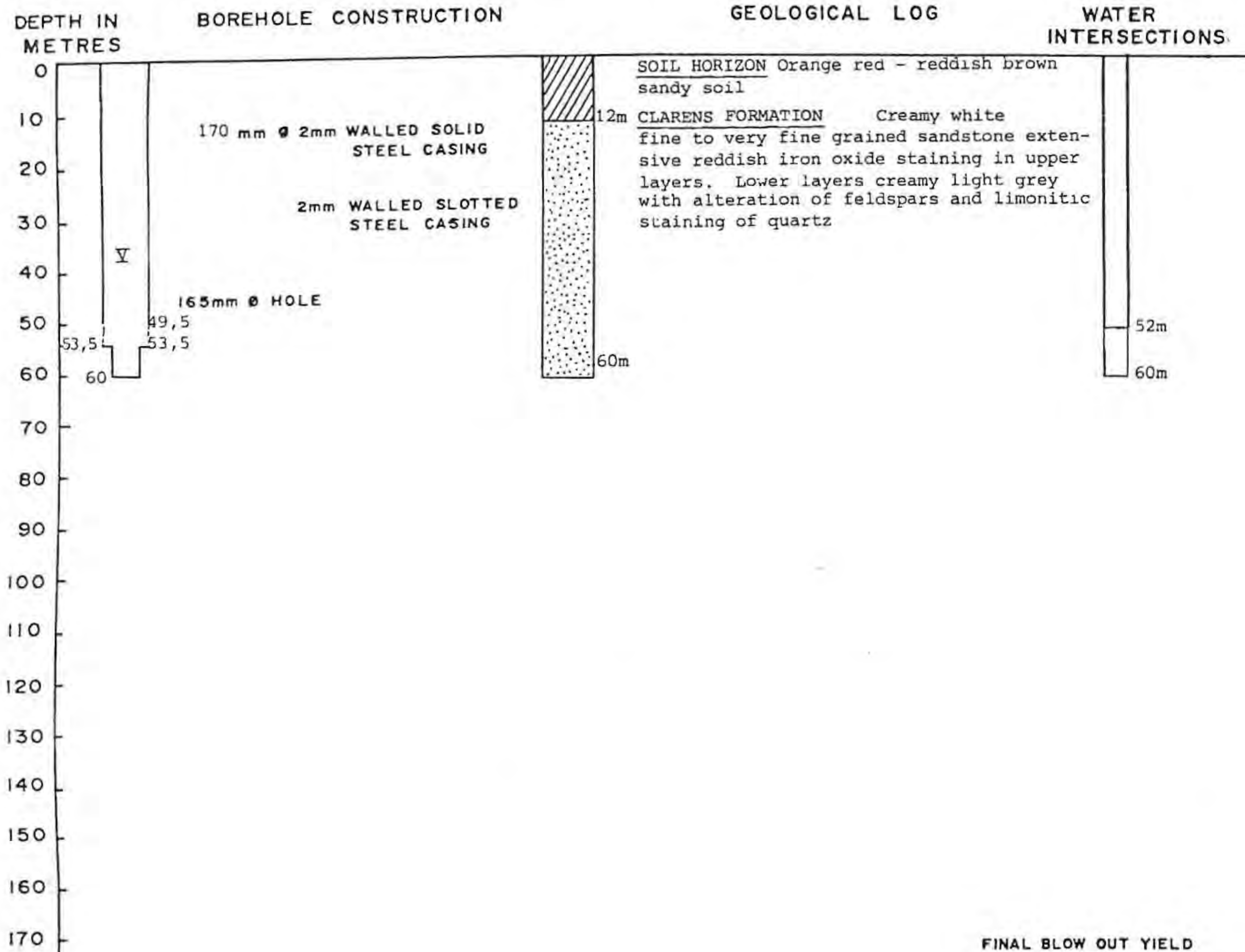
ELLIOT FORMATION Red mudstone and siltstone with abundant clay

FINAL BLOW OUT YIELD
0,83l/sec

V̲ Static water level 17,42mbc (30-10-1987)
Top of casing elevation: 879.550m

DATE OF DRILLING 13-02-1987

WBR 9 BOREHOLE LOG



SOIL HORIZON Orange red – reddish brown sandy soil

CLARENS FORMATION Creamy white fine to very fine grained sandstone extensive reddish iron oxide staining in upper layers. Lower layers creamy light grey with alteration of feldspars and limonitic staining of quartz

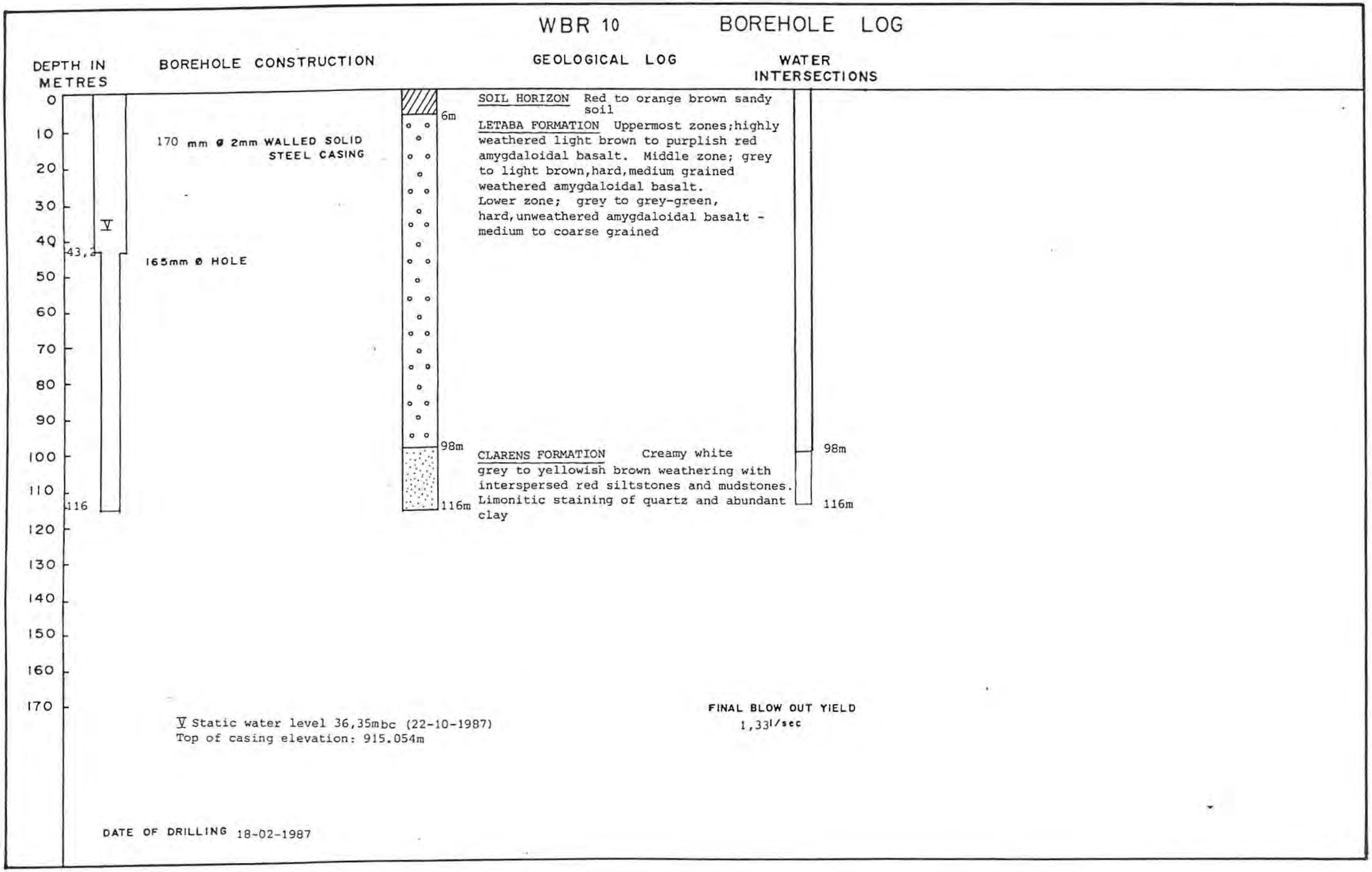
FINAL BLOW OUT YIELD
0,28 l/sec

⊻ Static water level 36,50mbc (23-10-1987)

Top of casing elevation: 919.085m

DATE OF DRILLING 17-02-1987

WBR 10 BOREHOLE LOG



SOIL HORIZON Red to orange brown sandy soil

LETABA FORMATION Uppermost zones; highly weathered light brown to purplish red amygdaloidal basalt. Middle zone; grey to light brown, hard, medium grained weathered amygdaloidal basalt. Lower zone; grey to grey-green, hard, unweathered amygdaloidal basalt - medium to coarse grained

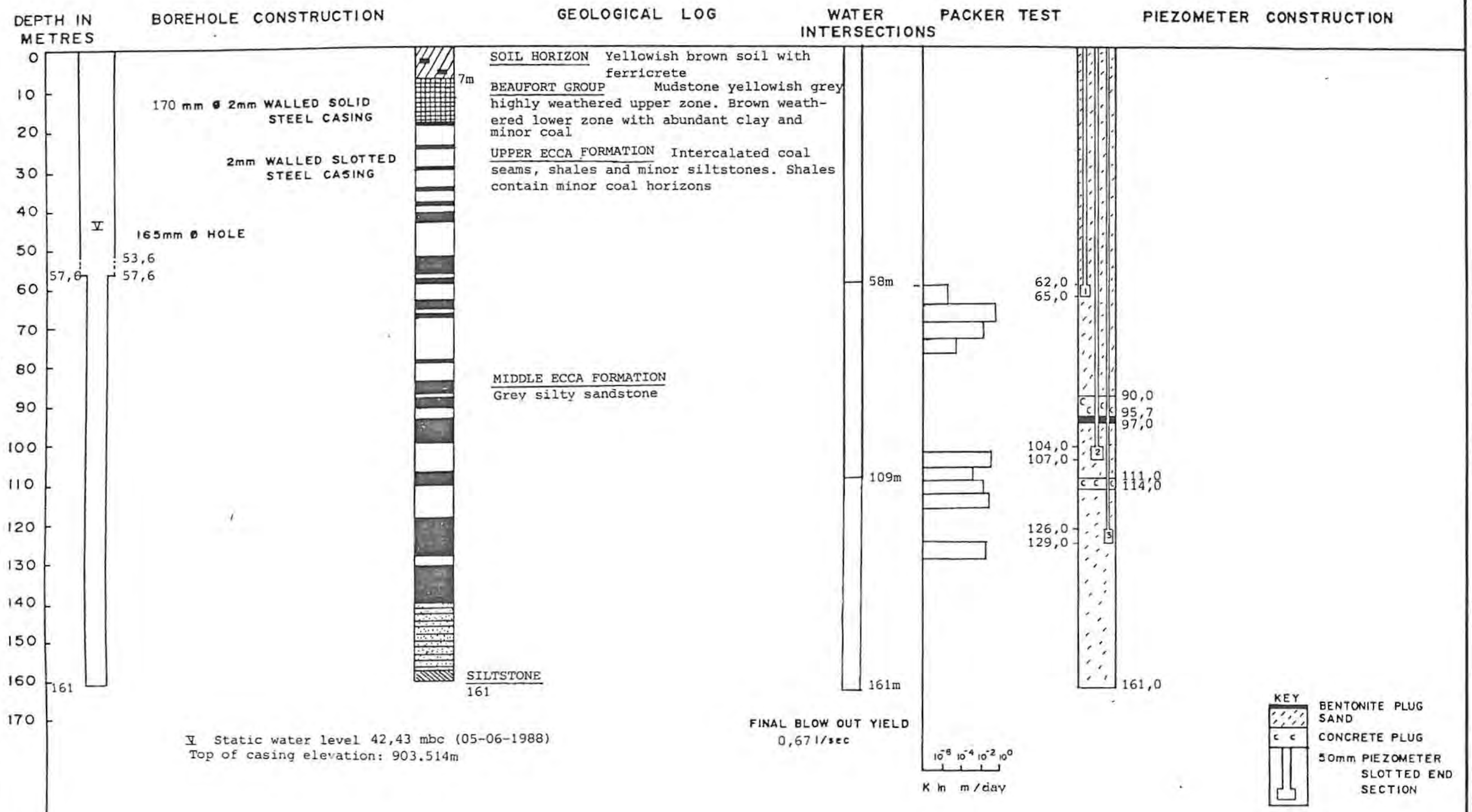
CLARENS FORMATION Creamy white grey to yellowish brown weathering with interspersed red siltstones and mudstones. Limonitic staining of quartz and abundant clay

⊽ Static water level 36,35mbc (22-10-1987)
Top of casing elevation: 915.054m

FINAL BLOW OUT YIELD
1,33l/sec

DATE OF DRILLING 18-02-1987

WBR 11 BOREHOLE LOG



SOIL HORIZON Yellowish brown soil with ferricrete

BEAUFORT GROUP Mudstone yellowish grey highly weathered upper zone. Brown weathered lower zone with abundant clay and minor coal

UPPER ECCA FORMATION Intercalated coal seams, shales and minor siltstones. Shales contain minor coal horizons

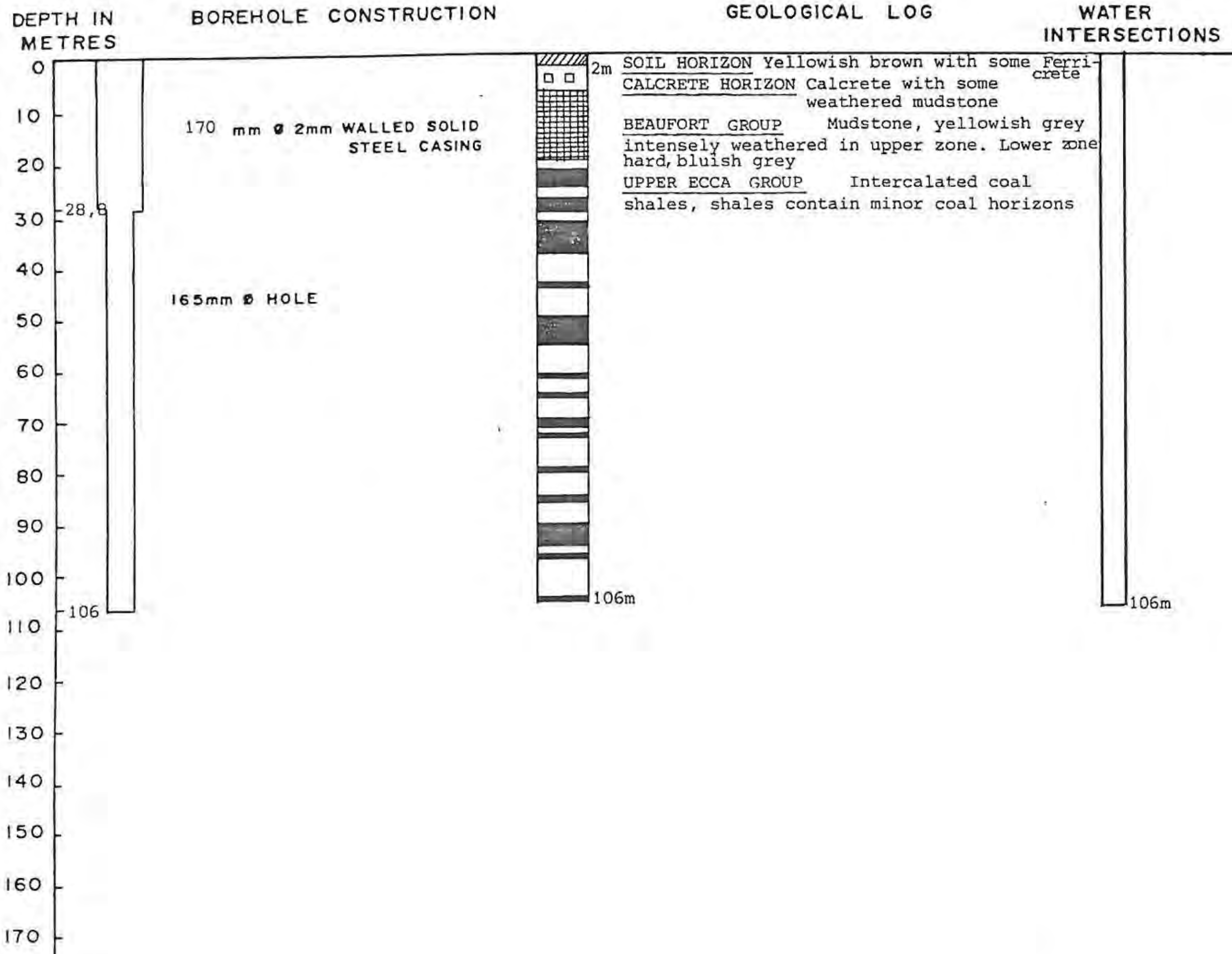
MIDDLE ECCA FORMATION Grey silty sandstone

▽ Static water level 42,43 mbc (05-06-1988)
Top of casing elevation: 903.514m

FINAL BLOW OUT YIELD
0,67 l/sec

DATE OF DRILLING 19-02-1987

WBR 12 BOREHOLE LOG



SOIL HORIZON Yellowish brown with some Ferricrete

CALCRETE HORIZON Calcrete with some weathered mudstone

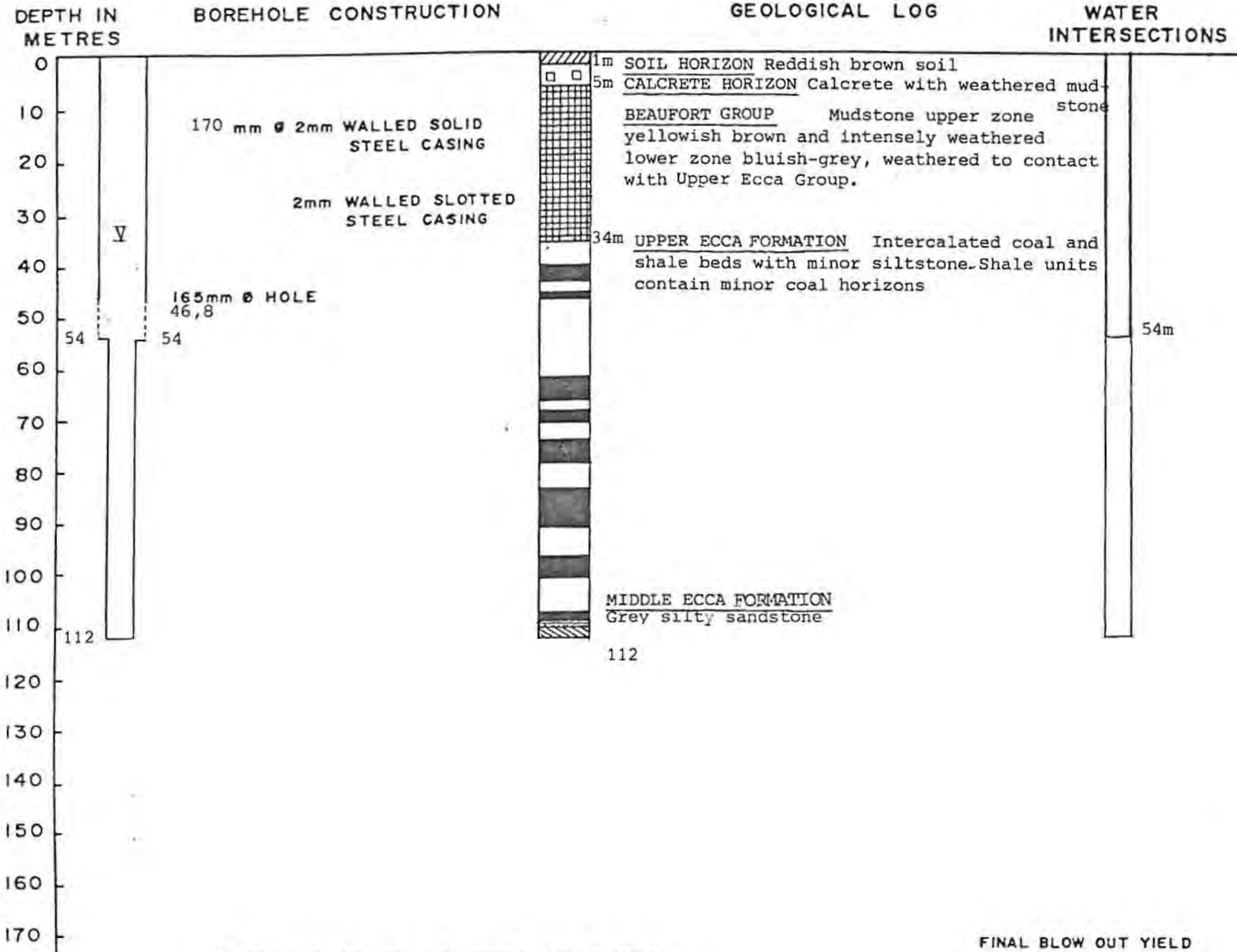
BEAUFORT GROUP Mudstone, yellowish grey intensely weathered in upper zone. Lower zone hard, bluish grey

UPPER ECCA GROUP Intercalated coal shales, shales contain minor coal horizons

Top of casing elevation: 903.378m

DATE OF DRILLING 21-02-1987

WBR 13 BOREHOLE LOG



SOIL HORIZON Reddish brown soil

CALCRETE HORIZON Calcrete with weathered mudstone

BEAUFORT GROUP Mudstone upper zone yellowish brown and intensely weathered lower zone bluish-grey, weathered to contact with Upper Ecca Group.

UPPER ECCA FORMATION Intercalated coal and shale beds with minor siltstone. Shale units contain minor coal horizons

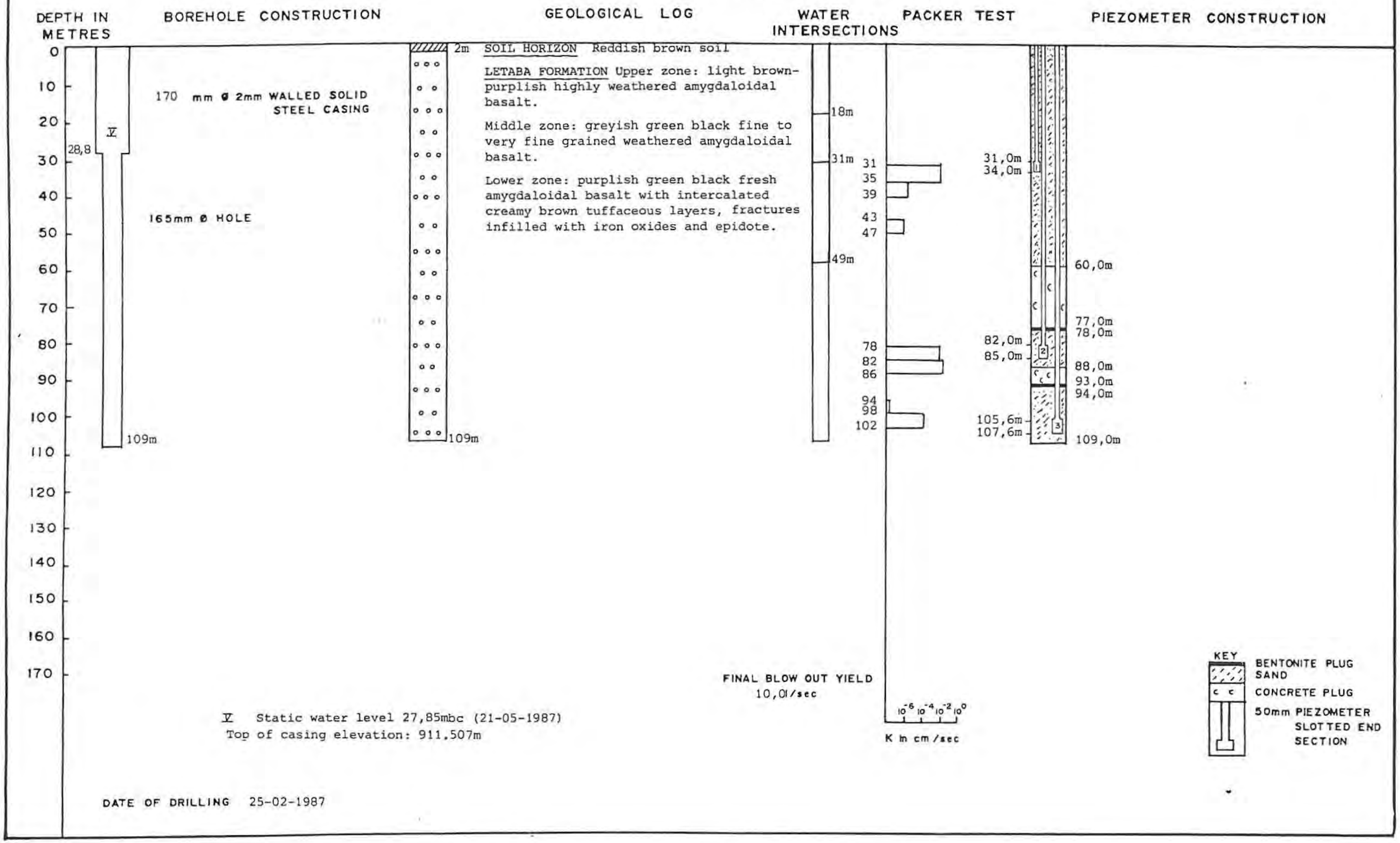
MIDDLE ECCA FORMATION
Grey silty sandstone

▽ Static water level 31,75mbc (21-10-1987)
Top of casing elevation: 906.608m

FINAL BLOW OUT YIELD
0,33 l/sec

DATE OF DRILLING 24-02-1987

WBR14 BOREHOLE LOG



SOIL HORIZON Reddish brown soil

LETABA FORMATION Upper zone: light brown-purplish highly weathered amygdaloidal basalt.

Middle zone: greyish green black fine to very fine grained weathered amygdaloidal basalt.

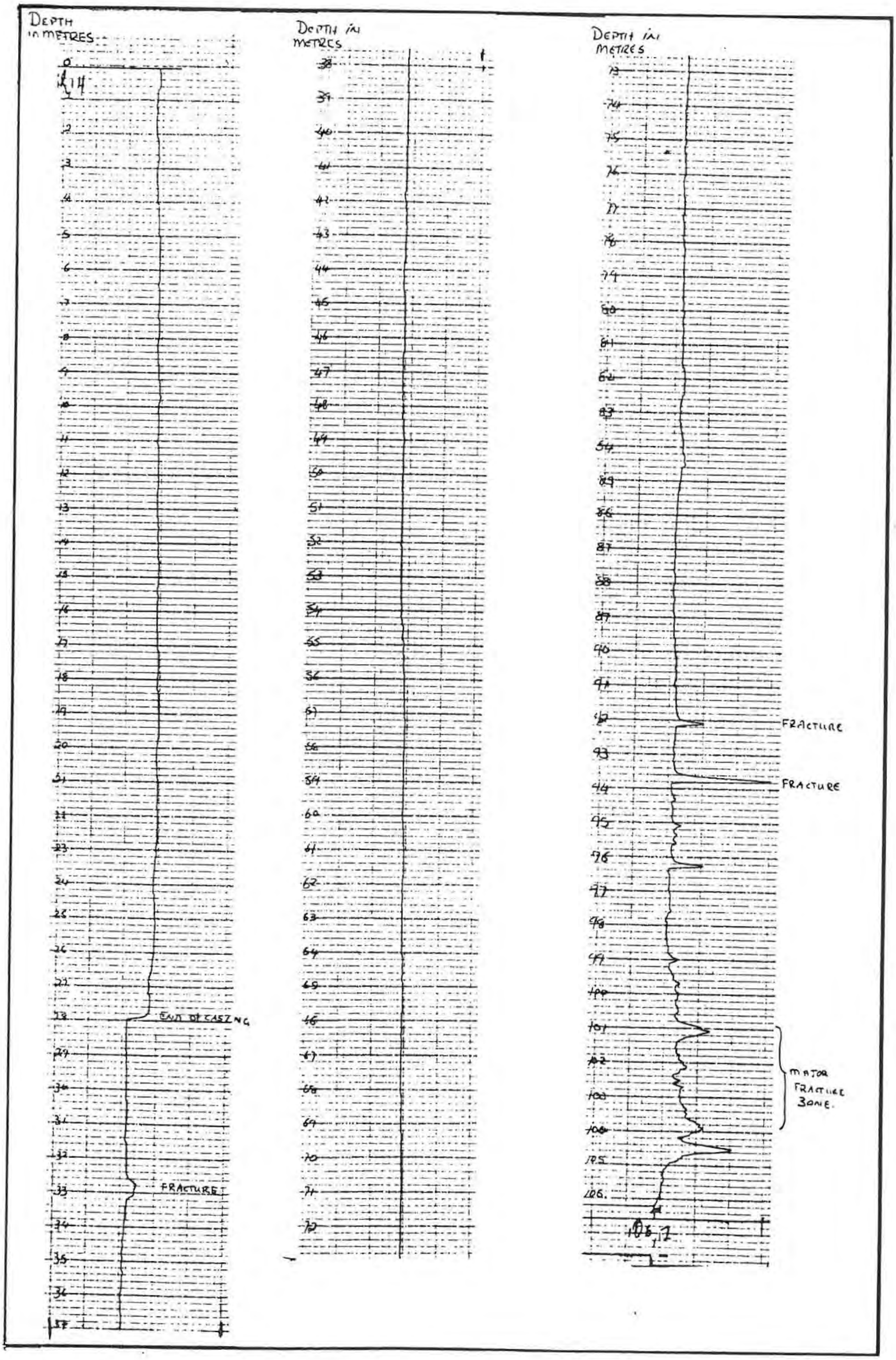
Lower zone: purplish green black fresh amygdaloidal basalt with intercalated creamy brown tuffaceous layers, fractures infilled with iron oxides and epidote.

FINAL BLOW OUT YIELD
10,0 l/sec

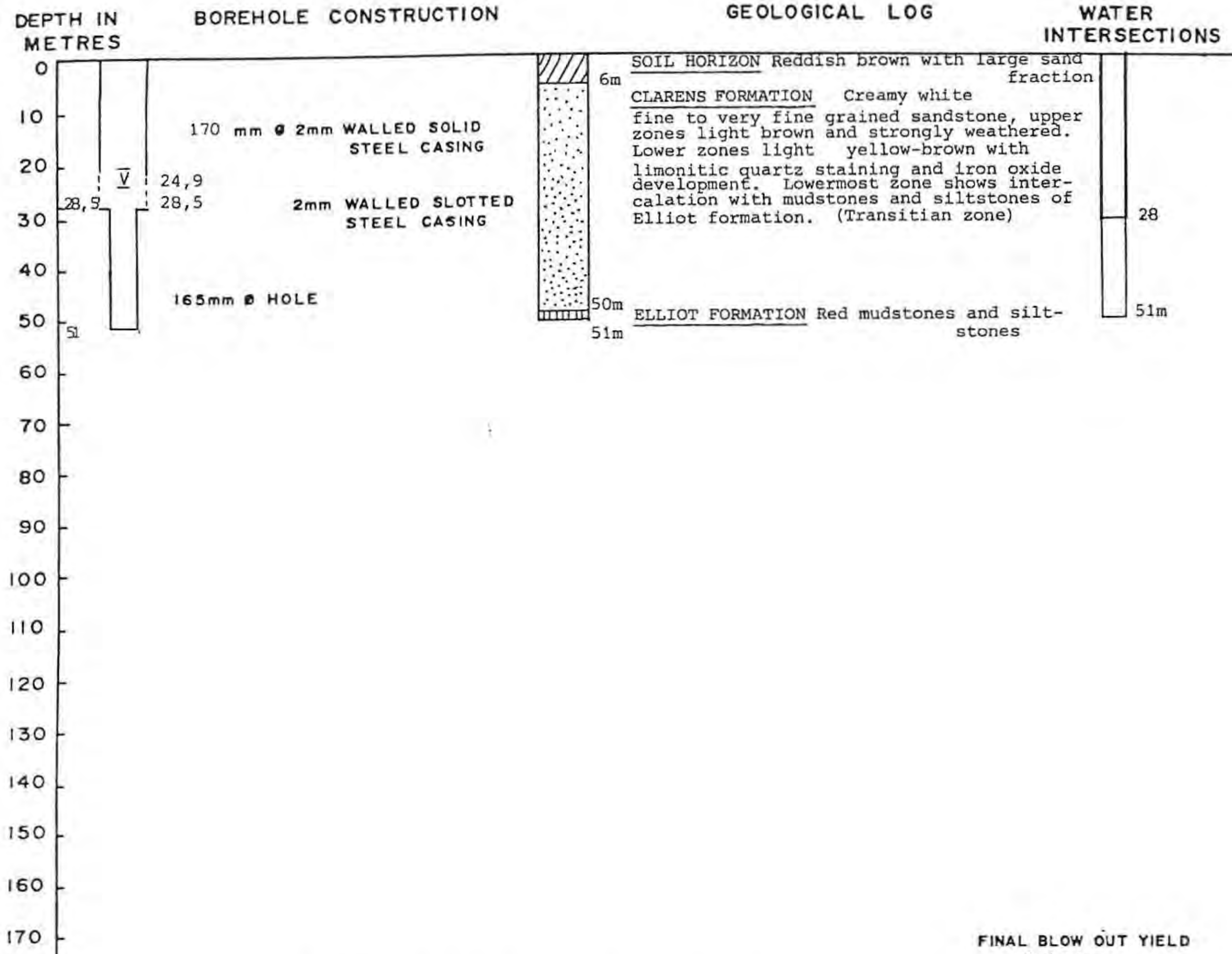
Ⅴ Static water level 27,85mbc (21-05-1987)
Top of casing elevation: 911,507m

DATE OF DRILLING 25-02-1987

CALIPER LOG OF BOREHOLE WBR 14



WBR 15 BOREHOLE LOG



SOIL HORIZON Reddish brown with large sand fraction

CLARENS FORMATION Creamy white fine to very fine grained sandstone, upper zones light brown and strongly weathered. Lower zones light yellow-brown with limonitic quartz staining and iron oxide development. Lowermost zone shows intercalation with mudstones and siltstones of Elliot formation. (Transitian zone)

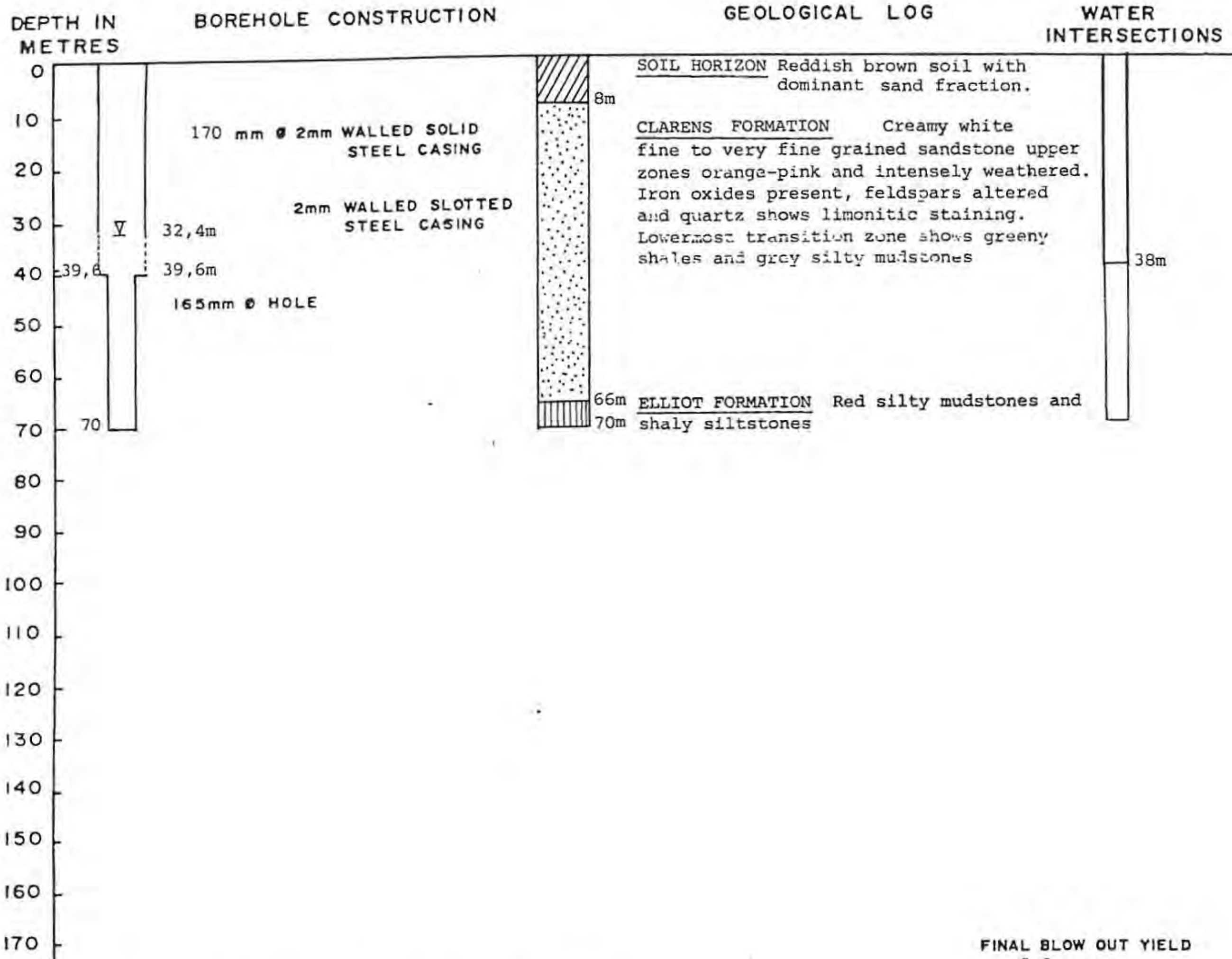
ELLIOT FORMATION Red mudstones and siltstones

FINAL BLOW OUT YIELD
2,0 l/sec

$\underline{\text{V}}$ Static water level 20,20mbc (09-10-1987)
Top of casing elevation: 902.242m

DATE OF DRILLING 26-02-1987

WBR 16 BOREHOLE LOG



SOIL HORIZON Reddish brown soil with dominant sand fraction.

CLARENS FORMATION Creamy white fine to very fine grained sandstone upper zones orange-pink and intensely weathered. Iron oxides present, feldspars altered and quartz shows limonitic staining. Lowermost transition zone shows greeny shales and grey silty mudstones

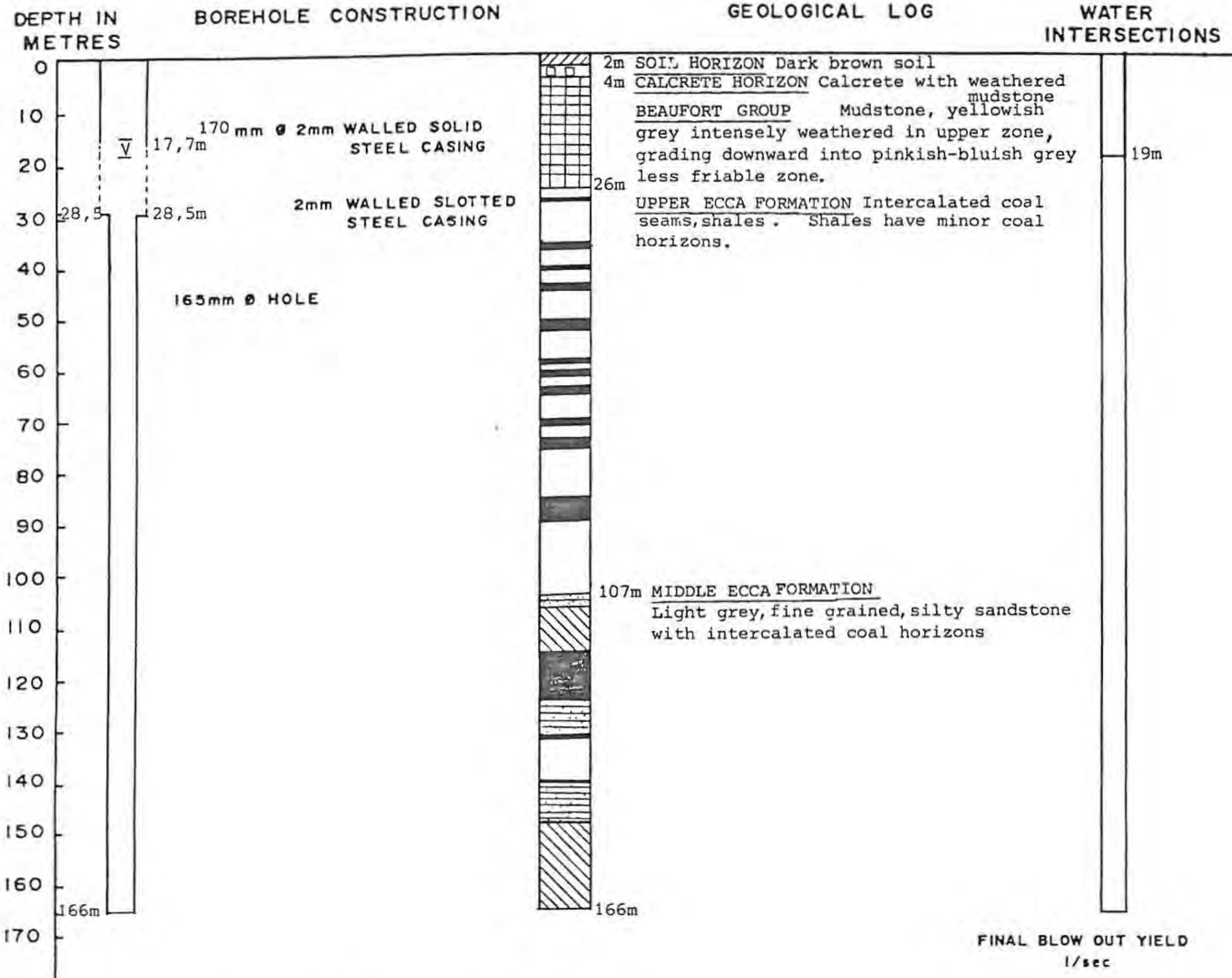
ELLIOT FORMATION Red silty mudstones and shaly siltstones

FINAL BLOW OUT YIELD
0,8 l/sec

∇ Static water level 31,97mbc (07-10-1987)
Top of casing elevation: 908.681m

DATE OF DRILLING 26-02-1987

WBR 17 BOREHOLE LOG



2m SOIL HORIZON Dark brown soil

4m CALCRETE HORIZON Calcrete with weathered mudstone

BEAUFORT GROUP Mudstone, yellowish grey intensely weathered in upper zone, grading downward into pinkish-bluish grey less friable zone.

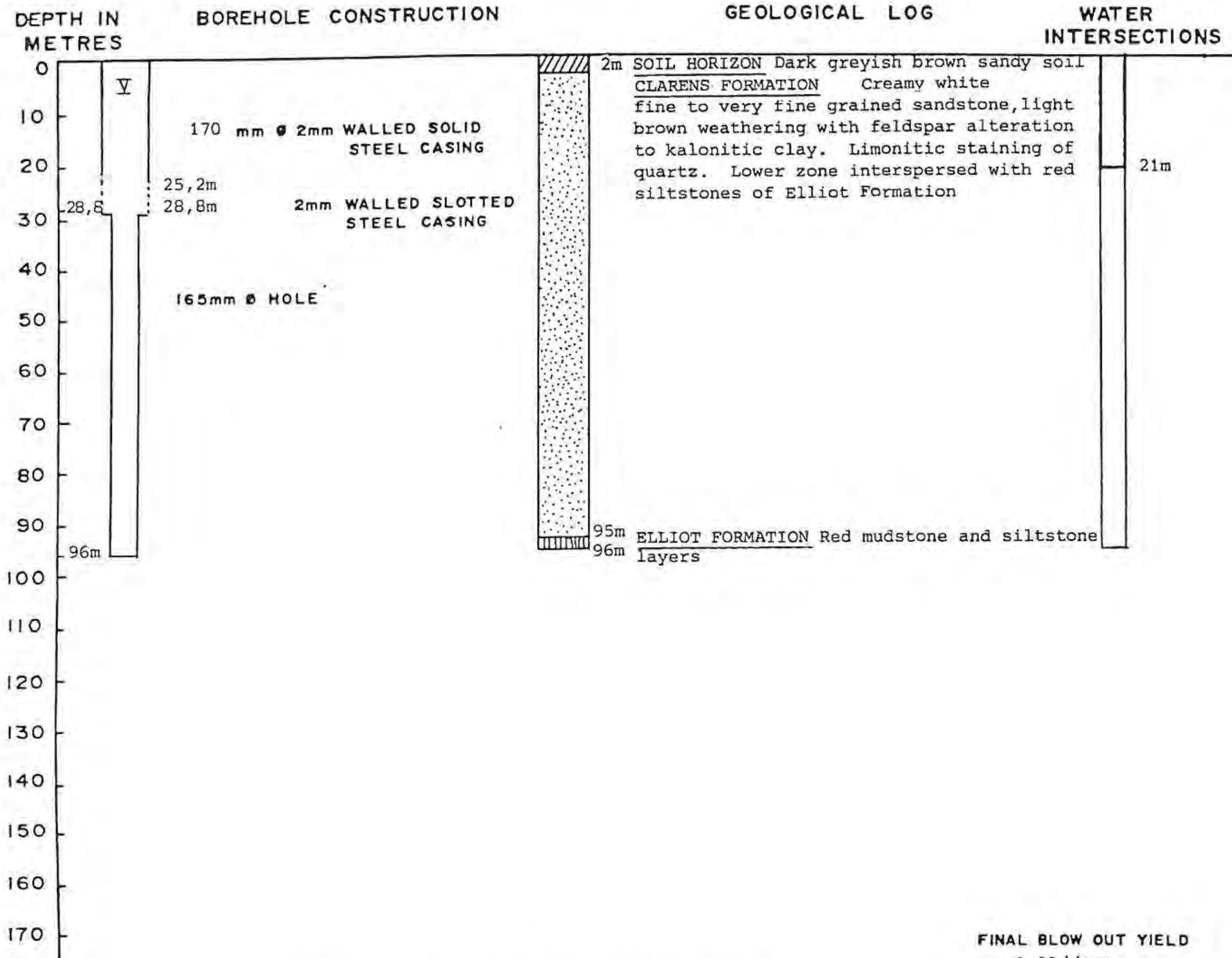
26m UPPER ECCA FORMATION Intercalated coal seams, shales. Shales have minor coal horizons.

107m MIDDLE ECCA FORMATION Light grey, fine grained, silty sandstone with intercalated coal horizons

V Static water level 18,43mbc (19-10-1987)
Top of casing elevation: 894.385m

DATE OF DRILLING

WBR 18 BOREHOLE LOG



SOIL HORIZON Dark greyish brown sandy soil

CLARENS FORMATION Creamy white fine to very fine grained sandstone, light brown weathering with feldspar alteration to kalonitic clay. Limonitic staining of quartz. Lower zone interspersed with red siltstones of Elliot Formation

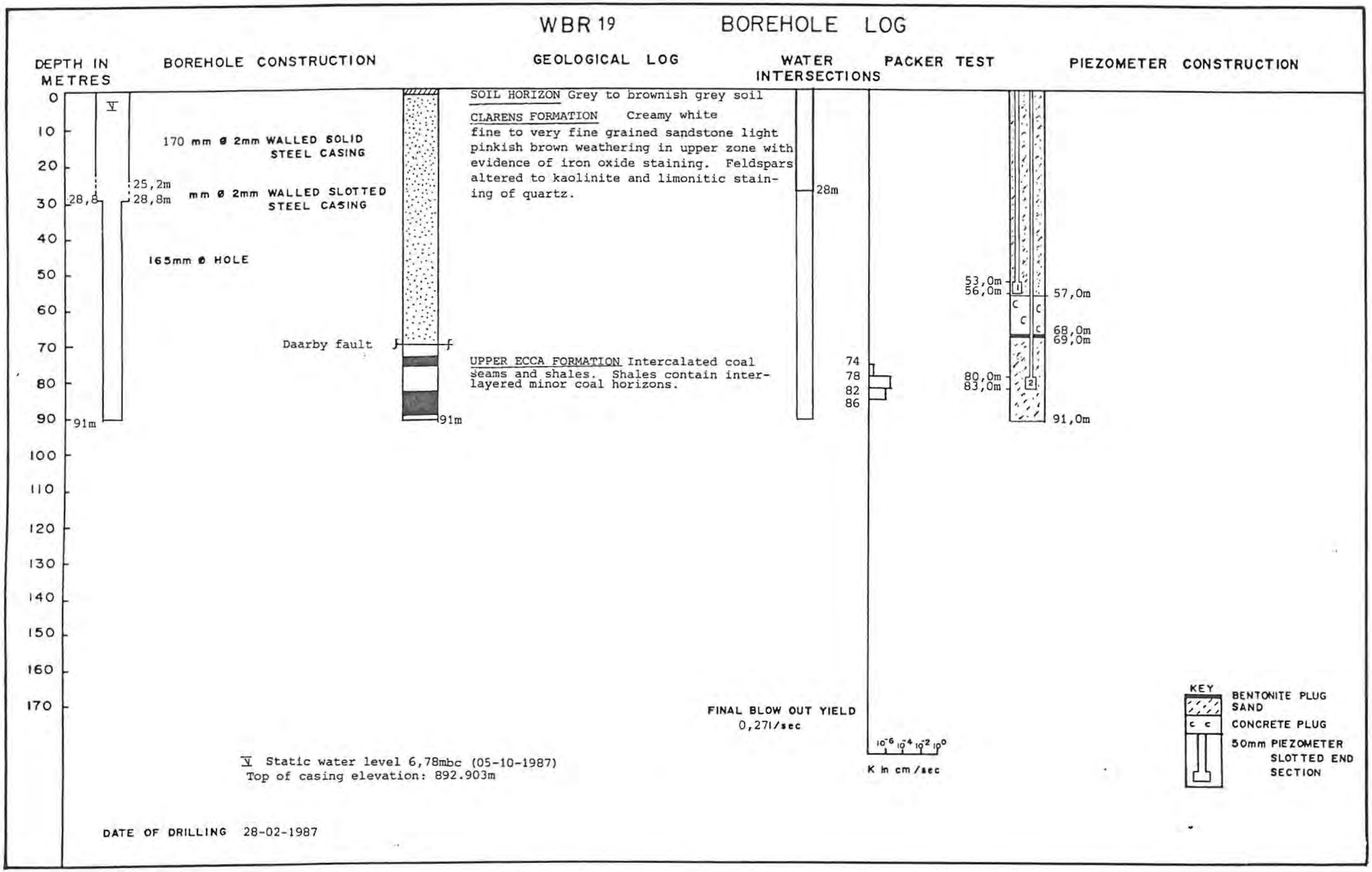
ELLIOT FORMATION Red mudstone and siltstone layers

FINAL BLOW OUT YIELD
0,33 l/sec

∇ Static water level 5.63m bc (24.10.1987)
Top of casing elevation: 892.981m

DATE OF DRILLING 27-02-1987

WBR 19 BOREHOLE LOG



SOIL HORIZON Grey to brownish grey soil

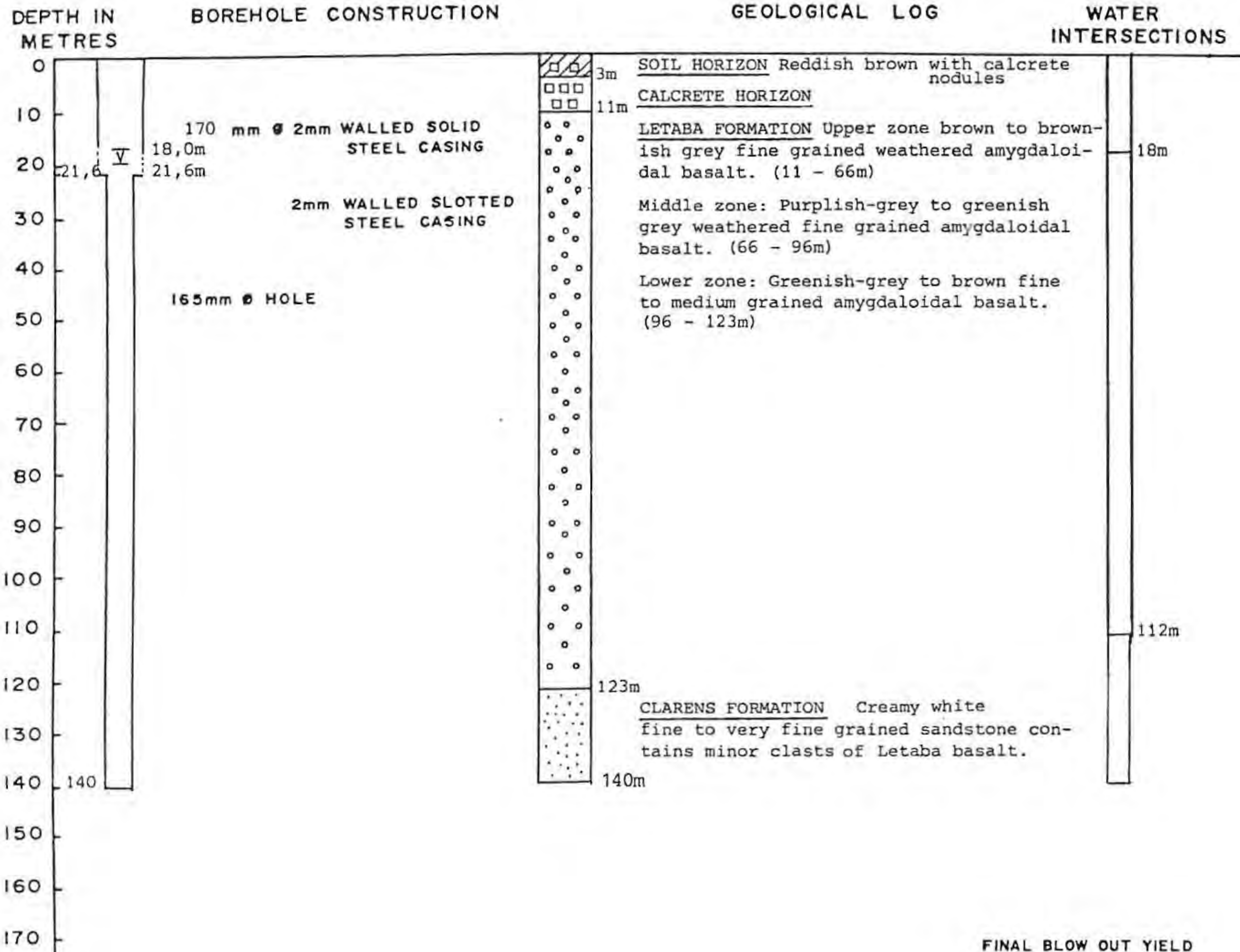
CLARENS FORMATION Creamy white fine to very fine grained sandstone light pinkish brown weathering in upper zone with evidence of iron oxide staining. Feldspars altered to kaolinite and limonitic staining of quartz.

UPPER ECCA FORMATION Intercalated coal seams and shales. Shales contain interlayered minor coal horizons.

Ɐ Static water level 6,78mbc (05-10-1987)
Top of casing elevation: 892.903m

DATE OF DRILLING 28-02-1987

WBR 20 BOREHOLE LOG



SOIL HORIZON Reddish brown with calcrete nodules

CALCRETE HORIZON

LETABA FORMATION Upper zone brown to brownish grey fine grained weathered amygdaloidal basalt. (11 - 66m)

Middle zone: Purplish-grey to greenish grey weathered fine grained amygdaloidal basalt. (66 - 96m)

Lower zone: Greenish-grey to brown fine to medium grained amygdaloidal basalt. (96 - 123m)

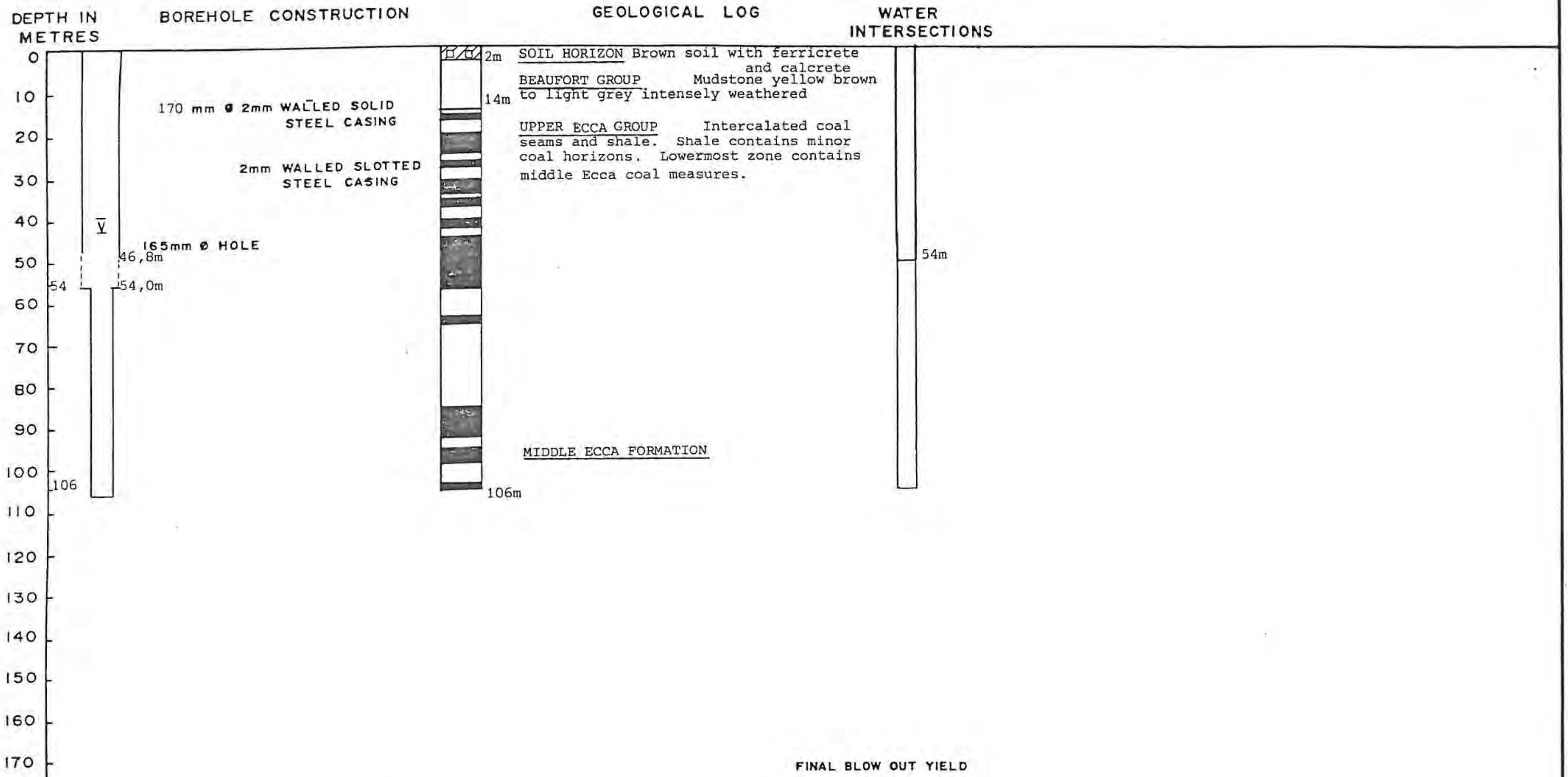
CLARENS FORMATION Creamy white fine to very fine grained sandstone contains minor clasts of Letaba basalt.

FINAL BLOW OUT YIELD
0,67l/sec

∇ Static water level 18,76mbc (20-10-1987)
Top of casing elevation: 903.789m

DATE OF DRILLING 02-03-1987

WBR 21 BOREHOLE LOG



SOIL HORIZON Brown soil with ferricrete and calcrete

BEAUFORT GROUP Mudstone yellow brown to light grey intensely weathered

UPPER ECCA GROUP Intercalated coal seams and shale. Shale contains minor coal horizons. Lowermost zone contains middle Ecca coal measures.

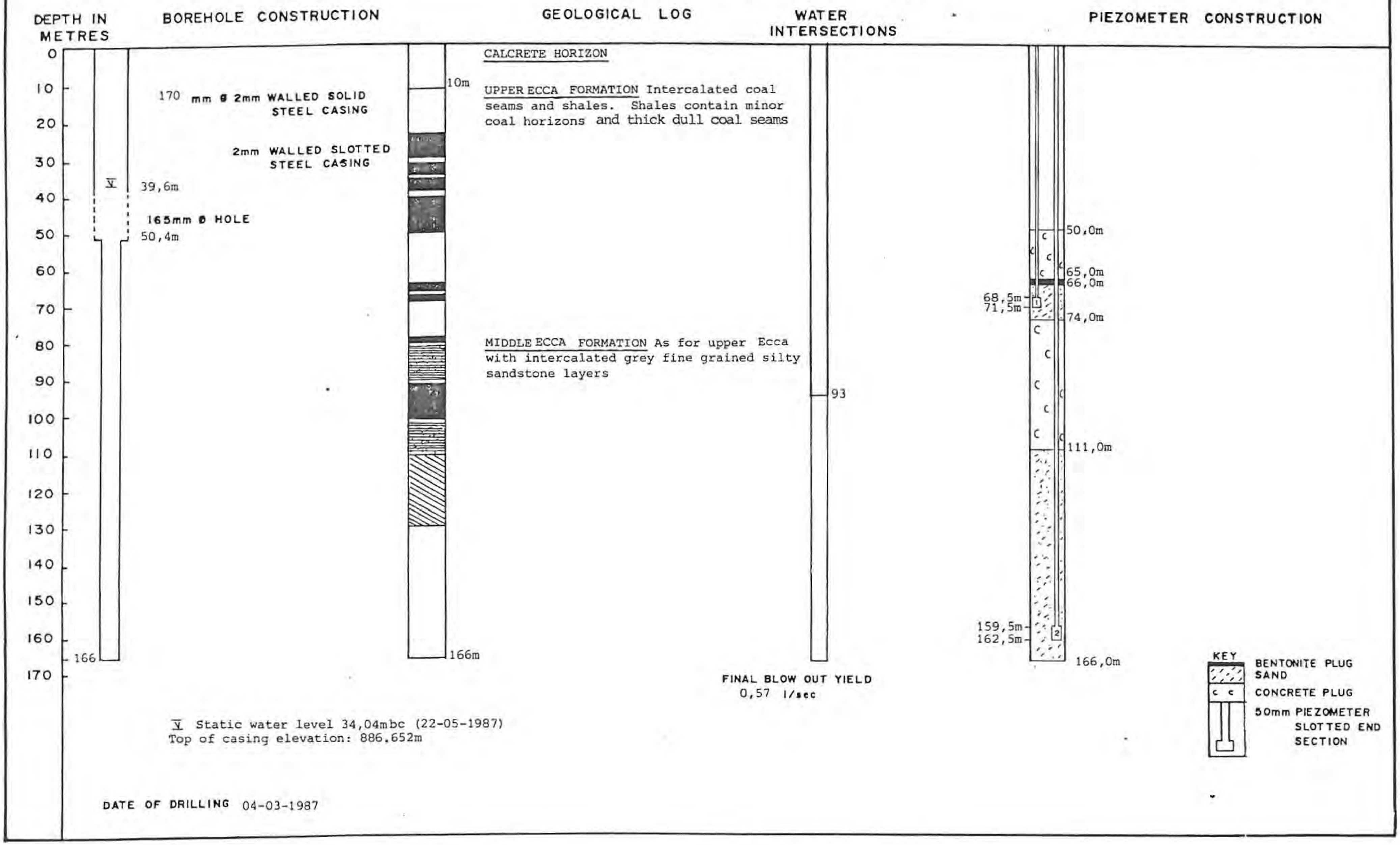
MIDDLE ECCA FORMATION

FINAL BLOW OUT YIELD
0,33 l/sec

V Static water level 40.42mbc (26-10-1987)
Top of casing elevation: 899.554m

DATE OF DRILLING 04-03-1987

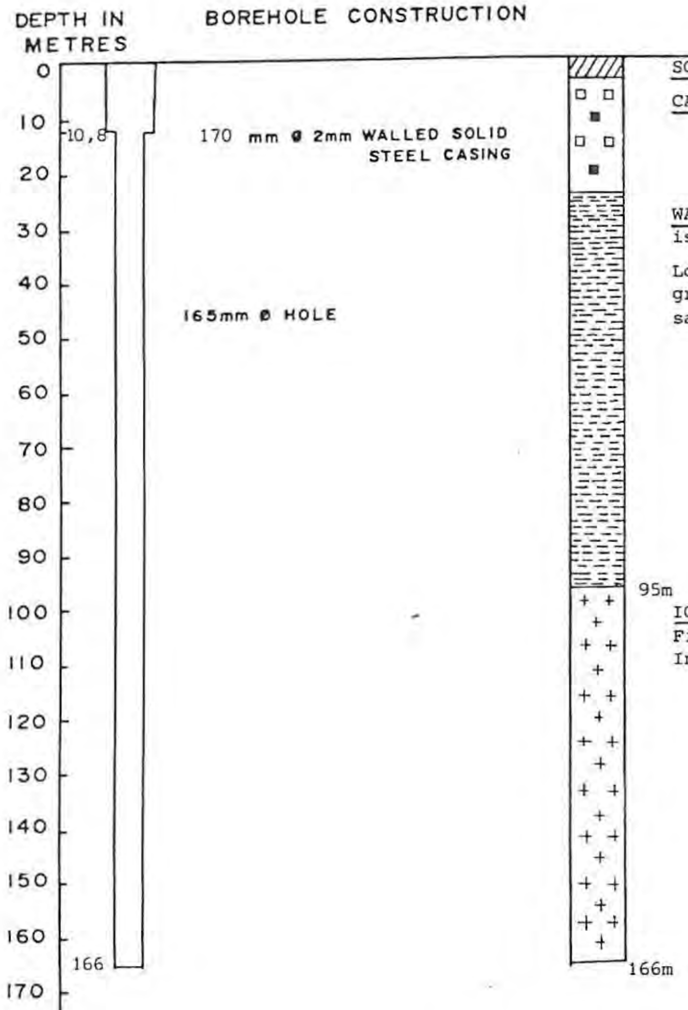
WBR 22 BOREHOLE LOG



⊻ Static water level 34,04mbc (22-05-1987)
Top of casing elevation: 886.652m

DATE OF DRILLING 04-03-1987

WBR 23 BOREHOLE LOG



SOIL HORIZON Reddish-yellowish brown soil

CALCRETE Calcrete with ferricrete

WATERBERG GROUP Upper layers light yellowish brown fine to medium grained sandstone.

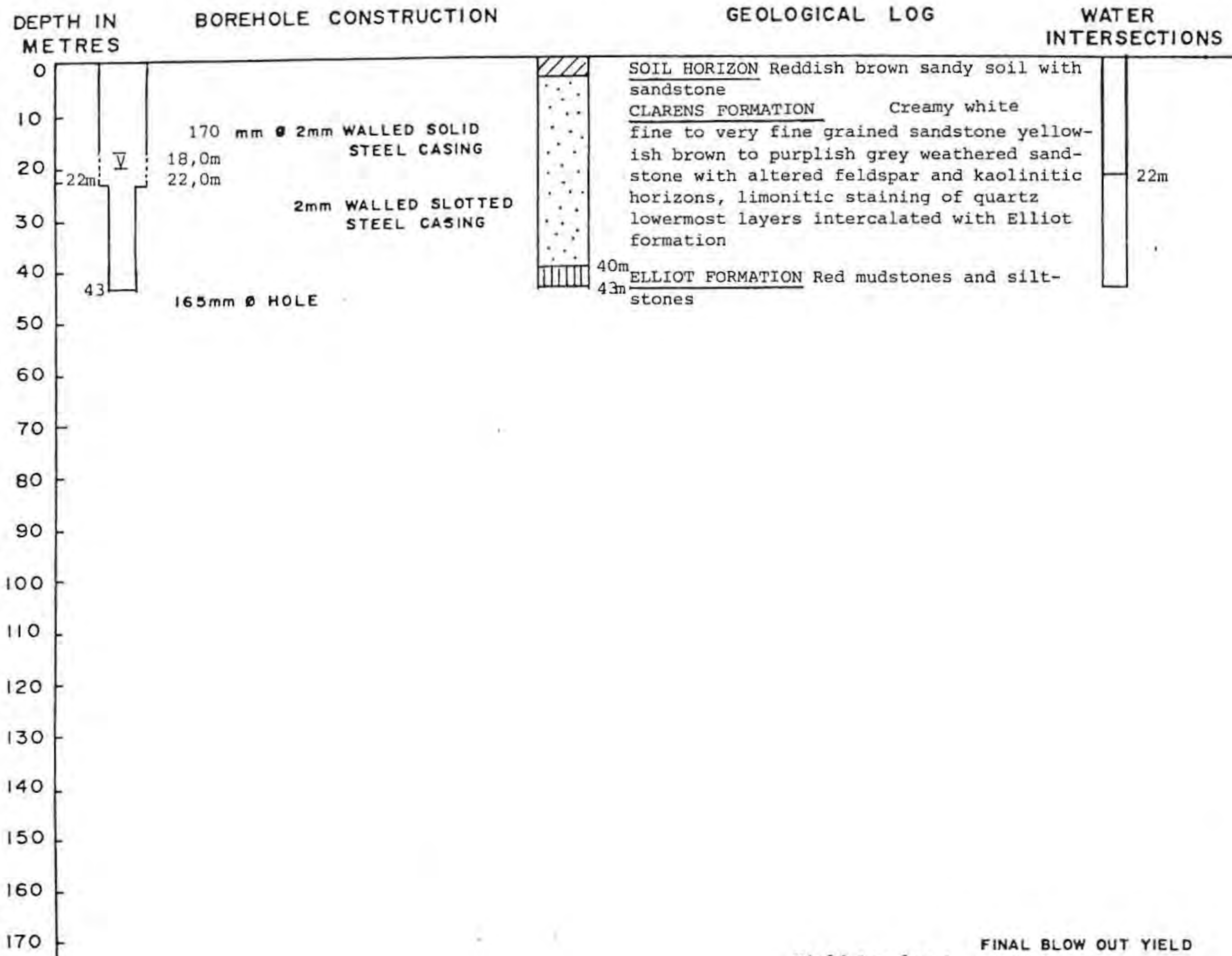
Lower layers light greenish grey to greenish brown medium to coarse grained sandstone.

IGNEOUS INTRUSIVE
Fine grained dark green to black dolerite.
Interpreted as dolerite dyke.

DRY HOLE

DATE OF DRILLING 06-03-1987

WBR 24 BOREHOLE LOG



SOIL HORIZON Reddish brown sandy soil with sandstone

CLARENS FORMATION Creamy white fine to very fine grained sandstone yellowish brown to purplish grey weathered sandstone with altered feldspar and kaolinitic horizons, limonitic staining of quartz lowermost layers intercalated with Elliot formation

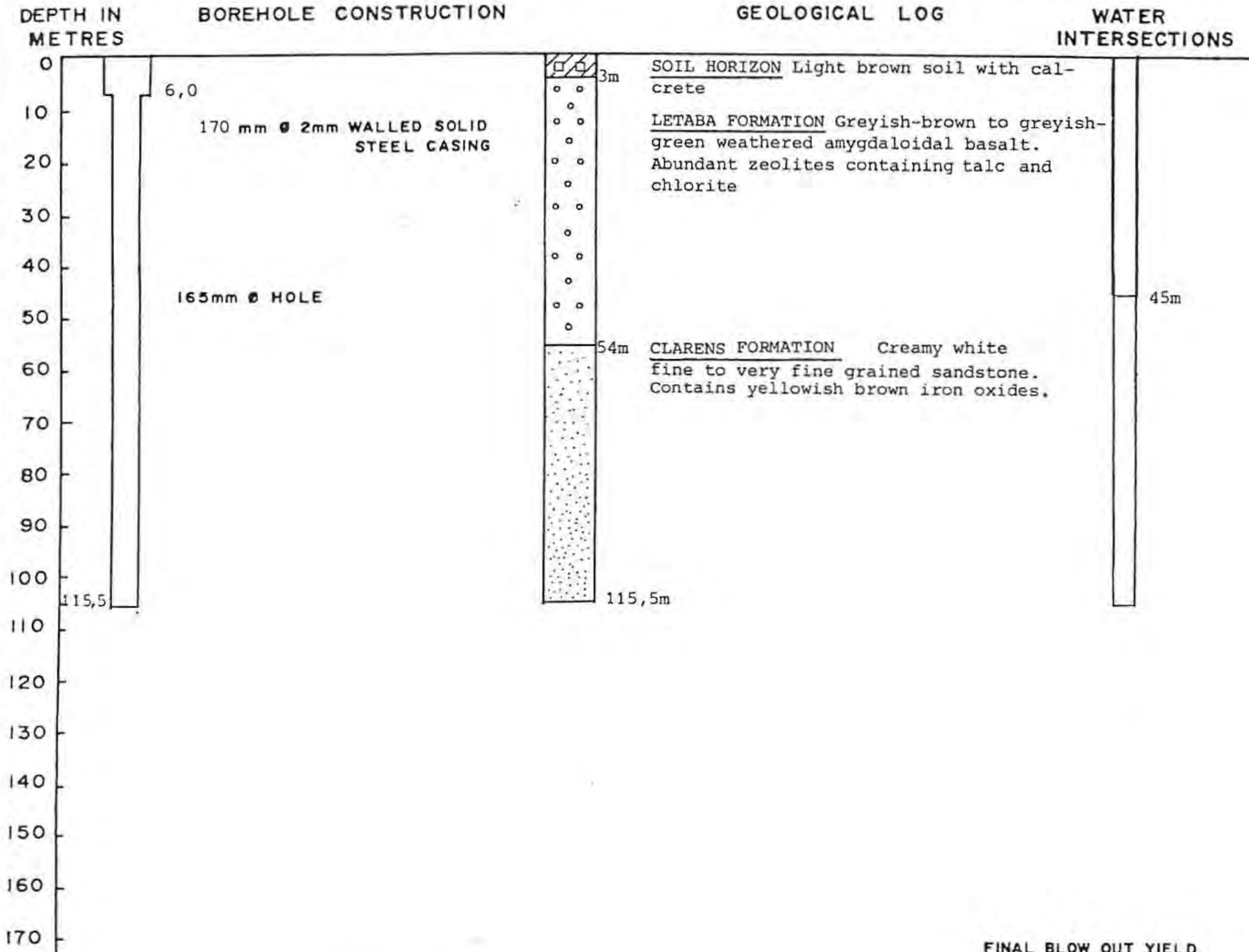
ELLIOT FORMATION Red mudstones and siltstones

FINAL BLOW OUT YIELD
Yield too low to measure l/sec

⊻ Static water level 19,60mbc (06-10-1987)
Top of casing elevation: 887.270m

DATE OF DRILLING 06-03-1987

WB 25 BOREHOLE LOG



SOIL HORIZON Light brown soil with calcrete

LETABA FORMATION Greyish-brown to greyish-green weathered amygdaloidal basalt. Abundant zeolites containing talc and chlorite

CLARENS FORMATION Creamy white fine to very fine grained sandstone. Contains yellowish brown iron oxides.

FINAL BLOW OUT YIELD
2,5 l/sec

⊻ Static water level
Top of casing elevation: 895.300m

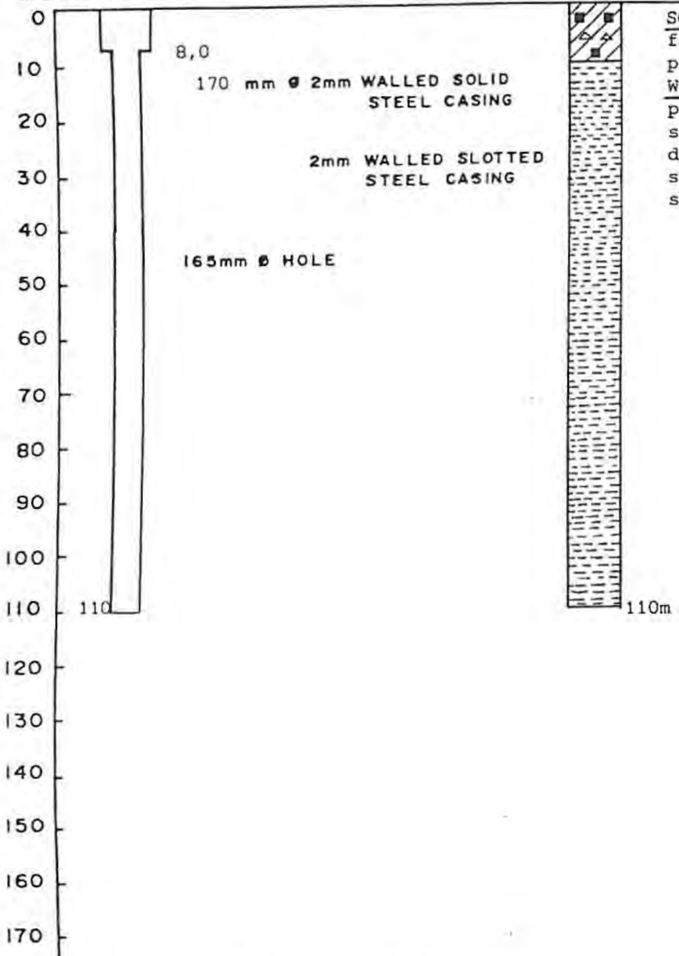
DATE OF DRILLING 20-08-1987

WB 26 BOREHOLE LOG

DEPTH IN METRES

BOREHOLE CONSTRUCTION

GEOLOGICAL LOG



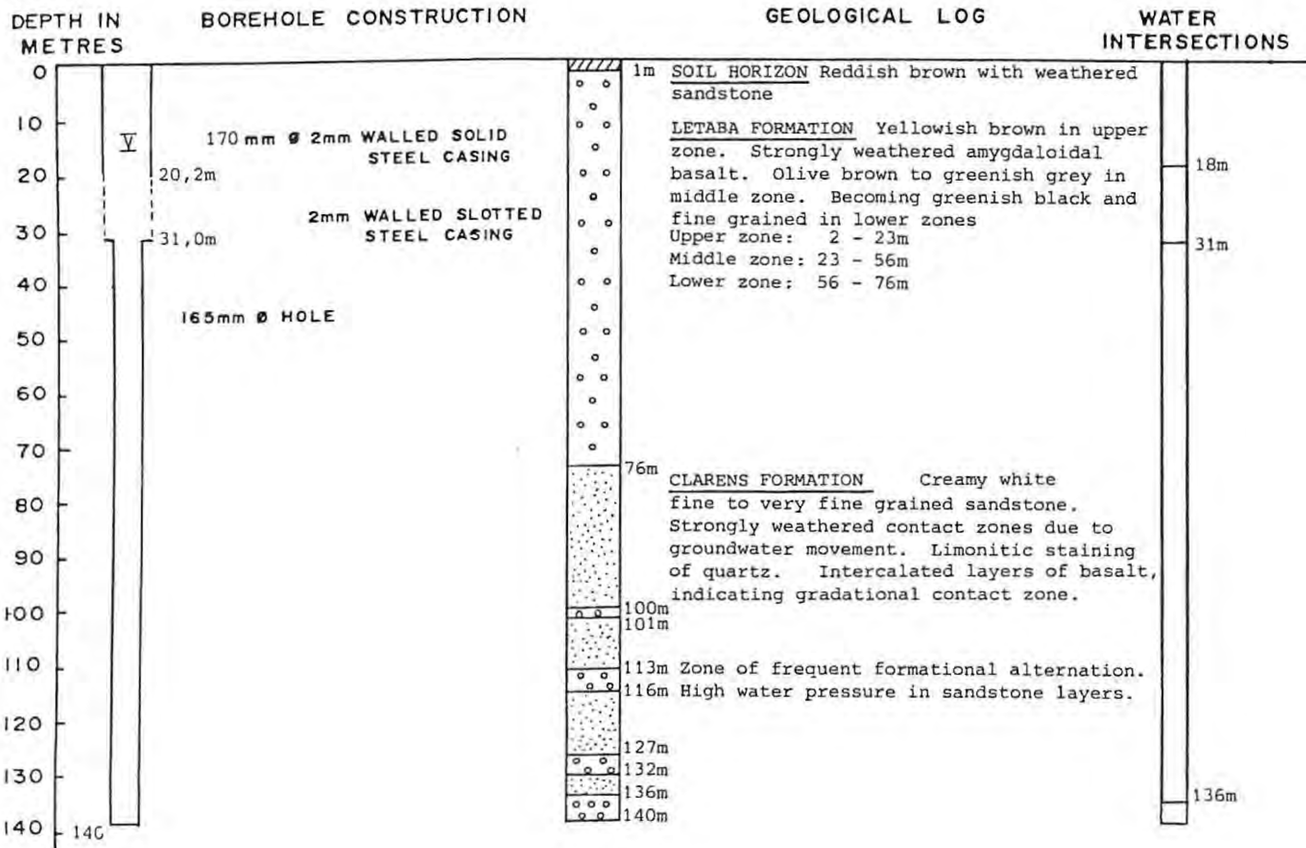
SOIL HORIZON Reddish brown sandy soil with ferricrete nodules and unconsolidated large pebbles with iron oxide staining

WATERBERG GROUP Sandy light brown, to pinkish white fine to medium grained sandstone. Contains pebbles up to 4cm in diameter, clayey quartzitic horizons and silty horizons. Pebbles show iron oxide staining

Top of casing elevation: 902.073m

DATE OF DRILLING 07-02-1987

WB 27 BOREHOLE LOG



SOIL HORIZON Reddish brown with weathered sandstone

LETABA FORMATION Yellowish brown in upper zone. Strongly weathered amygdaloidal basalt. Olive brown to greenish grey in middle zone. Becoming greenish black and fine grained in lower zones

Upper zone: 2 - 23m
Middle zone: 23 - 56m
Lower zone: 56 - 76m

CLARENS FORMATION Creamy white fine to very fine grained sandstone. Strongly weathered contact zones due to groundwater movement. Limonitic staining of quartz. Intercalated layers of basalt, indicating gradational contact zone.

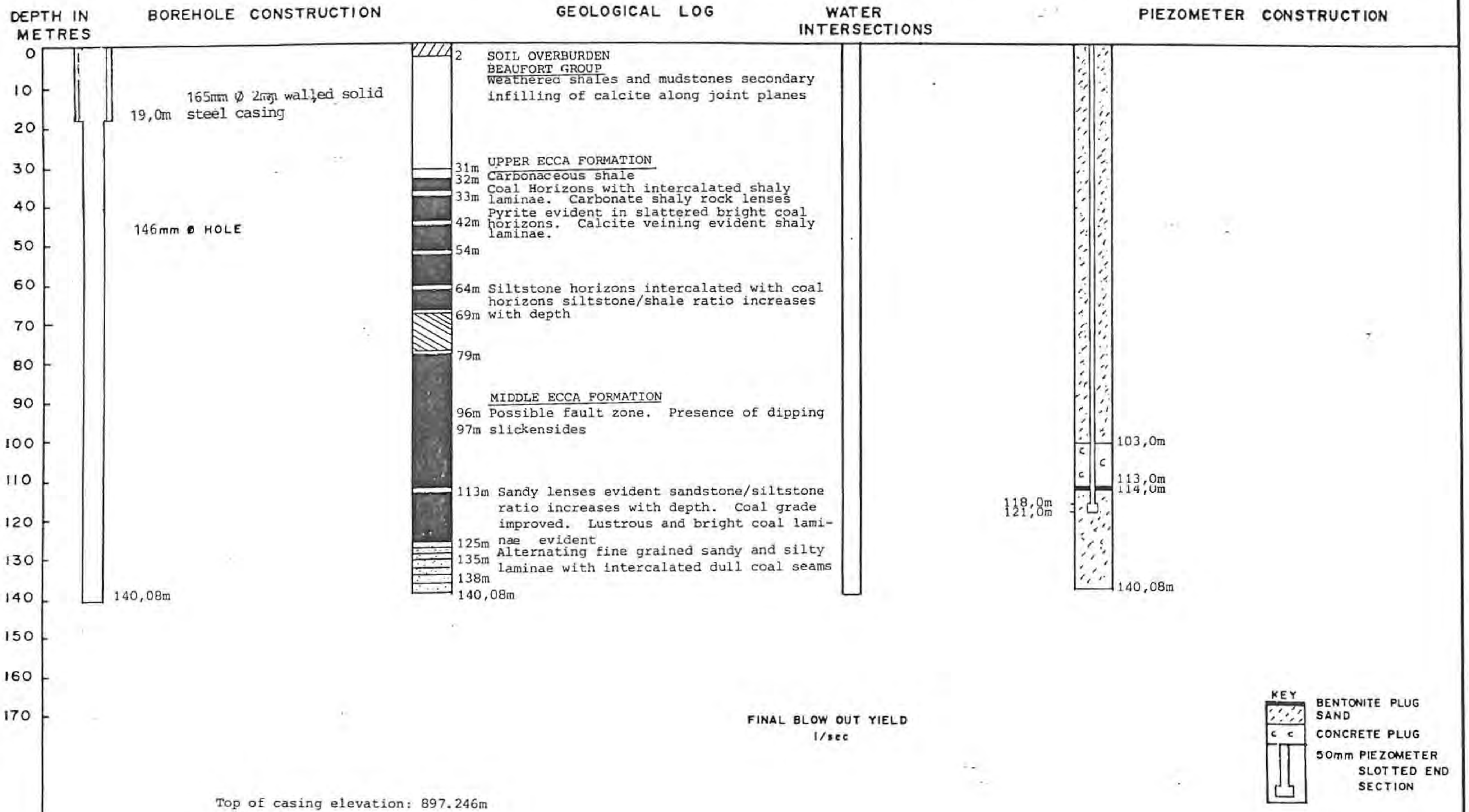
113m Zone of frequent formational alternation.
116m High water pressure in sandstone layers.

FINAL BLOW OUT YIELD
12,4 l/sec

Ṿ Static water level 13,83mbc (20-05-1987)

DATE OF DRILLING 03-03-1987

ET 124 BOREHOLE LOG



SOIL OVERBURDEN

BEAUFORT GROUP

Weathered shales and mudstones secondary infilling of calcite along joint planes

UPPER ECCA FORMATION

Carbonaceous shale

Coal Horizons with intercalated shaly laminae. Carbonate shaly rock lenses

Pyrite evident in slattered bright coal horizons. Calcite veining evident shaly laminae.

Siltstone horizons intercalated with coal horizons siltstone/shale ratio increases with depth

MIDDLE ECCA FORMATION

Possible fault zone. Presence of dipping slickensides

Sandy lenses evident sandstone/siltstone ratio increases with depth. Coal grade improved. Lustrous and bright coal laminae evident

Alternating fine grained sandy and silty laminae with intercalated dull coal seams

Top of casing elevation: 897.246m

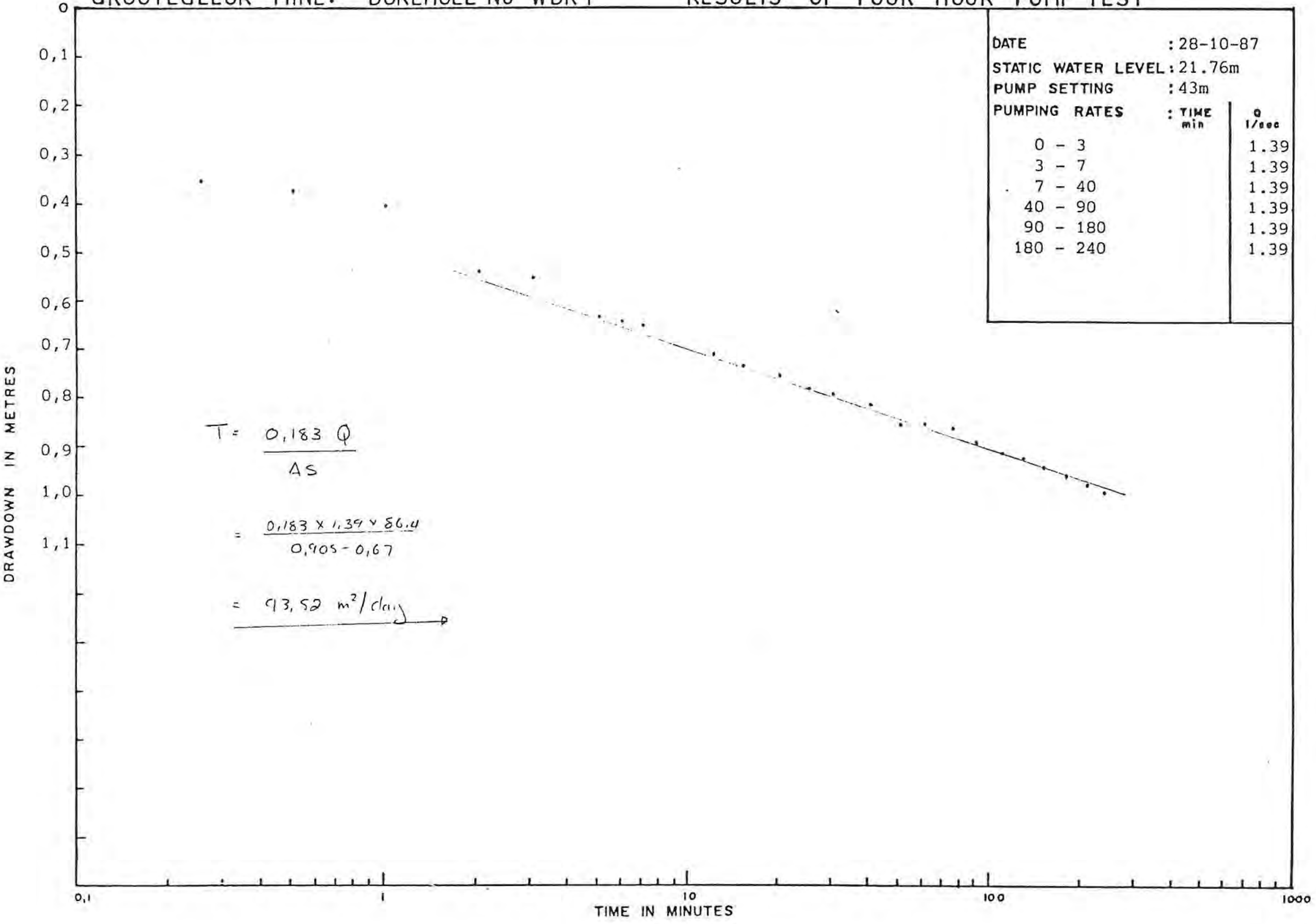
DATE OF DRILLING : EXPLORATION BOREHOLE

APPENDIX 5

WBR BOREHOLE TIME VERSUS WATER LEVEL AND T/T^1 PLOTS FOR DRAWDOWN AND RECOVERY AQUIFER TESTS

(Calculations of the transmissivity values are shown on each of the plots)

GROOTEGELUK MINE: BOREHOLE No WBR 1 RESULTS OF FOUR HOUR PUMP TEST



DATE : 28-10-87

STATIC WATER LEVEL : 21.76m

PUMP SETTING : 43m

PUMPING RATES :

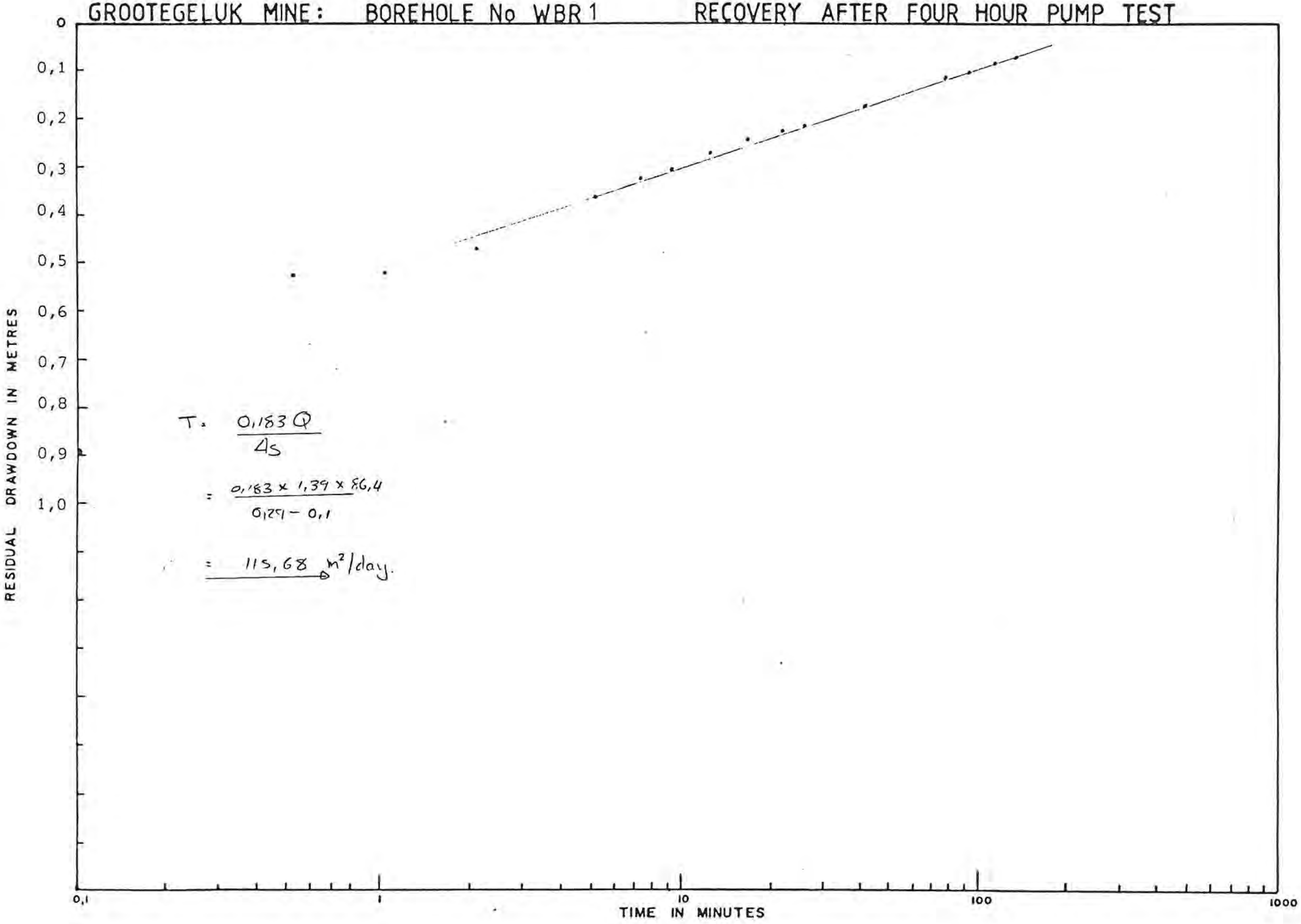
TIME min	Q l/sec
0 - 3	1.39
3 - 7	1.39
7 - 40	1.39
40 - 90	1.39
90 - 180	1.39
180 - 240	1.39

$$T = \frac{0,183\ Q}{\Delta S}$$

$$= \frac{0,183 \times 1,39 \times 86,4}{0,905 - 0,67}$$

$$= 93,52\ m^2/day$$

GROOTEGELUK MINE: BOREHOLE No WBR 1 RECOVERY AFTER FOUR HOUR PUMP TEST

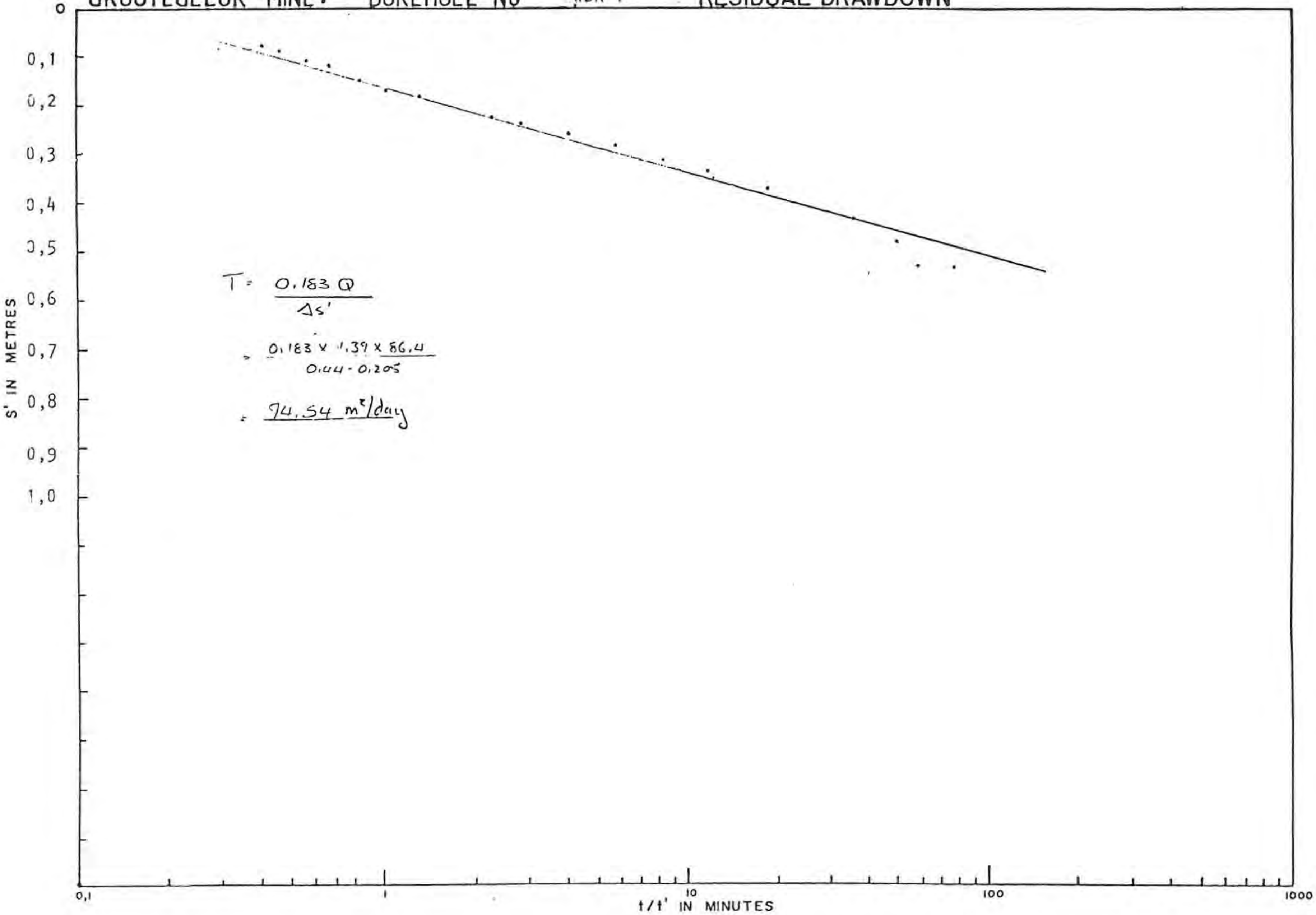


$$T = \frac{0{,}183\,Q}{\Delta s}$$

$$= \frac{0{,}183 \times 1{,}39 \times 86{,}4}{0{,}129 - 0{,}1}$$

$$= \underline{115{,}68} \ m^2/day.$$

GROOTEGELUK MINE: BOREHOLE No WBR 1 RESIDUAL DRAWDOWN

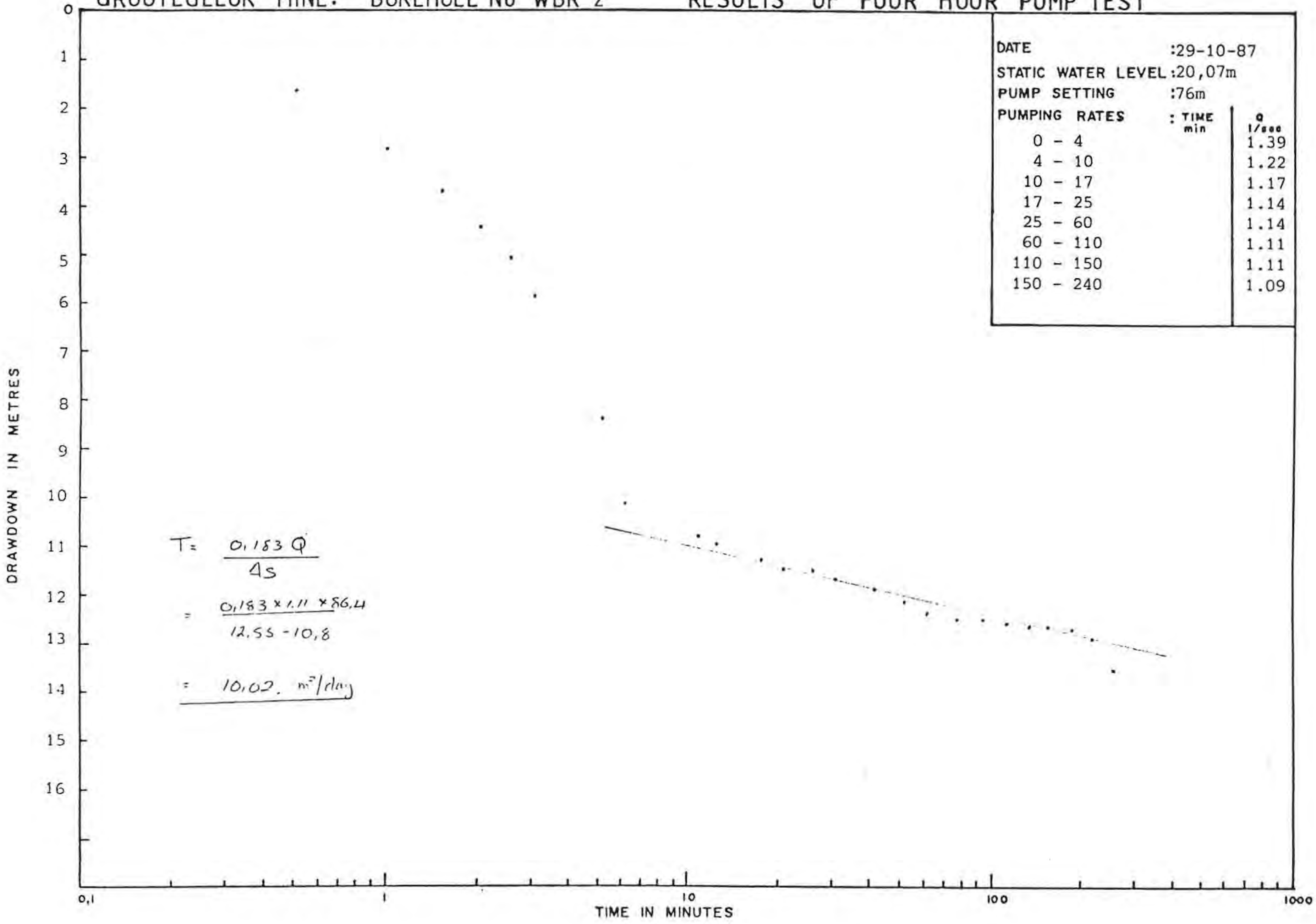


$$T = \frac{0{,}183\,Q}{\Delta s'}$$

$$= \frac{0{,}183 \times 1{,}39 \times 86{,}4}{0{,}44 - 0{,}205}$$

$$= \underline{94{,}54}\ \underline{m^2/day}$$

GROOTEGELUK MINE: BOREHOLE No WBR 2 RESULTS OF FOUR HOUR PUMP TEST



DATE :29-10-87
STATIC WATER LEVEL :20,07m
PUMP SETTING :76m

PUMPING RATES :

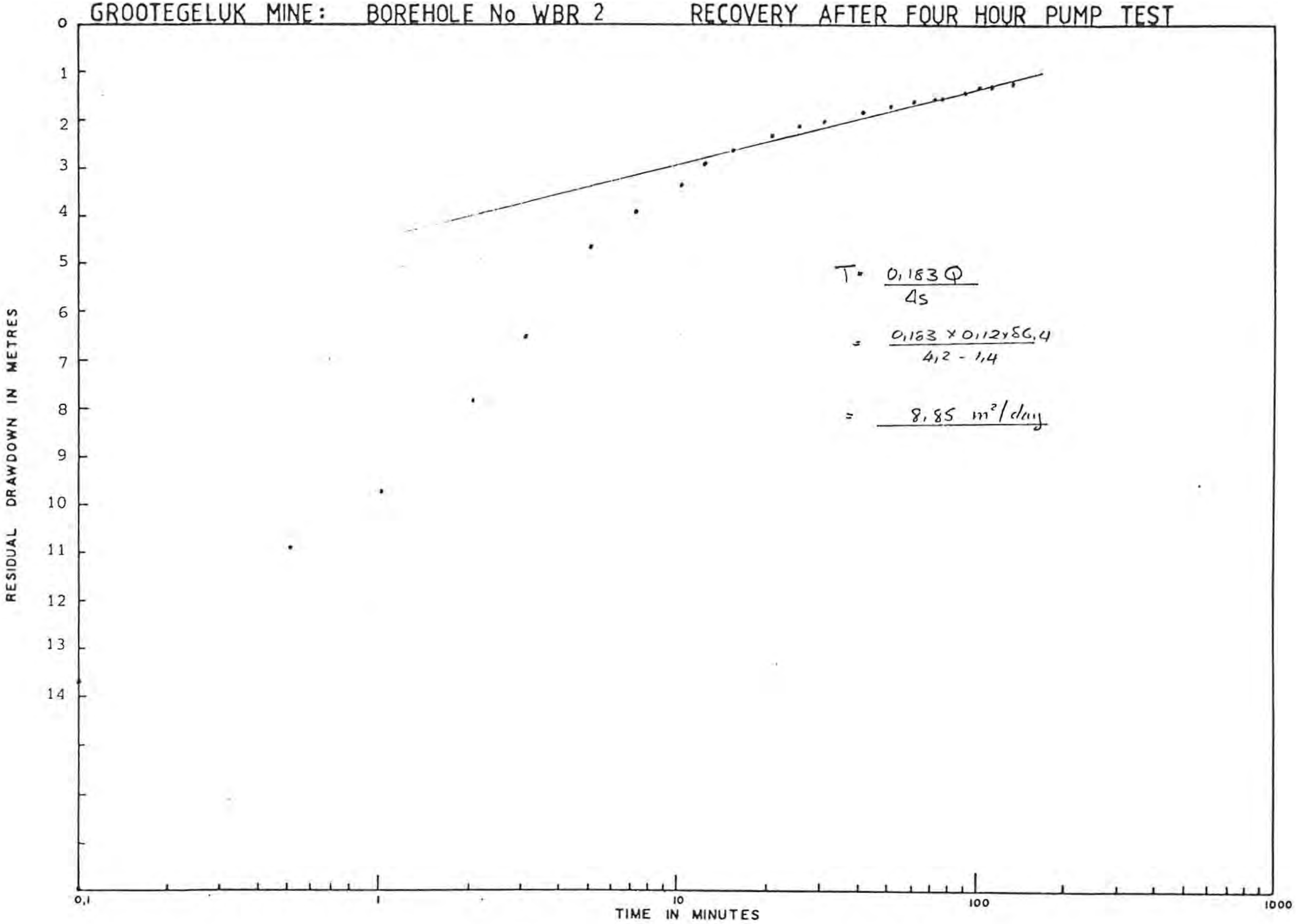
TIME min	Q l/sec
0 - 4	1.39
4 - 10	1.22
10 - 17	1.17
17 - 25	1.14
25 - 60	1.14
60 - 110	1.11
110 - 150	1.11
150 - 240	1.09

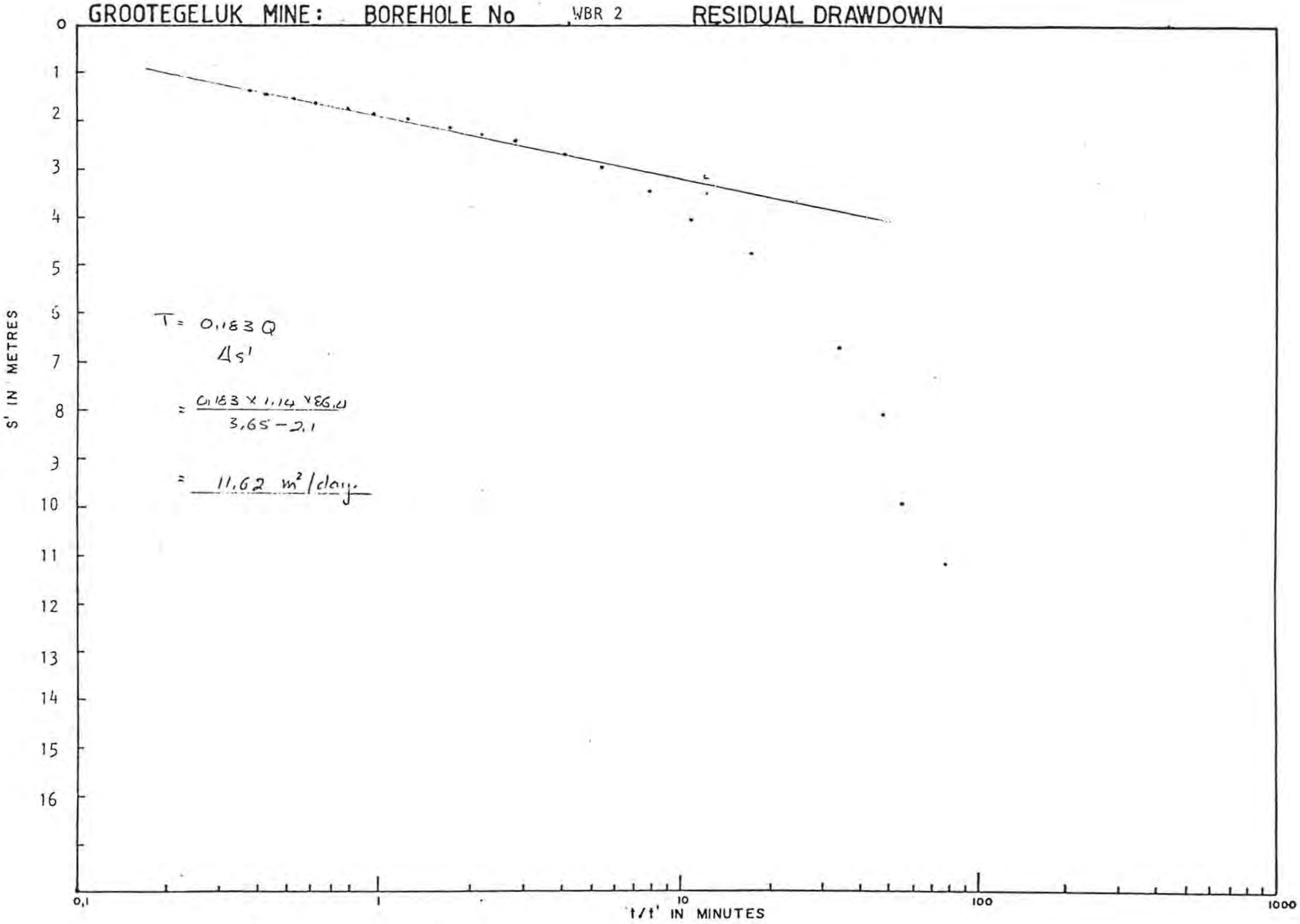
$$T = \frac{0,183\,Q}{\Delta s}$$

$$= \frac{0,183 \times 1.11 \times 86,4}{12,55 - 10,8}$$

$$= 10,02 \text{ m}^2/\text{day}$$

GROOTEGELUK MINE: BOREHOLE No WBR 2 RECOVERY AFTER FOUR HOUR PUMP TEST





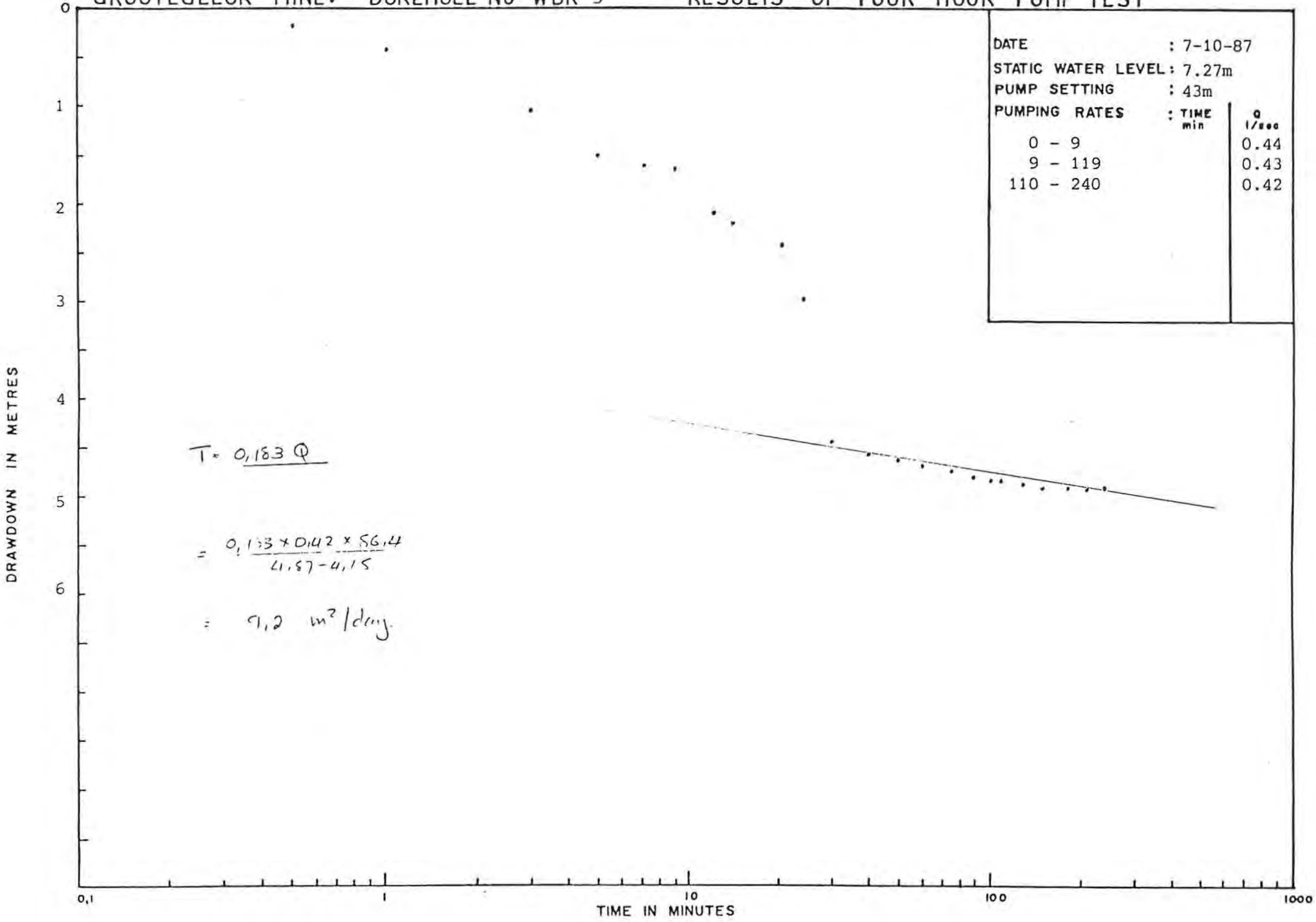
GROOTEGELUK MINE: BOREHOLE No WBR 2 RESIDUAL DRAWDOWN

$$T = \frac{0{,}183\,Q}{\Delta s'}$$

$$= \frac{0{,}183 \times 1{,}14 \times 86{,}4}{3{,}65 - 2{,}1}$$

$$= \underline{11{,}62\ m^2/day}$$

GROOTEGELUK MINE: BOREHOLE No WBR 3 RESULTS OF FOUR HOUR PUMP TEST



DATE : 7-10-87

STATIC WATER LEVEL : 7.27m

PUMP SETTING : 43m

PUMPING RATES

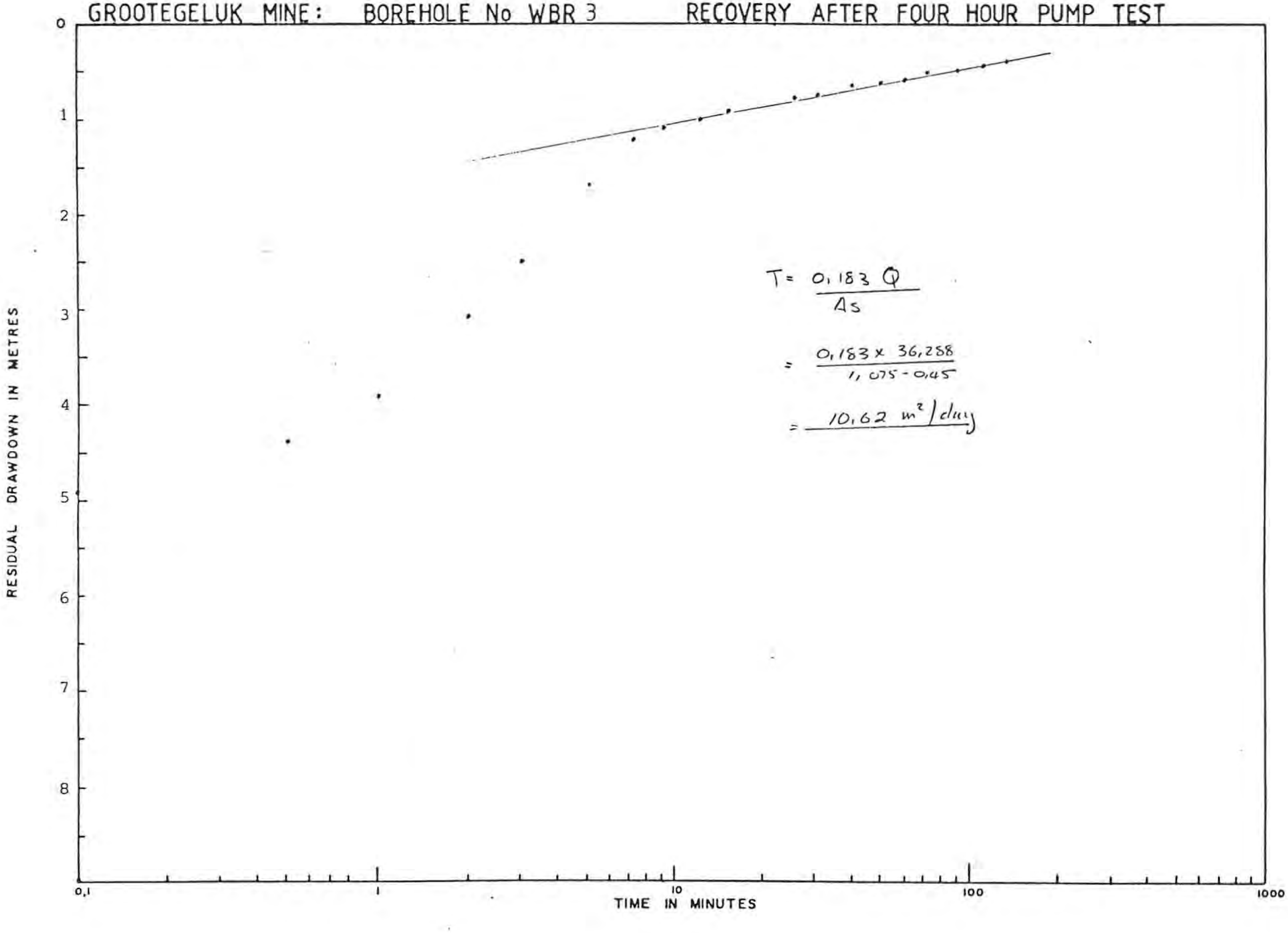
TIME min	Q l/sec
0 - 9	0.44
9 - 119	0.43
110 - 240	0.42

$T = \frac{0,183\,Q}{}$

$= \frac{0,183 \times 0,42 \times 86,4}{4,87 - 4,15}$

$= 9,2\ m^2/day$

GROOTEGELUK MINE: BOREHOLE No WBR 3 RECOVERY AFTER FOUR HOUR PUMP TEST

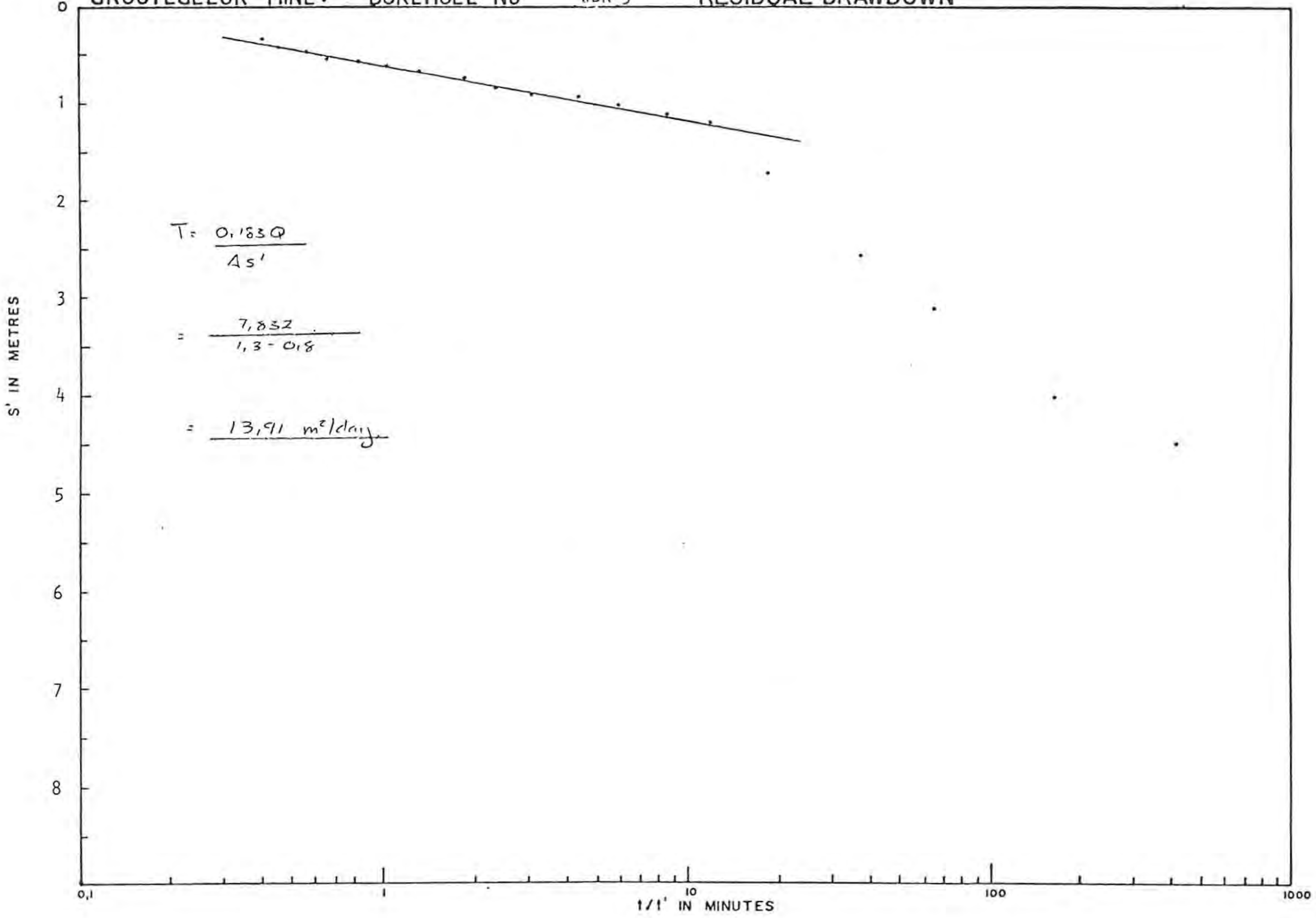


$$T = \frac{0{,}183\ Q}{\Delta s}$$

$$= \frac{0{,}183 \times 36{,}288}{1{,}075 - 0{,}45}$$

$$= \underline{10{,}62\ m^2/day}$$

GROOTEGELUK MINE: BOREHOLE No WBR 3 RESIDUAL DRAWDOWN

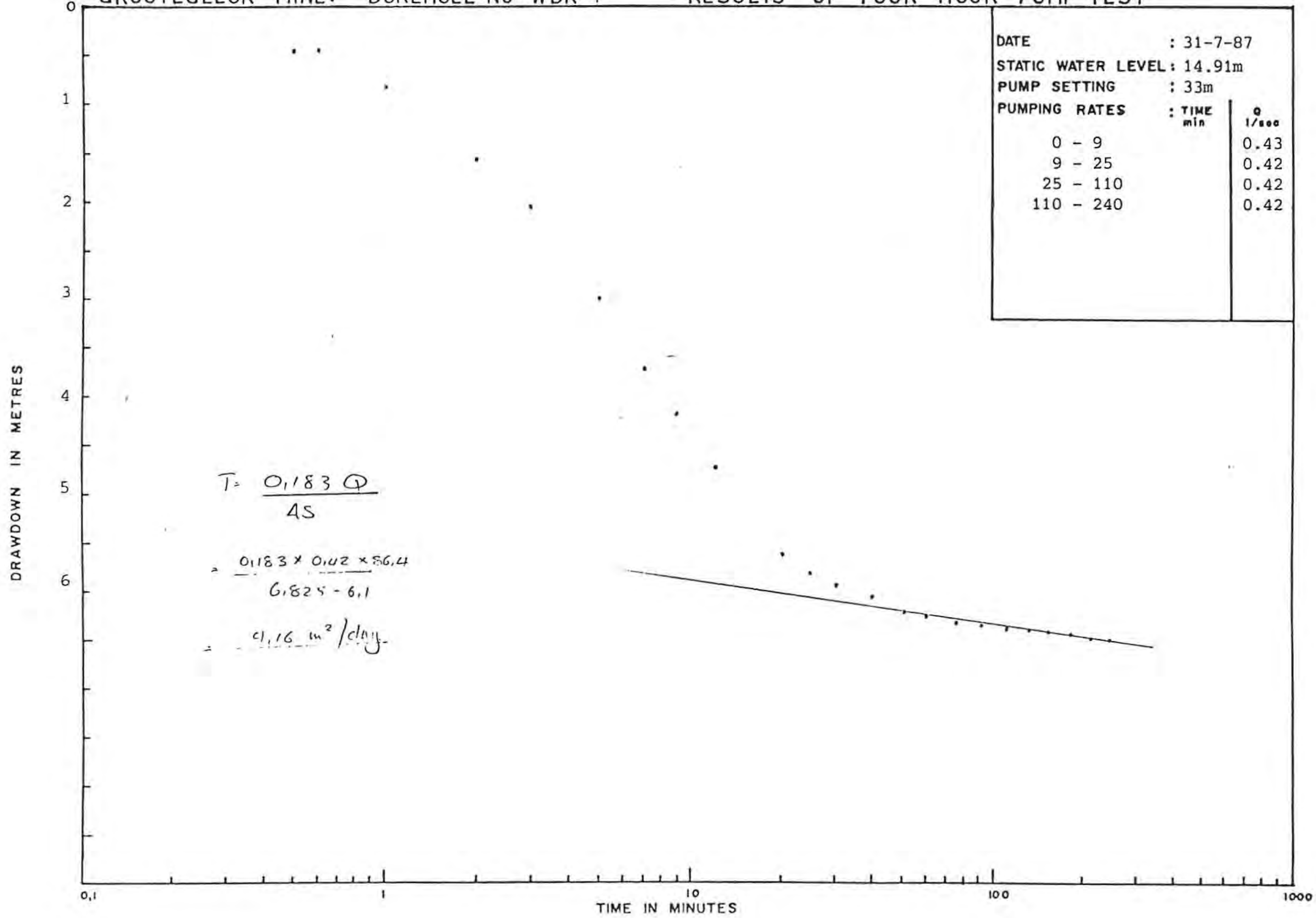


$$T = \frac{0{,}183Q}{\Delta s'}$$

$$= \frac{7{,}832}{1{,}3 - 0{,}8}$$

$$= 13{,}91 \text{ m}^2/\text{day}$$

GROOTEGELUK MINE: BOREHOLE No WBR 4 RESULTS OF FOUR HOUR PUMP TEST



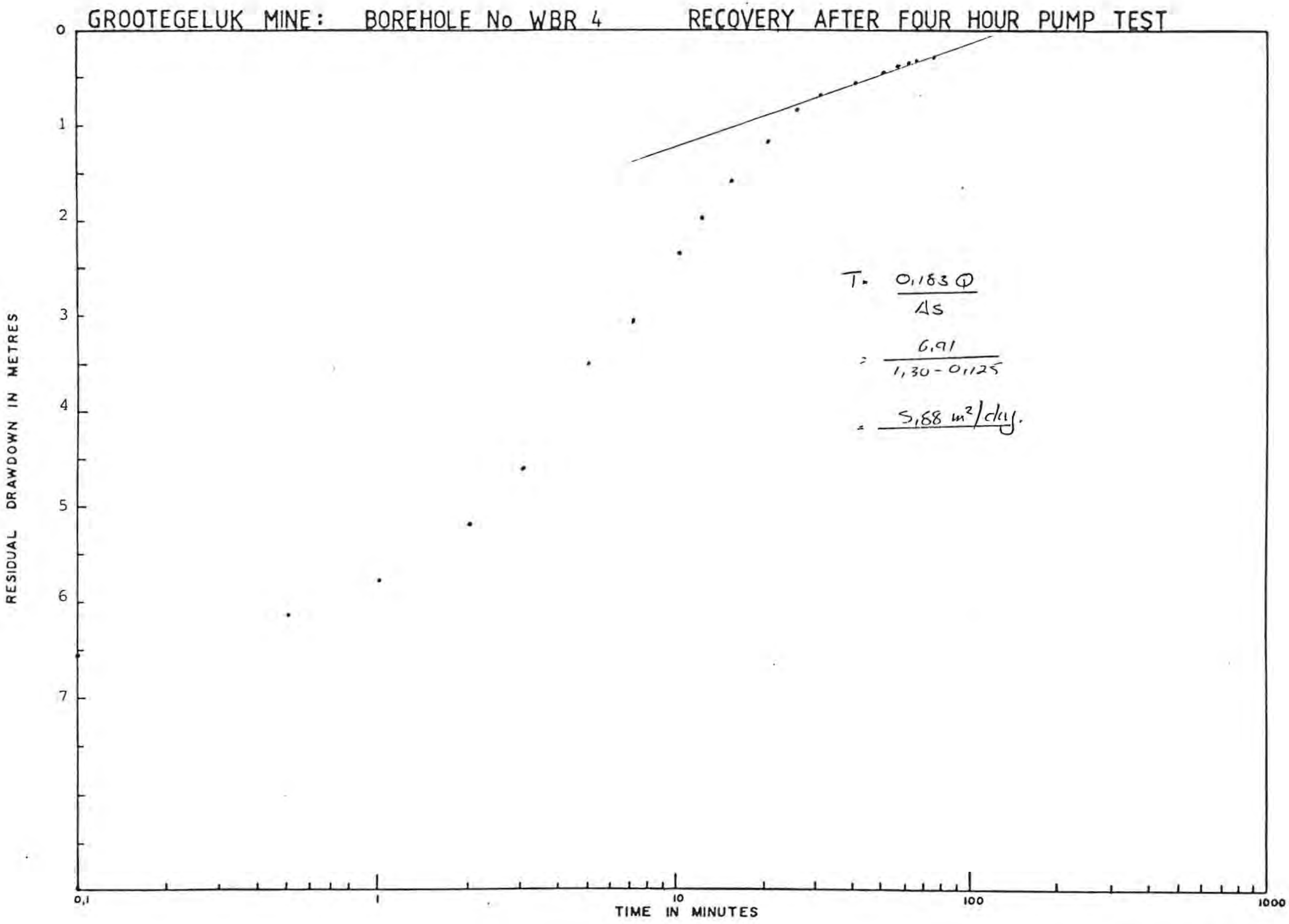
DATE : 31-7-87
STATIC WATER LEVEL : 14.91m
PUMP SETTING : 33m
PUMPING RATES :

TIME min	Q l/sec
0 - 9	0.43
9 - 25	0.42
25 - 110	0.42
110 - 240	0.42

$$T = \frac{0,183\,Q}{\Delta S}$$

$$= \frac{0,183 \times 0,42 \times 86,4}{6,825 - 6,1}$$

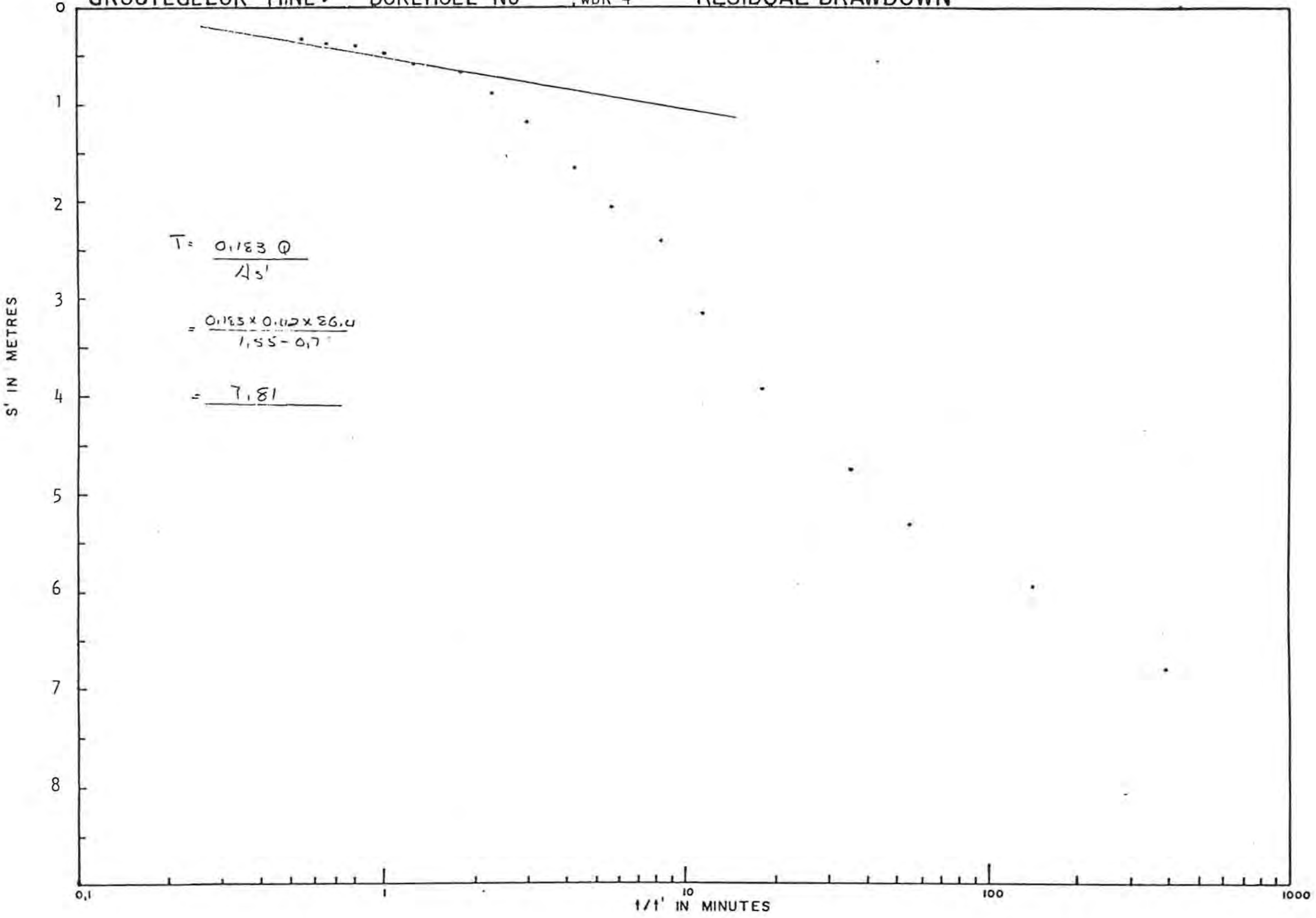
$= 9,16\ m^2/day$



GROOTEGELUK MINE: BOREHOLE No WBR 4 RECOVERY AFTER FOUR HOUR PUMP TEST

$$T = \frac{0{,}183\,Q}{\Delta s} = \frac{6{,}91}{1{,}30 - 0{,}125} = \underline{5{,}88\ m^2/day}.$$

GROOTEGELUK MINE: BOREHOLE No WBR 4 RESIDUAL DRAWDOWN

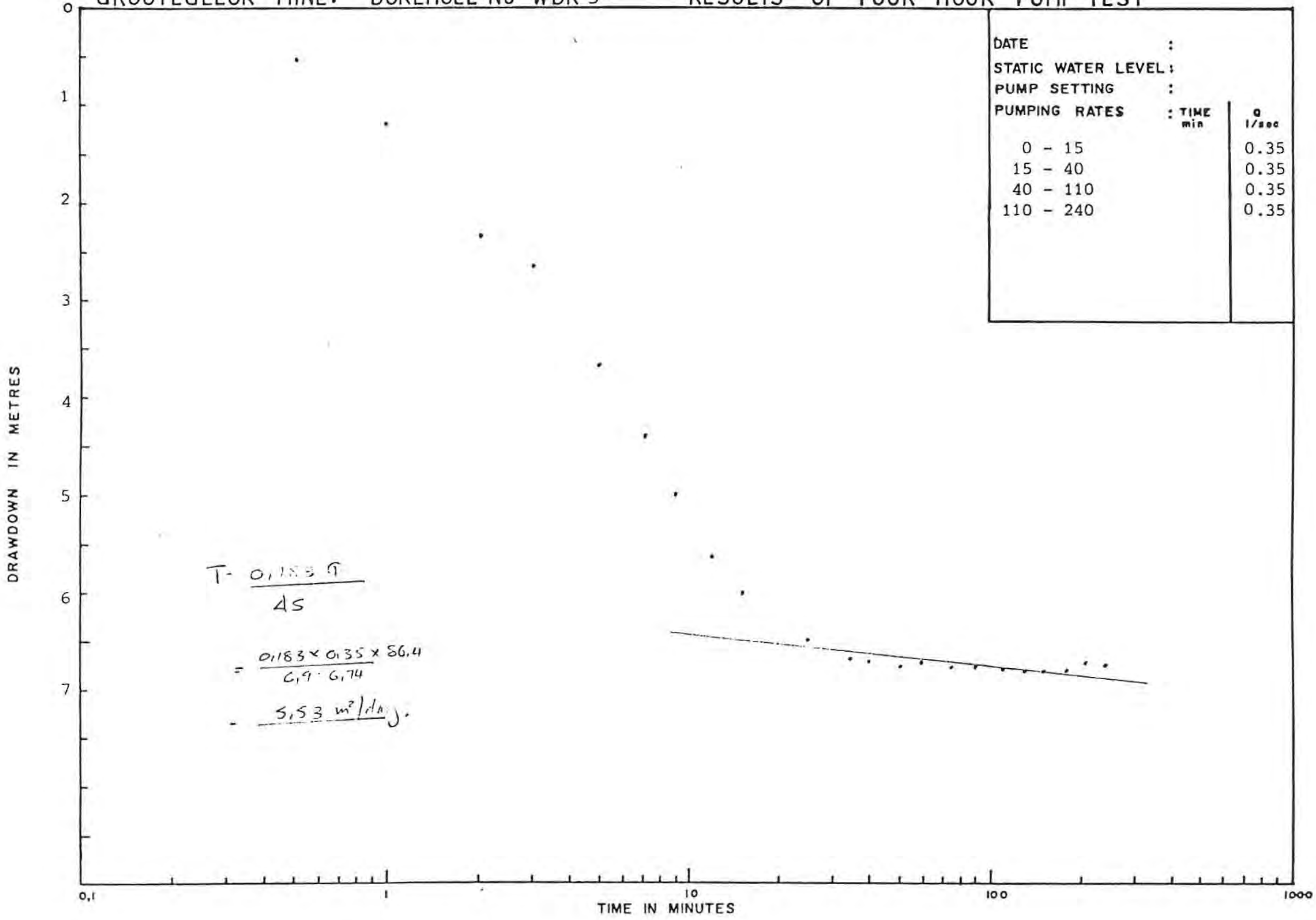


$$T = \frac{0{,}183\ Q}{\Delta s'}$$

$$= \frac{0{,}183 \times 0{,}112 \times 86{,}4}{1{,}55 - 0{,}7}$$

$$= \underline{7{,}81}$$

GROOTEGELUK MINE: BOREHOLE No WBR 5 RESULTS OF FOUR HOUR PUMP TEST



DATE :
STATIC WATER LEVEL :
PUMP SETTING :

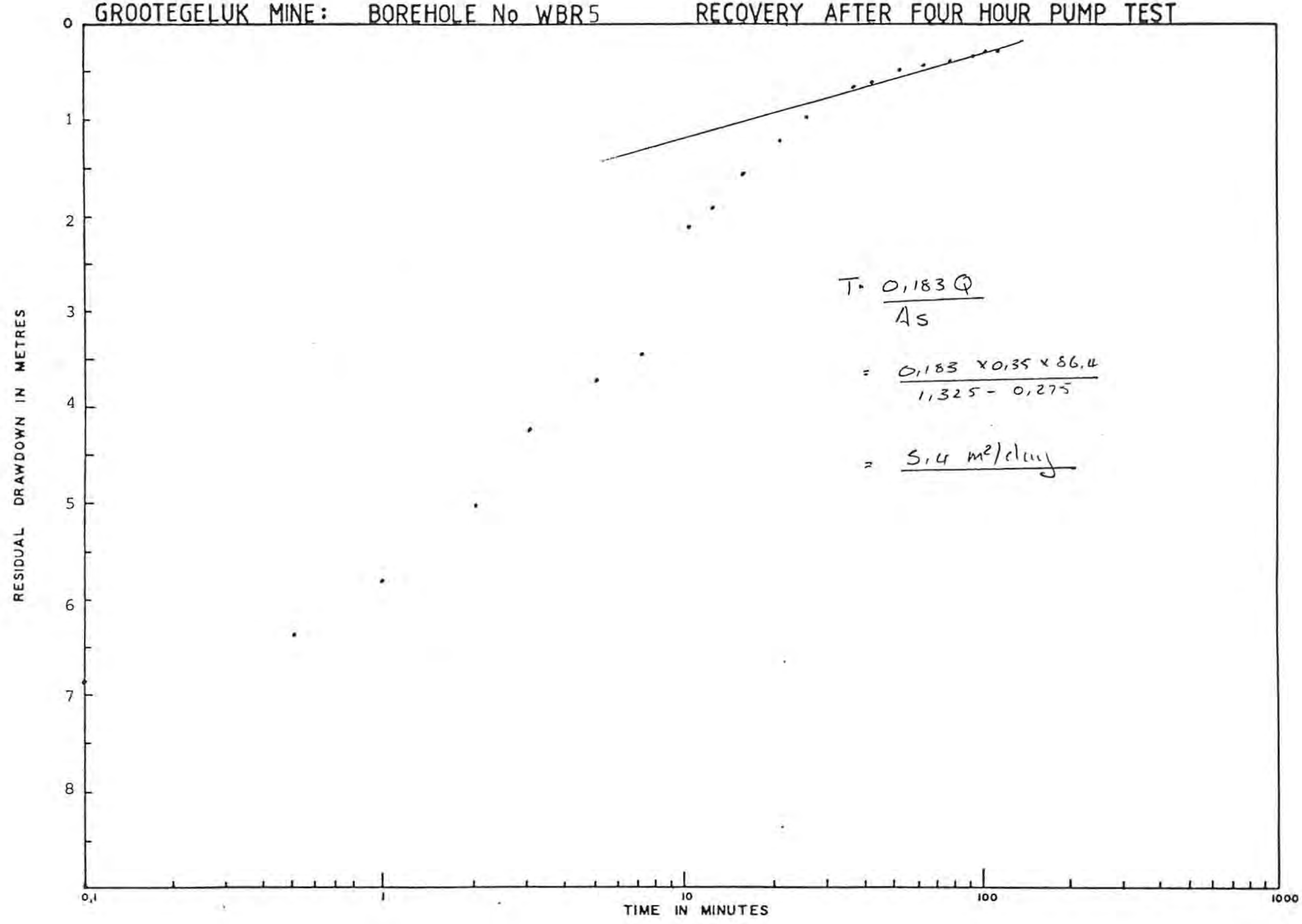
PUMPING RATES : TIME min	Q l/sec
0 - 15	0.35
15 - 40	0.35
40 - 110	0.35
110 - 240	0.35

$$T - \frac{0{,}183\ Q}{\Delta s}$$

$$= \frac{0{,}183 \times 0{,}35 \times 86{,}4}{6{,}9 \cdot 6{,}74}$$

$$- \underline{5{,}53\ m^2/day}.$$

GROOTEGELUK MINE: BOREHOLE No WBR5 RECOVERY AFTER FOUR HOUR PUMP TEST

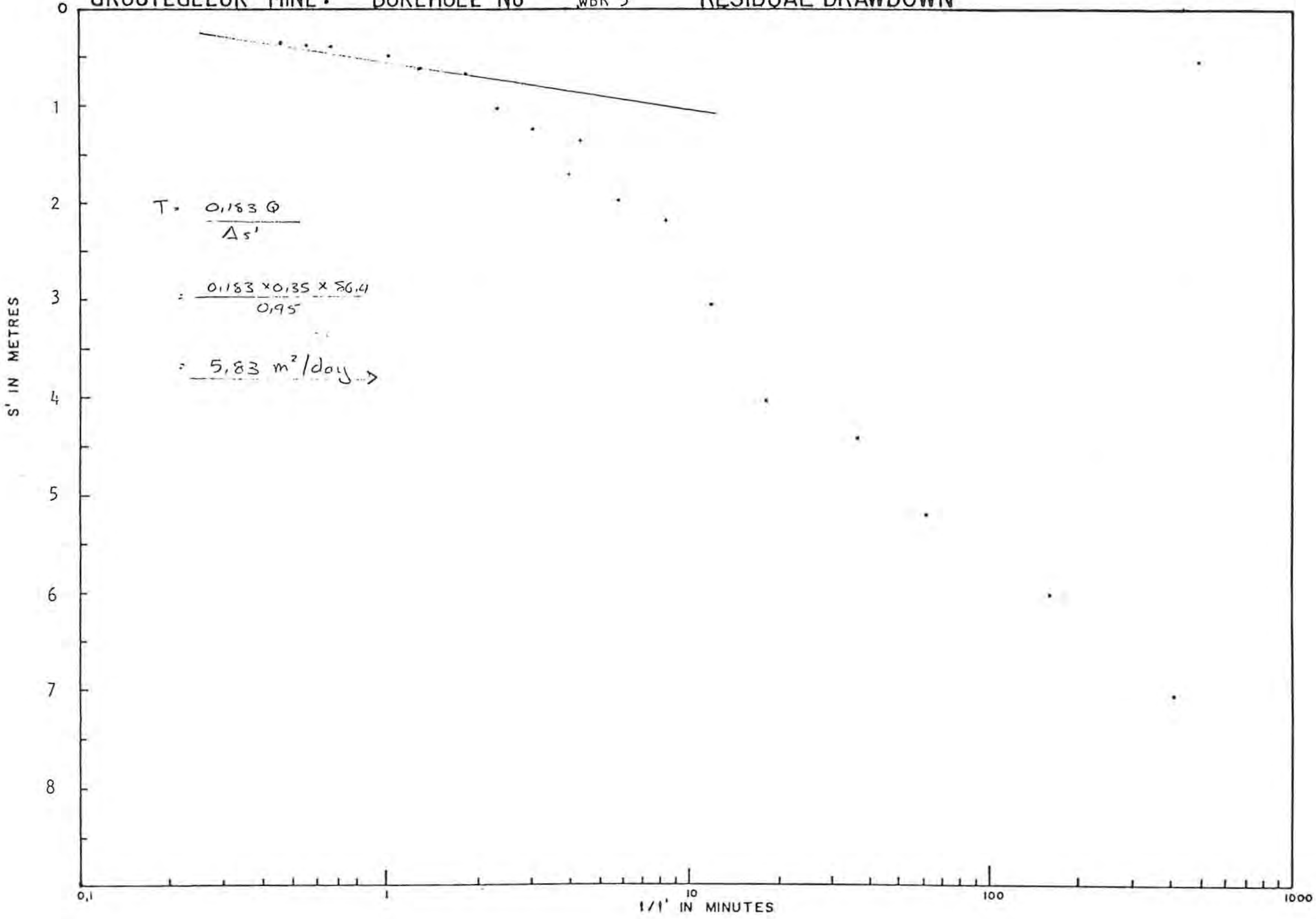


$$T = \frac{0{,}183\,Q}{\Delta s}$$

$$= \frac{0{,}183 \times 0{,}35 \times 86{,}4}{1{,}325 - 0{,}275}$$

$$= \underline{5{,}4\ m^2/day}$$

GROOTEGELUK MINE: BOREHOLE No WBR 5 RESIDUAL DRAWDOWN

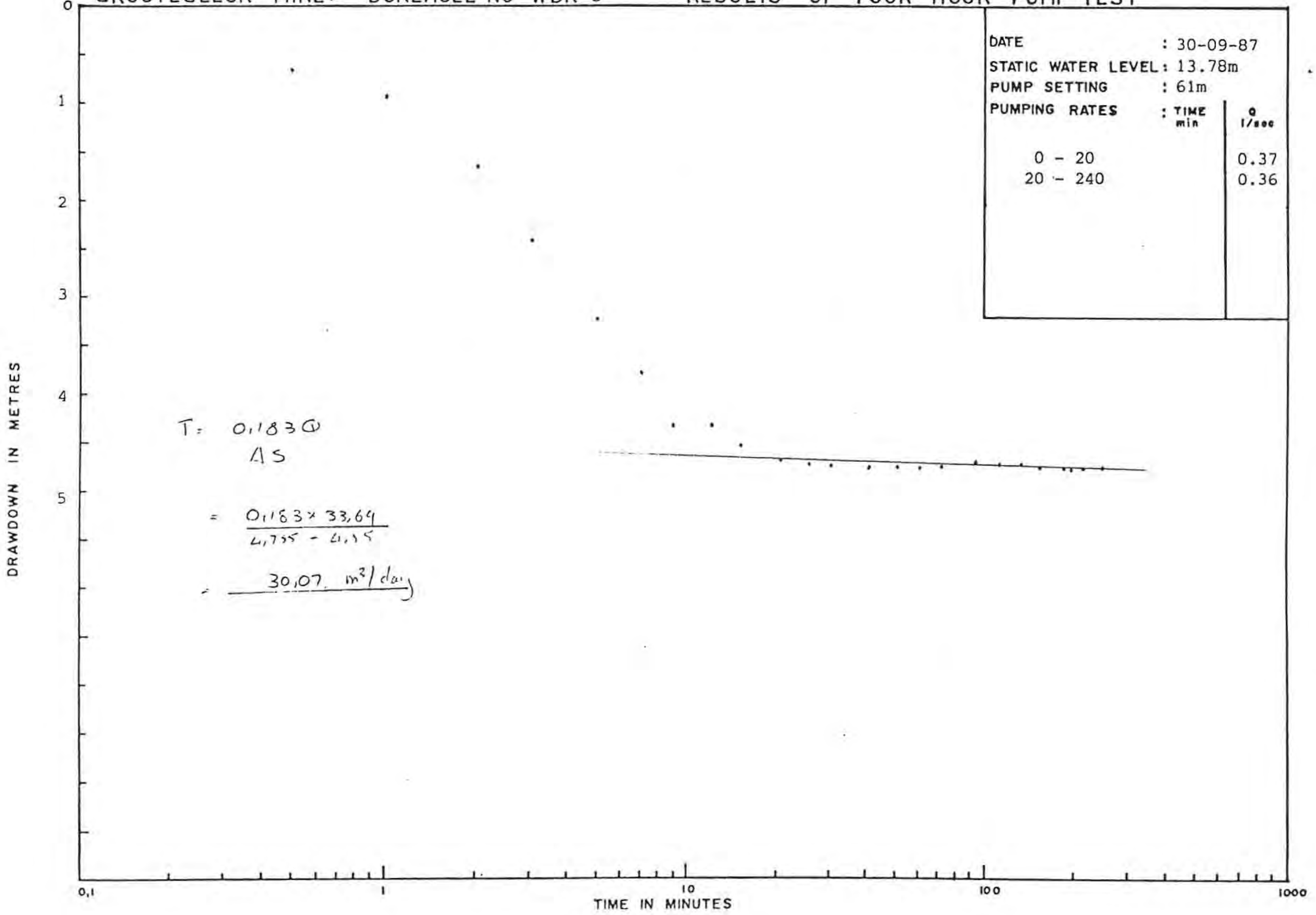


$T = \frac{0,183\,Q}{\Delta s'}$

$= \frac{0,183 \times 0,35 \times 86,4}{0,95}$

$= 5,83\ m^2/day$

GROOTEGELUK MINE: BOREHOLE No WBR 6 RESULTS OF FOUR HOUR PUMP TEST



DATE : 30-09-87
STATIC WATER LEVEL : 13.78m
PUMP SETTING : 61m

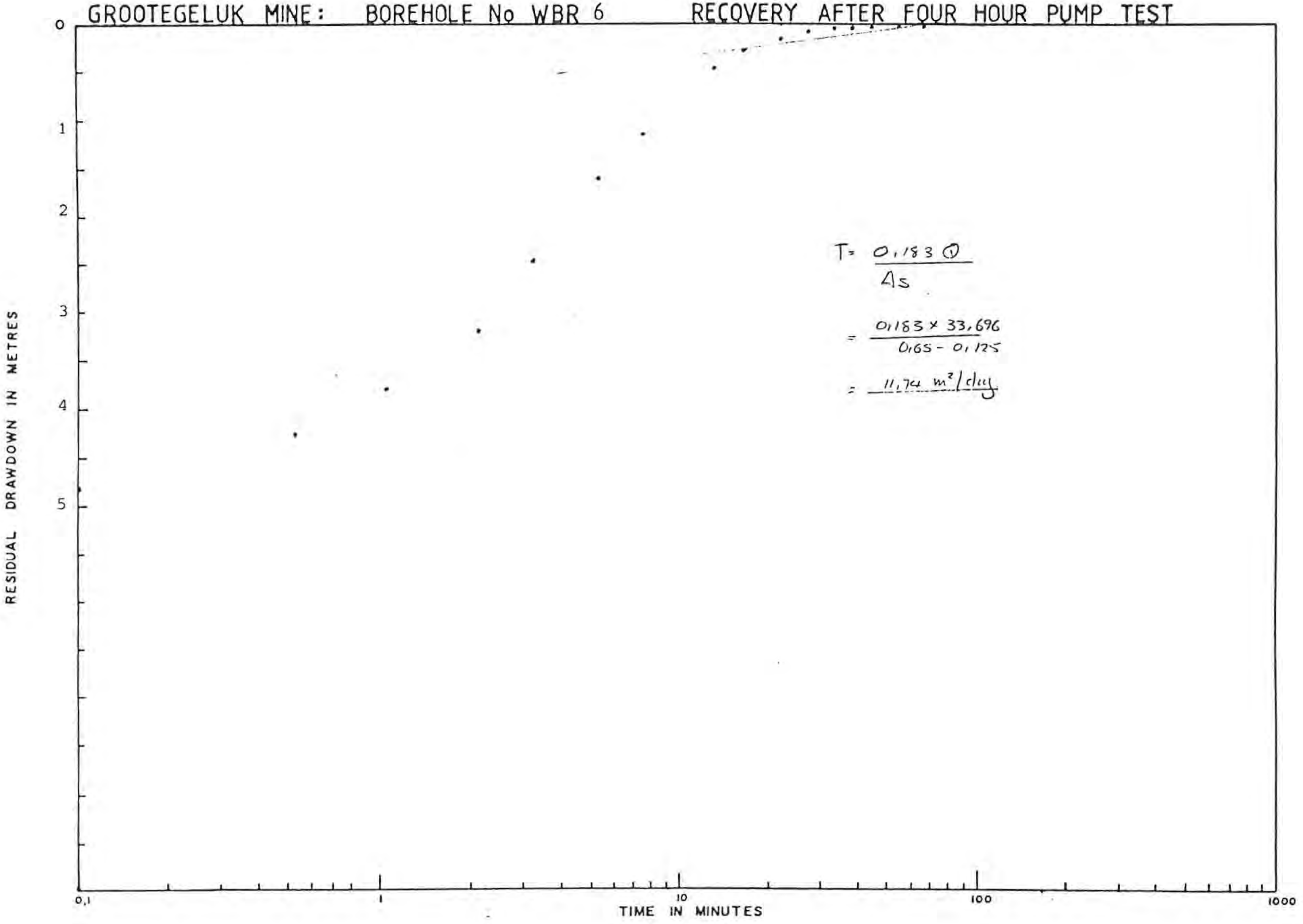
PUMPING RATES : TIME min	Q l/sec
0 - 20	0.37
20 - 240	0.36

$$T = \frac{0,183Q}{\Delta S}$$

$$= \frac{0,183 \times 33,64}{4,755 - 4,15}$$

= 30,07 m²/day

GROOTEGELUK MINE: BOREHOLE No WBR 6 RECOVERY AFTER FOUR HOUR PUMP TEST

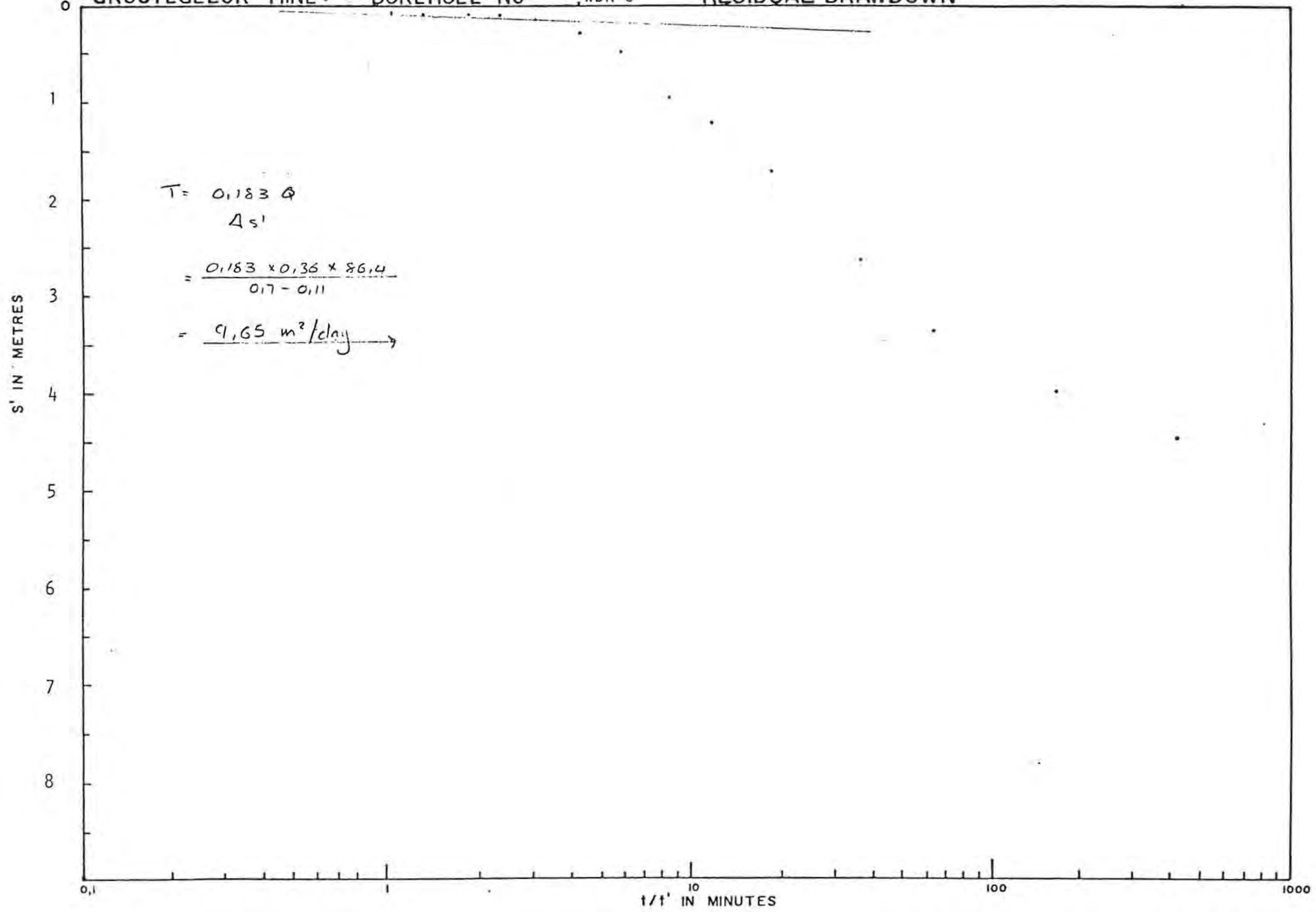


$$T = \frac{0{,}183\,Q}{\Delta s}$$

$$= \frac{0{,}183 \times 33{,}696}{0{,}65 - 0{,}125}$$

$$= \underline{11{,}74\ m^2/day}$$

GROOTEGELUK MINE: BOREHOLE No WBR 6 RESIDUAL DRAWDOWN

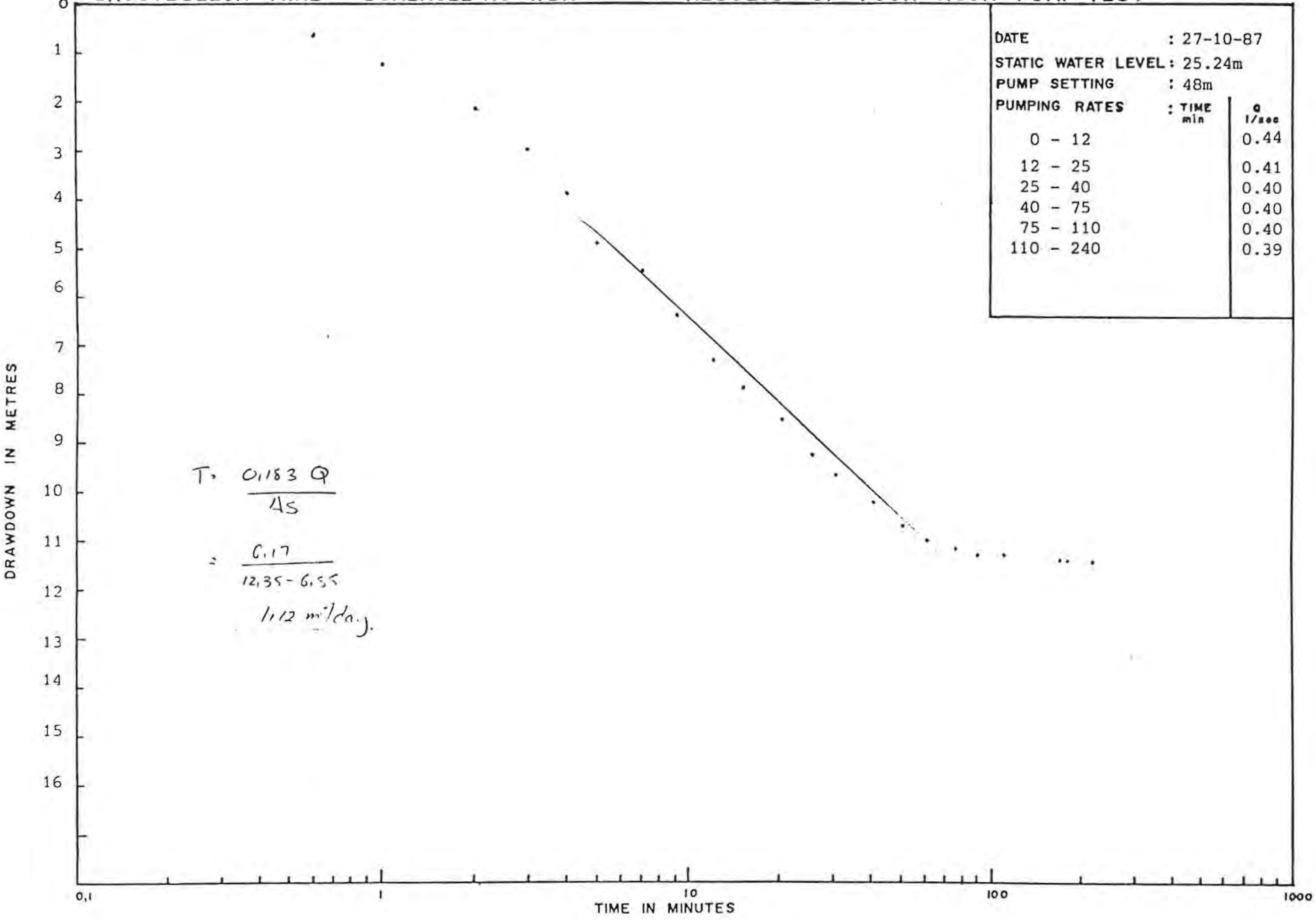


$$T = \frac{0{,}183\,Q}{\Delta s'}$$

$$= \frac{0{,}183 \times 0{,}36 \times 86{,}4}{0{,}7 - 0{,}11}$$

$$= 9{,}65\ m^2/day \rightarrow$$

GROOTEGELUK MINE: BOREHOLE No WBR 7 RESULTS OF FOUR HOUR PUMP TEST



DATE : 27-10-87
STATIC WATER LEVEL : 25.24m
PUMP SETTING : 48m

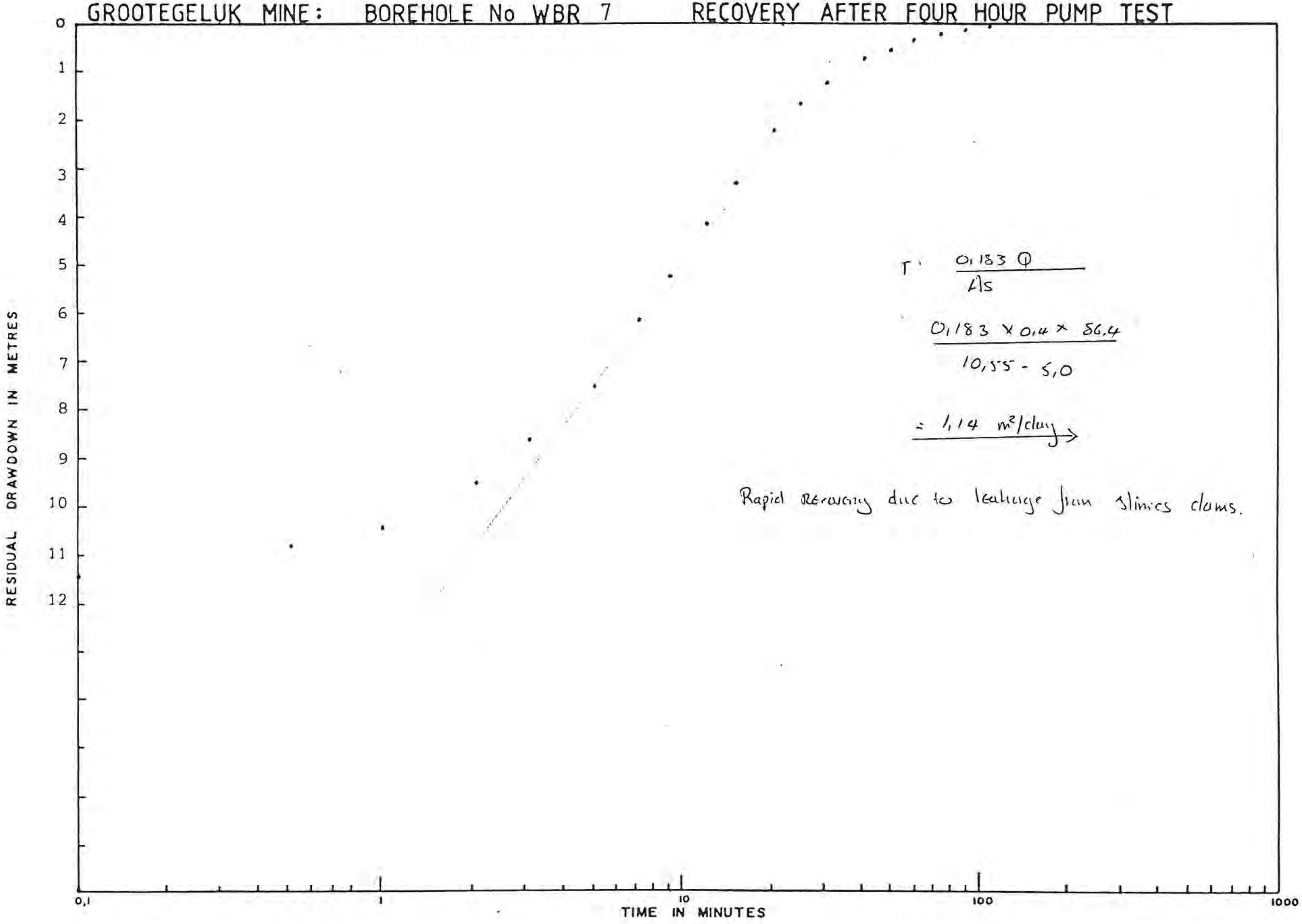
PUMPING RATES : TIME min	Q l/sec
0 - 12	0.44
12 - 25	0.41
25 - 40	0.40
40 - 75	0.40
75 - 110	0.40
110 - 240	0.39

$$T = \frac{0,183\ Q}{\Delta s}$$

$$= \frac{6,17}{12,35 - 6,55}$$

1,12 m²/day.

GROOTEGELUK MINE: BOREHOLE No WBR 7 RECOVERY AFTER FOUR HOUR PUMP TEST



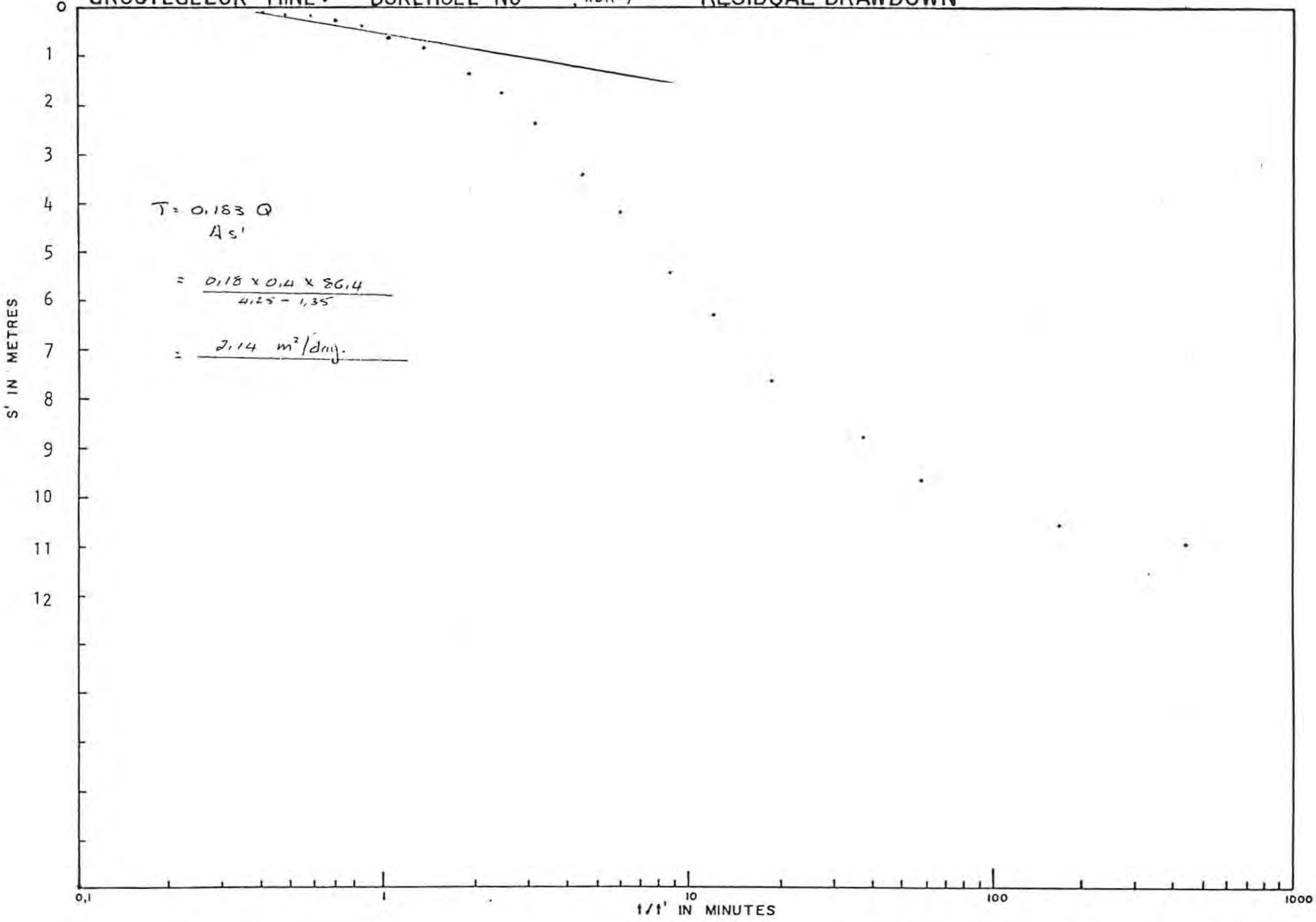
$$T = \frac{0{,}183\ Q}{\Delta s}$$

$$= \frac{0{,}183 \times 0{,}4 \times 86.4}{10{,}55 - 5{,}0}$$

$$= 1{,}14\ m^2/day$$

Rapid recovery due to leakage from slimes dams.

GROOTEGELUK MINE: BOREHOLE No WBR 7 RESIDUAL DRAWDOWN

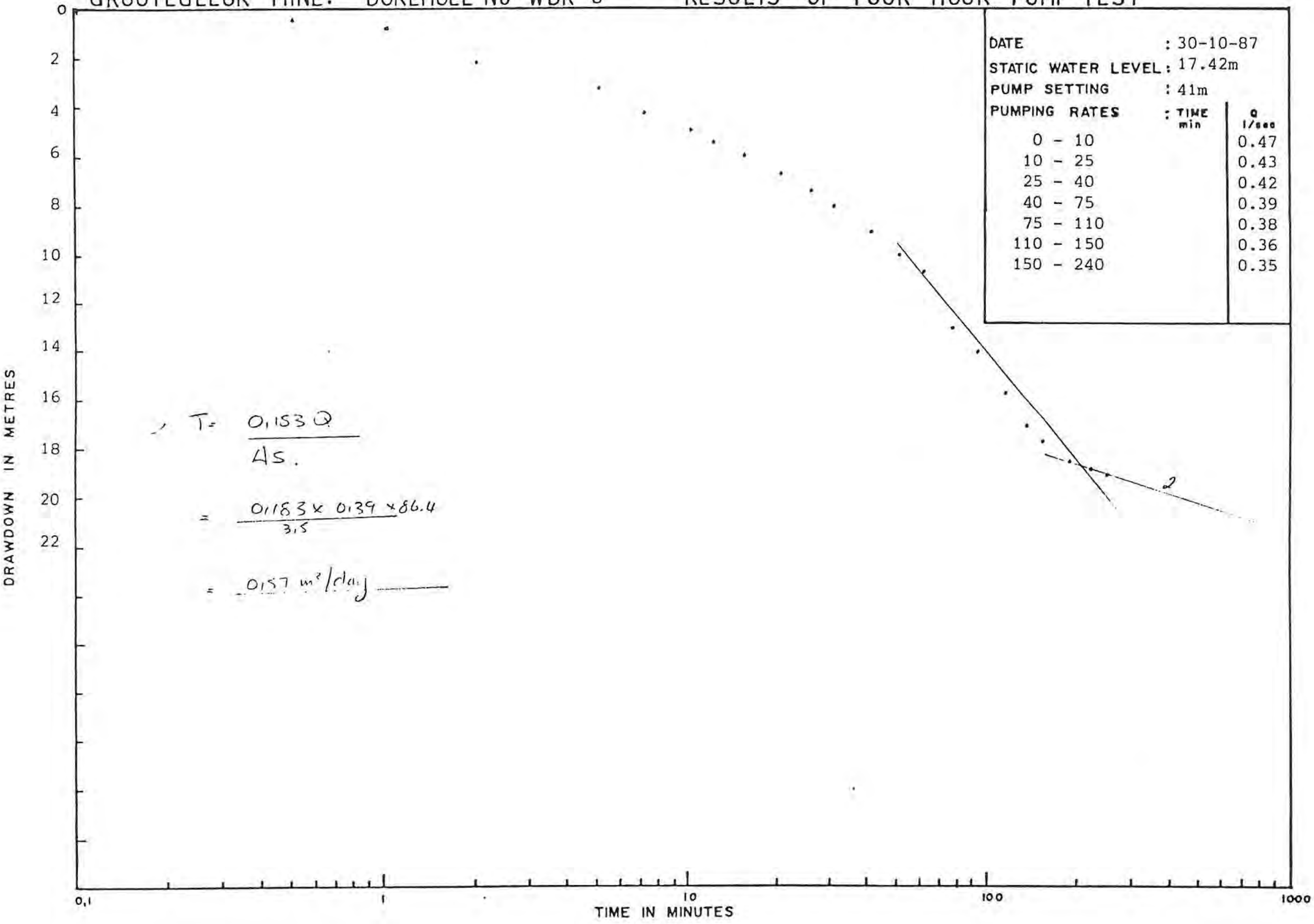


$$T = \frac{0{,}183\ Q}{\Delta s'}$$

$$= \frac{0{,}18 \times 0{,}4 \times 86{,}4}{4{,}25 - 1{,}35}$$

$$= \underline{2{,}14\ m^2/day.}$$

GROOTEGELUK MINE: BOREHOLE No WBR 8 RESULTS OF FOUR HOUR PUMP TEST



DATE : 30-10-87

STATIC WATER LEVEL : 17.42m

PUMP SETTING : 41m

PUMPING RATES :

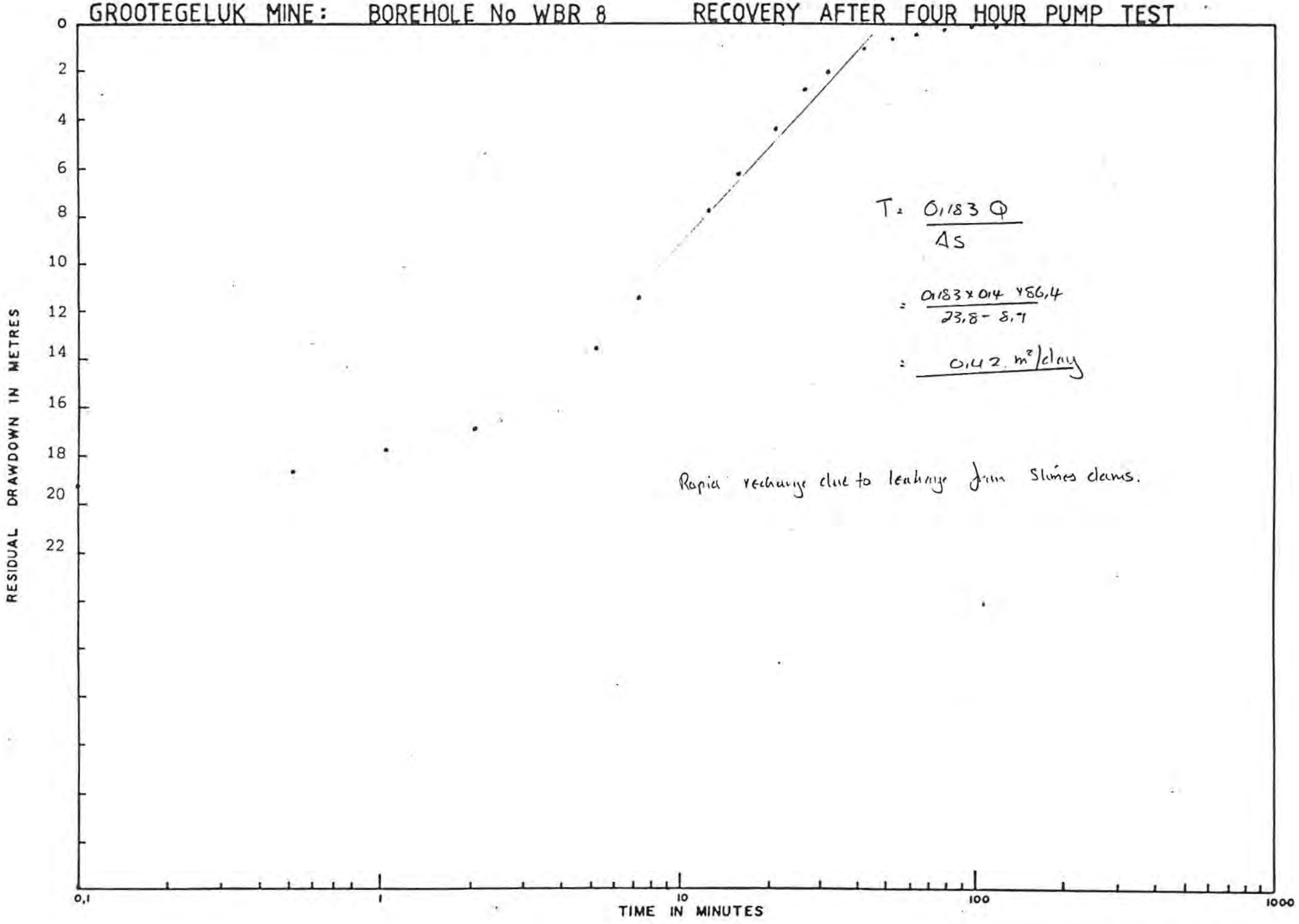
TIME min	Q l/sec
0 - 10	0.47
10 - 25	0.43
25 - 40	0.42
40 - 75	0.39
75 - 110	0.38
110 - 150	0.36
150 - 240	0.35

$$T = \frac{0,153\,Q}{\Delta s}$$

$$= \frac{0,183 \times 0,39 \times 86.4}{3,5}$$

$$= 0,57\ m^2/day$$

GROOTEGELUK MINE: BOREHOLE No WBR 8 RECOVERY AFTER FOUR HOUR PUMP TEST



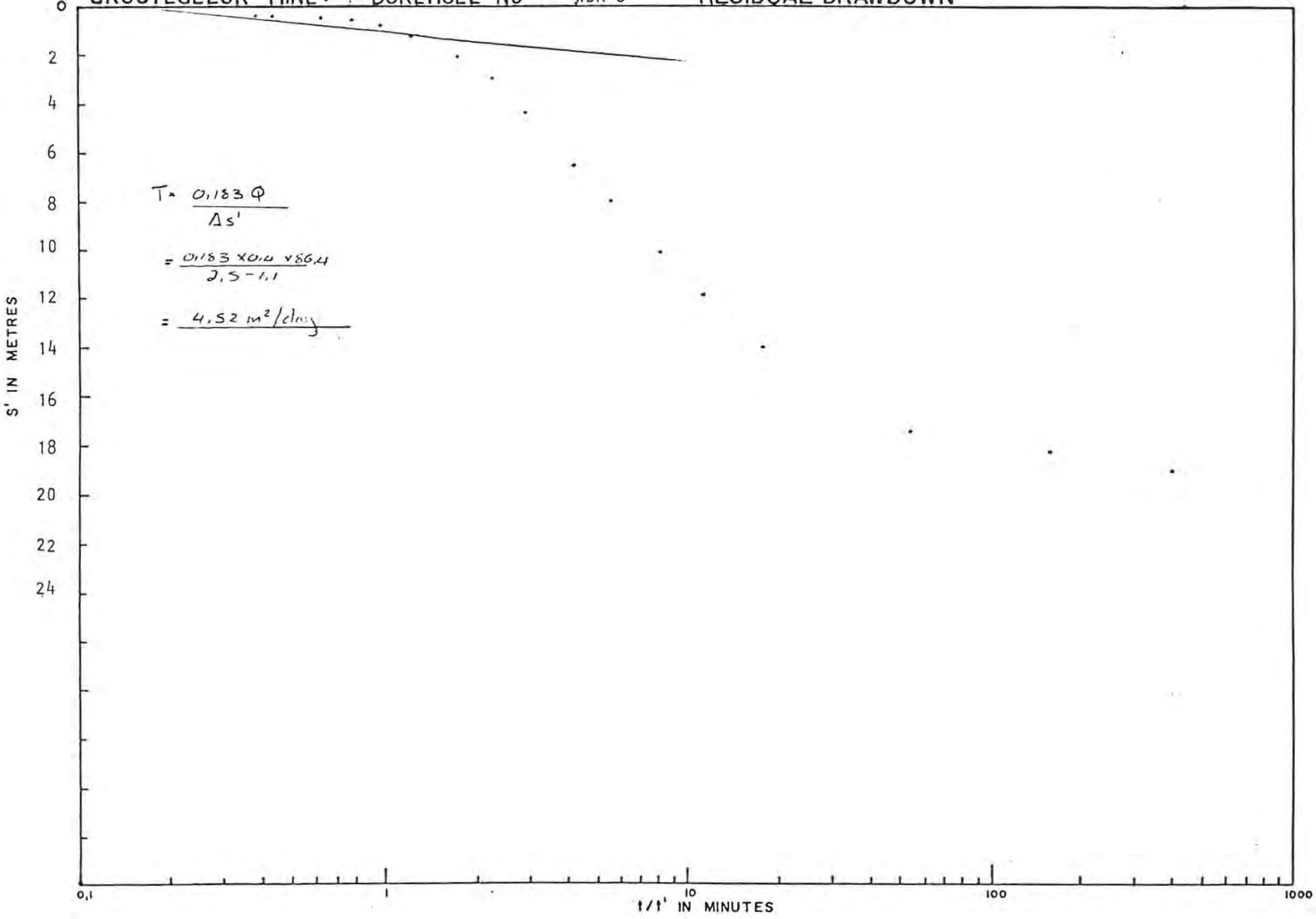
$$T = \frac{0{,}183\ Q}{\Delta s}$$

$$= \frac{0{,}183 \times 0{,}4 \times 86{,}4}{23{,}8 - 8{,}9}$$

$$= \underline{0{,}42\ m^2/day}$$

Rapid recharge due to leakage from Slimes dams.

GROOTEGELUK MINE: BOREHOLE No WBR 8 RESIDUAL DRAWDOWN

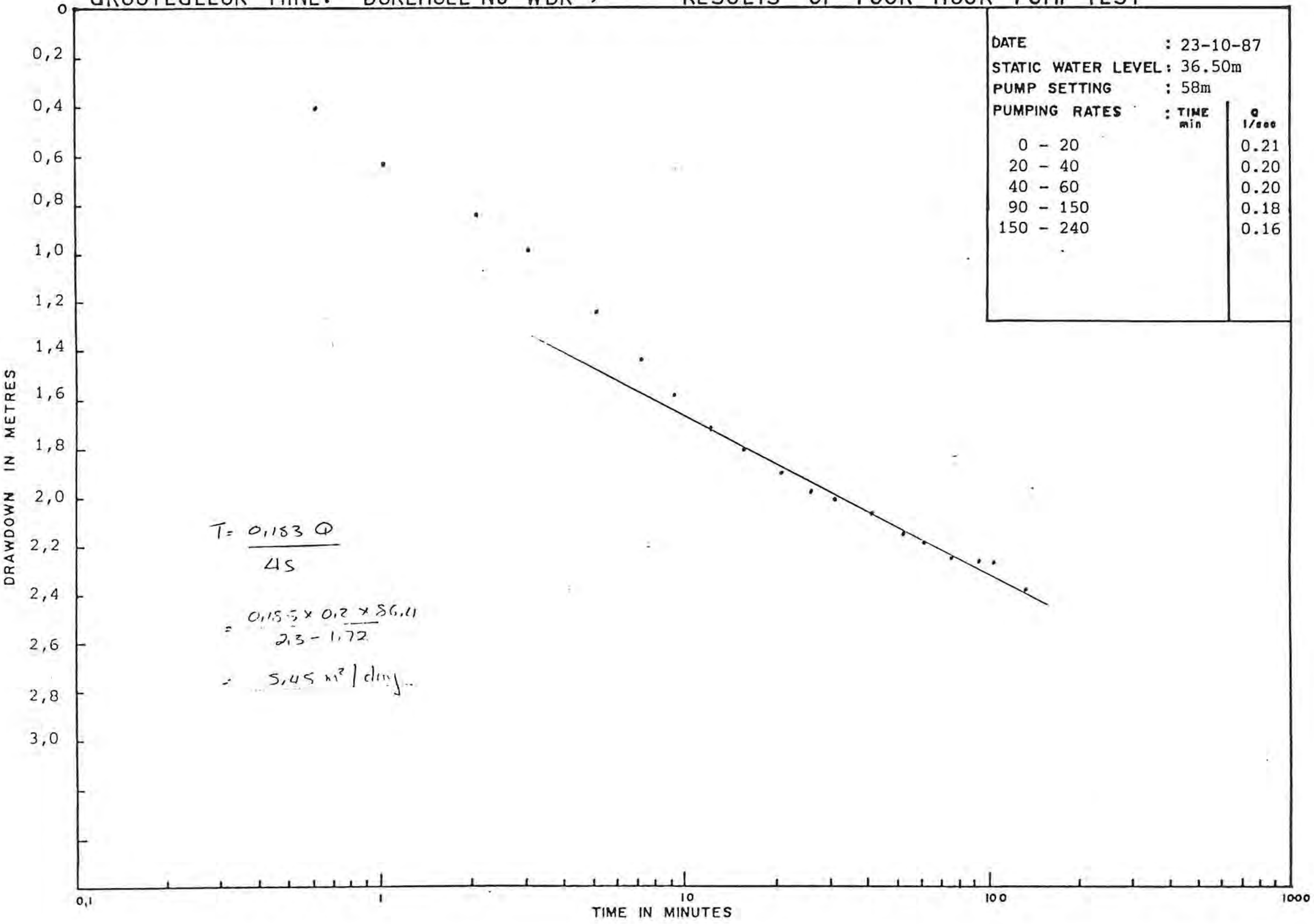


$$T = \frac{0{,}183\,Q}{\Delta s'}$$

$$= \frac{0{,}183 \times 0{,}4 \times 86{,}4}{2{,}5 - 1{,}1}$$

$$= \underline{4{,}52\ m^2/day}$$

GROOTEGELUK MINE: BOREHOLE No WBR 9 RESULTS OF FOUR HOUR PUMP TEST



DATE : 23-10-87
STATIC WATER LEVEL : 36.50m
PUMP SETTING : 58m
PUMPING RATES :

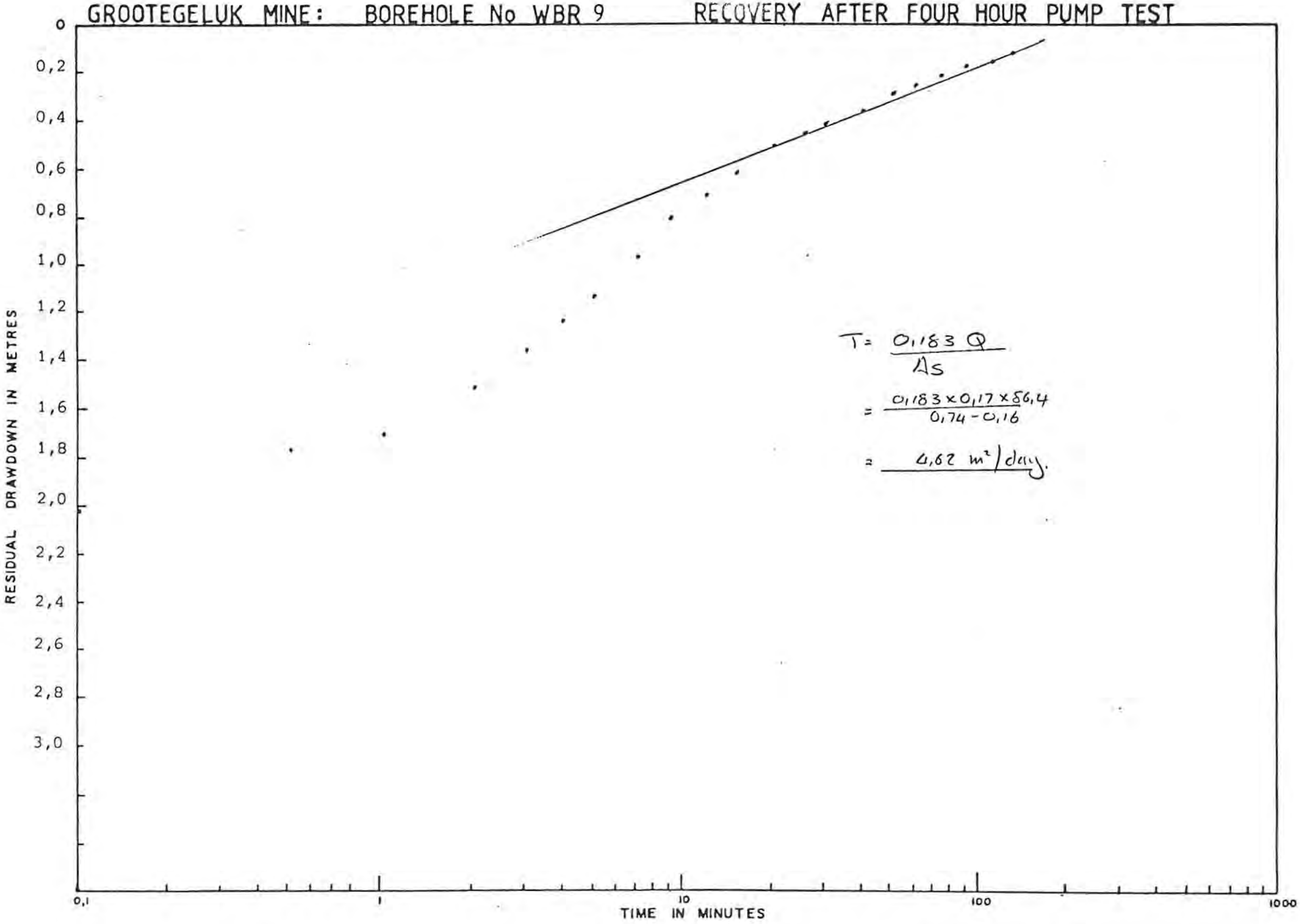
TIME min	Q l/sec
0 - 20	0.21
20 - 40	0.20
40 - 60	0.20
90 - 150	0.18
150 - 240	0.16

$$T = \frac{0,183\ Q}{\Delta s}$$

$$= \frac{0,183 \times 0,2 \times 86,4}{2,3 - 1,72}$$

$= 5,45\ m^2/day$

GROOTEGELUK MINE: BOREHOLE No WBR 9 RECOVERY AFTER FOUR HOUR PUMP TEST

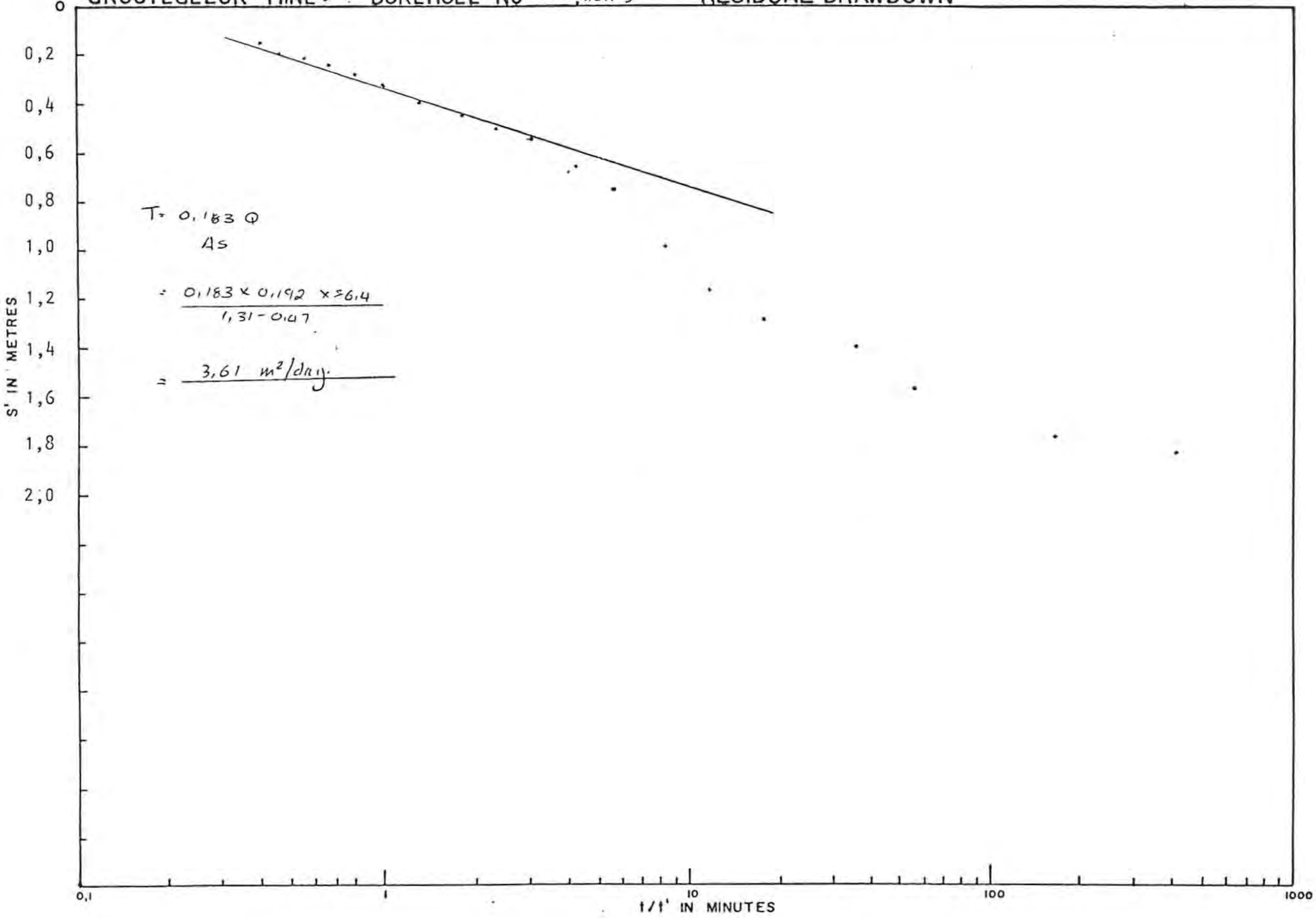


$$T = \frac{0{,}183\ Q}{\Delta s}$$

$$= \frac{0{,}183 \times 0{,}17 \times 86{,}4}{0{,}74 - 0{,}16}$$

$$= \underline{4{,}62\ m^2/day.}$$

GROOTEGELUK MINE: BOREHOLE No WBR 9 RESIDUAL DRAWDOWN

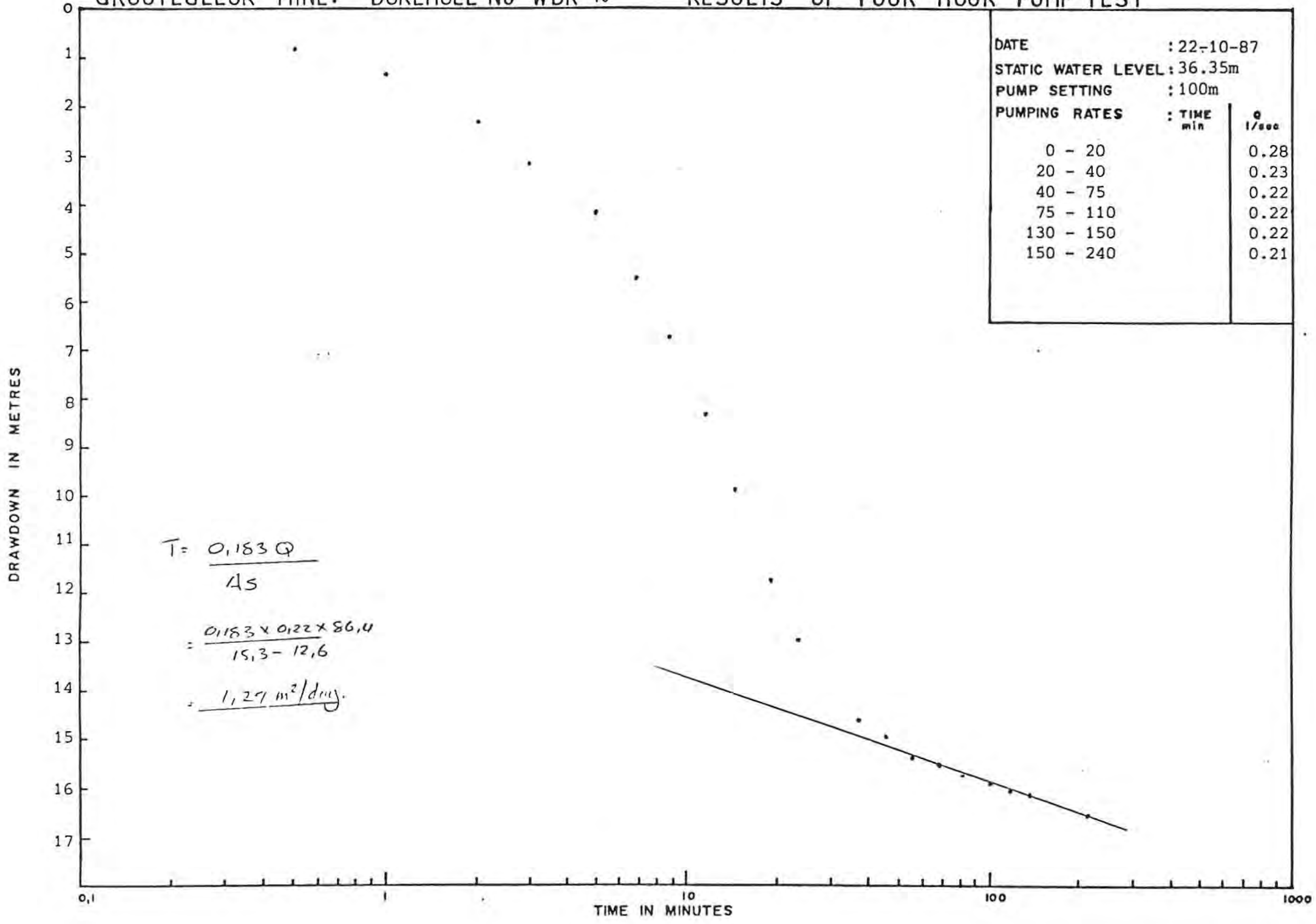


$$T = \frac{0,183\,Q}{As}$$

$$= \frac{0,183 \times 0,192 \times 86,4}{1,31 - 0,47}$$

$$= \underline{3,61 \text{ m}^2/\text{day}.}$$

GROOTEGELUK MINE: BOREHOLE No WBR 10 RESULTS OF FOUR HOUR PUMP TEST



DATE : 22-10-87
STATIC WATER LEVEL : 36.35m
PUMP SETTING : 100m

PUMPING RATES

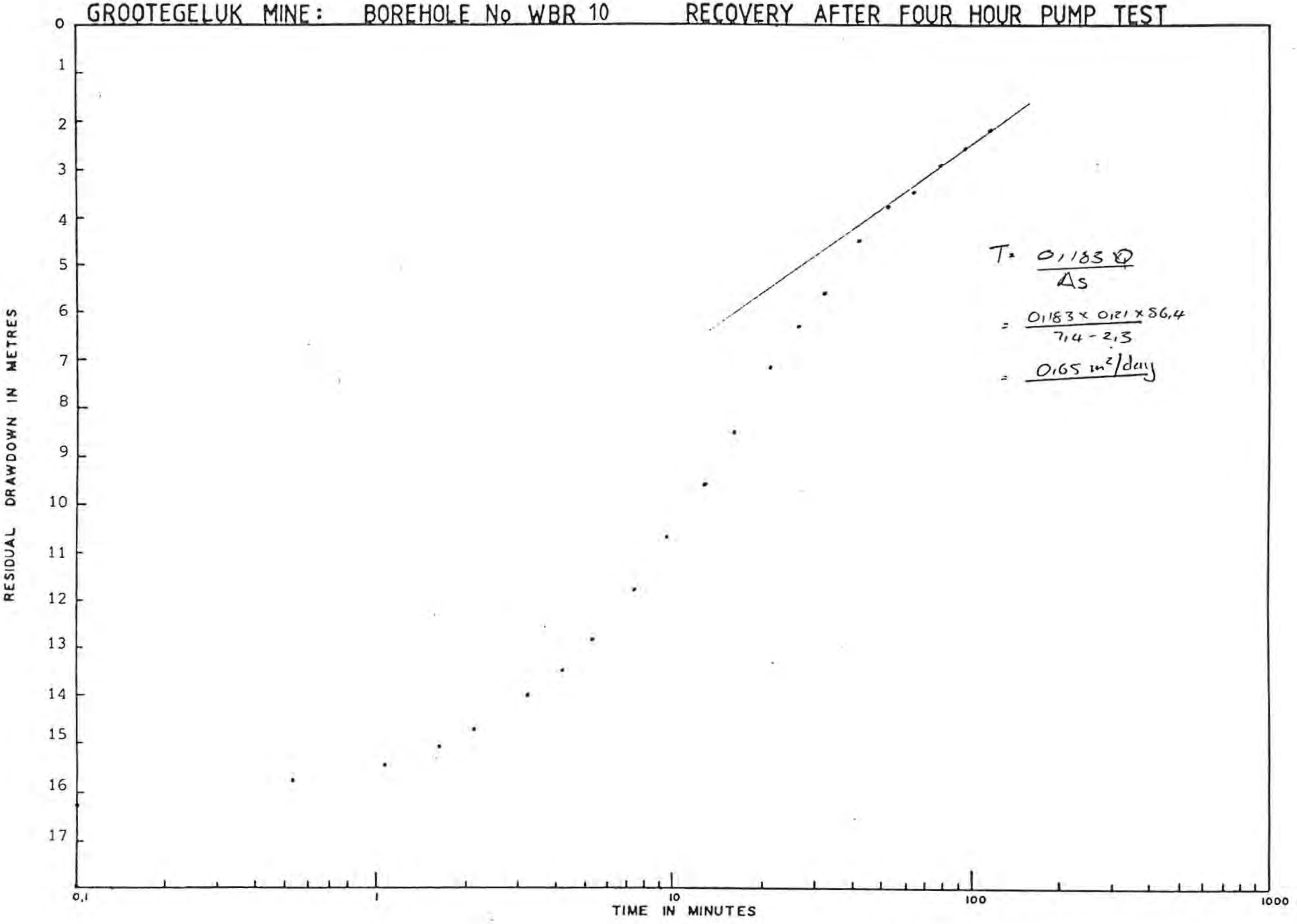
TIME min	Q l/sec
0 - 20	0.28
20 - 40	0.23
40 - 75	0.22
75 - 110	0.22
130 - 150	0.22
150 - 240	0.21

$$T = \frac{0,183\,Q}{\Delta s}$$

$$= \frac{0,183 \times 0,22 \times 86,4}{15,3 - 12,6}$$

$$= \underline{1,27\ m^2/day.}$$

GROOTEGELUK MINE: BOREHOLE No WBR 10 RECOVERY AFTER FOUR HOUR PUMP TEST

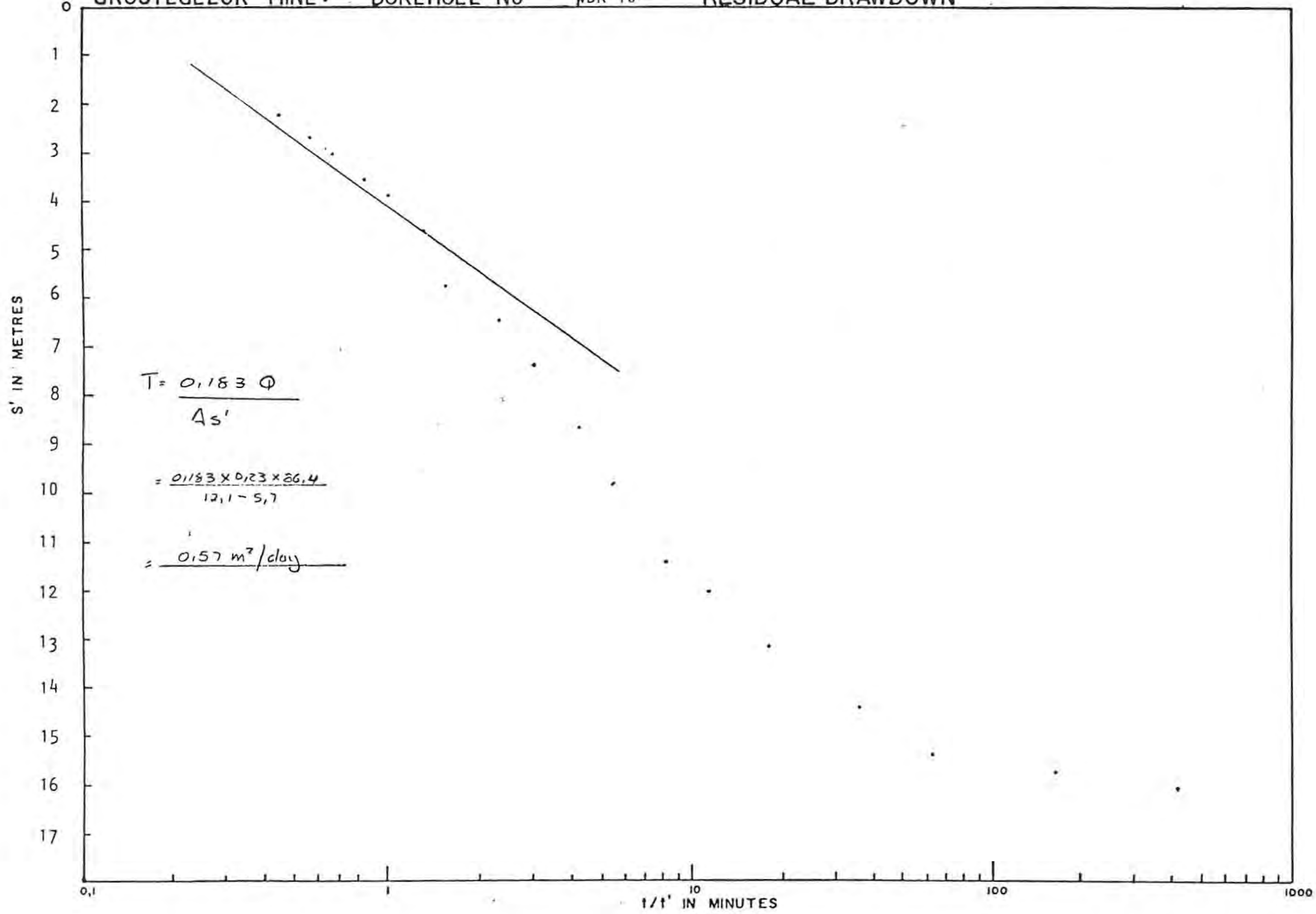


$$T = \frac{0{,}183\,Q}{\Delta s}$$

$$= \frac{0{,}183 \times 0{,}21 \times 86{,}4}{7{,}4 - 2{,}3}$$

$$= \underline{0{,}65\ m^2/day}$$

GROOTEGELUK MINE: BOREHOLE No WBR 10 RESIDUAL DRAWDOWN

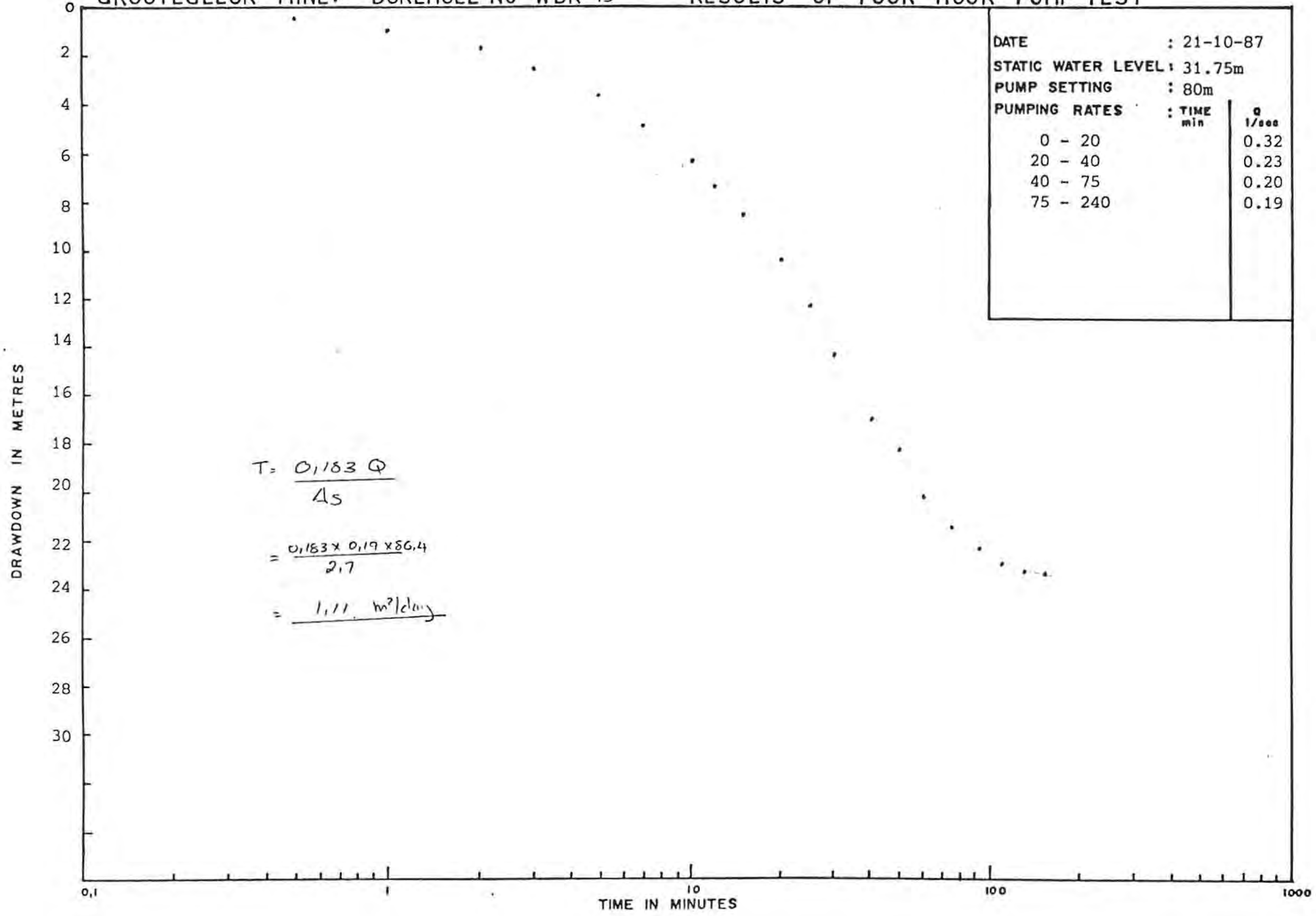


$$T = \frac{0{,}183\,Q}{\Delta s'}$$

$$= \frac{0{,}183 \times 0{,}23 \times 86{,}4}{12{,}1 - 5{,}7}$$

$$= 0{,}57\ m^2/day$$

GROOTEGELUK MINE: BOREHOLE No WBR 13 RESULTS OF FOUR HOUR PUMP TEST



DATE : 21-10-87
STATIC WATER LEVEL : 31.75m
PUMP SETTING : 80m
PUMPING RATES :

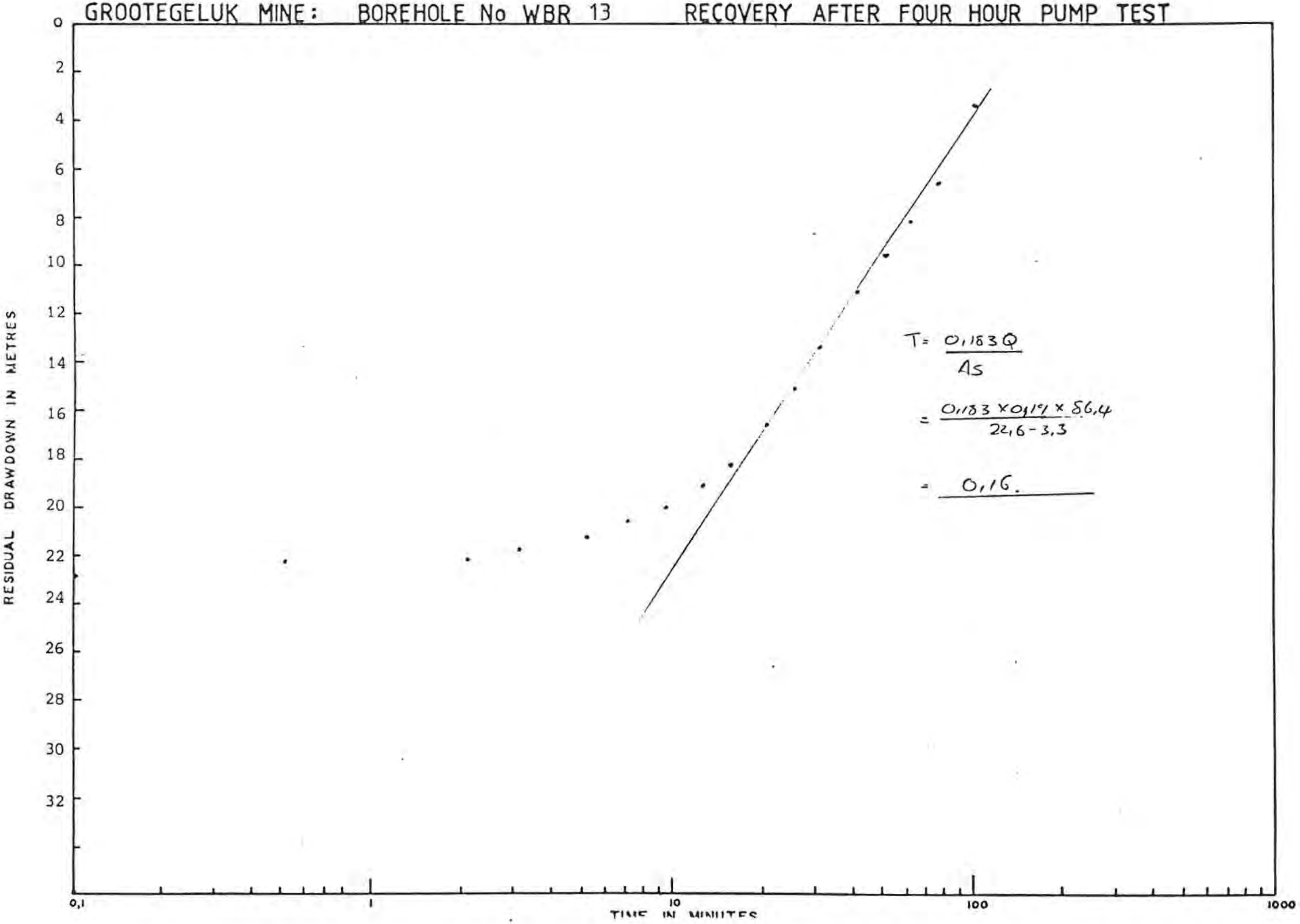
TIME min	Q l/sec
0 - 20	0.32
20 - 40	0.23
40 - 75	0.20
75 - 240	0.19

$$T = \frac{0,183\ Q}{\Delta s}$$

$$= \frac{0,183 \times 0,19 \times 86,4}{2,7}$$

$$= 1,11\ m^2/day$$

GROOTEGELUK MINE: BOREHOLE No WBR 13 RECOVERY AFTER FOUR HOUR PUMP TEST

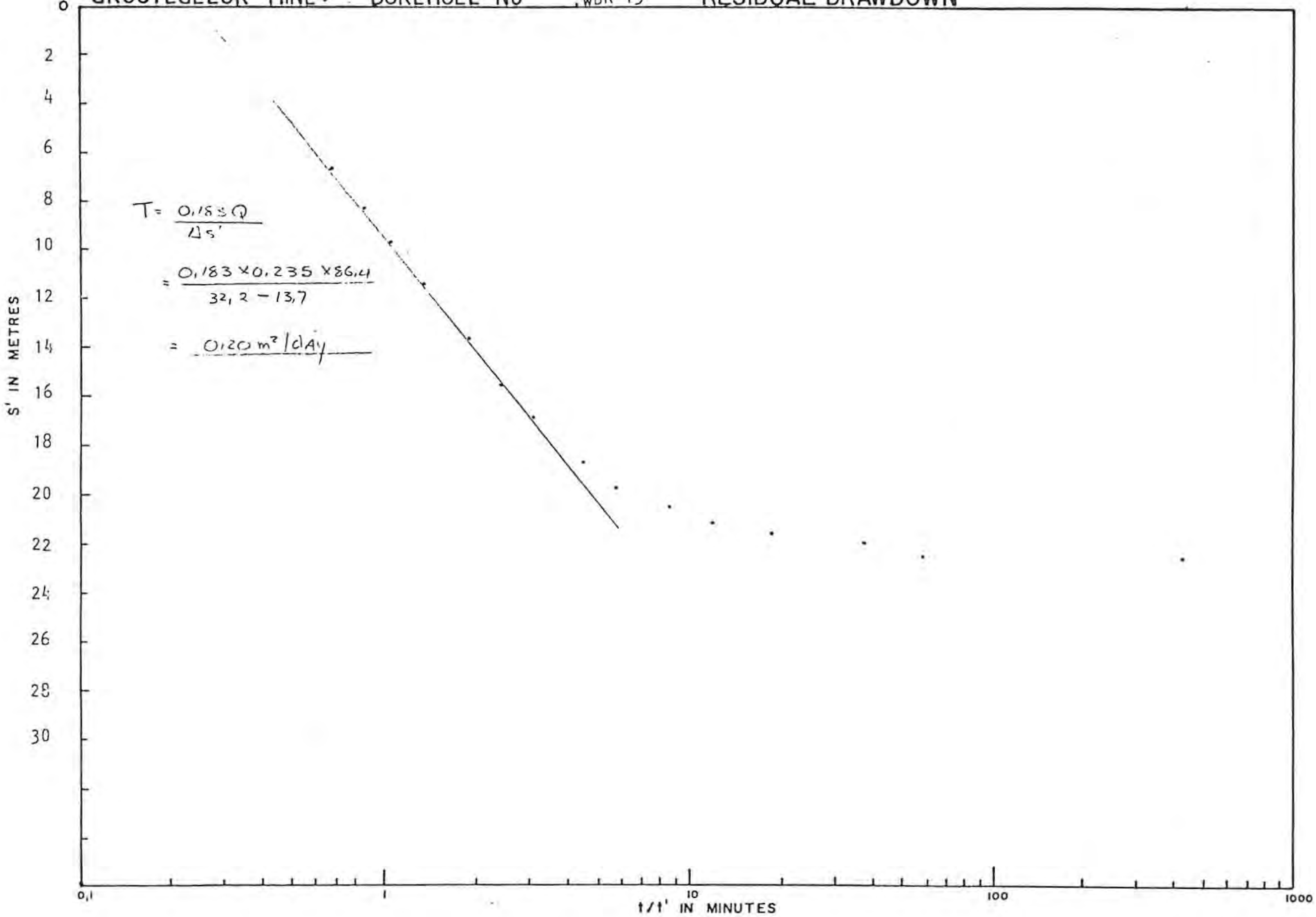


$$T = \frac{0{,}183Q}{\Delta s}$$

$$= \frac{0{,}183 \times 0{,}19 \times 86{,}4}{22{,}6 - 3{,}3}$$

$$= \underline{0{,}16.}$$

GROOTEGELUK MINE: BOREHOLE No WBR 13 RESIDUAL DRAWDOWN

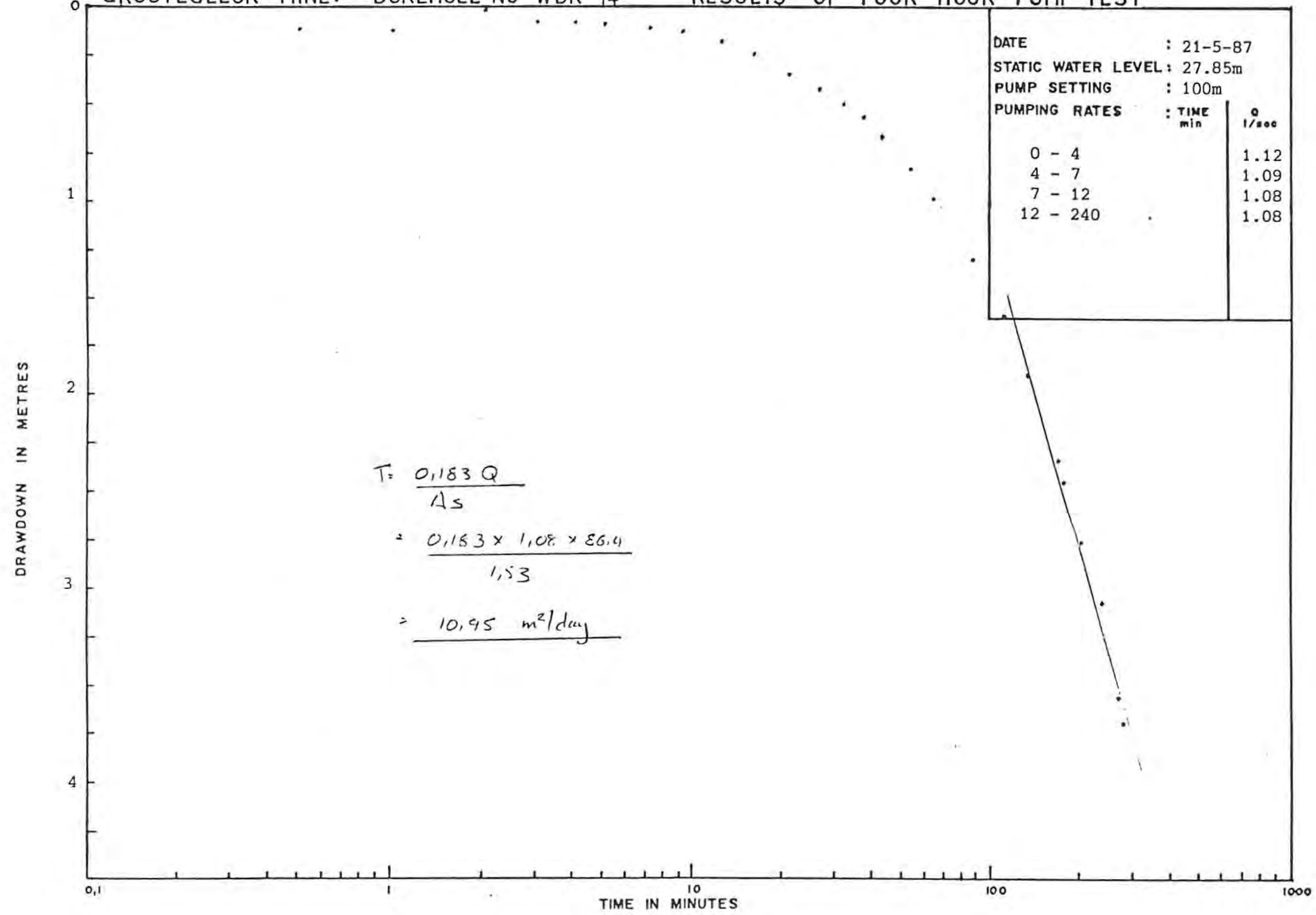


$$T = \frac{0{,}183\,Q}{\Delta s'}$$

$$= \frac{0{,}183 \times 0{,}235 \times 86{,}4}{32{,}2 - 13{,}7}$$

$$= 0{,}20 \text{ m}^2/\text{day}$$

GROOTEGELUK MINE: BOREHOLE No WBR 14 RESULTS OF FOUR HOUR PUMP TEST



DATE : 21-5-87

STATIC WATER LEVEL : 27.85m

PUMP SETTING : 100m

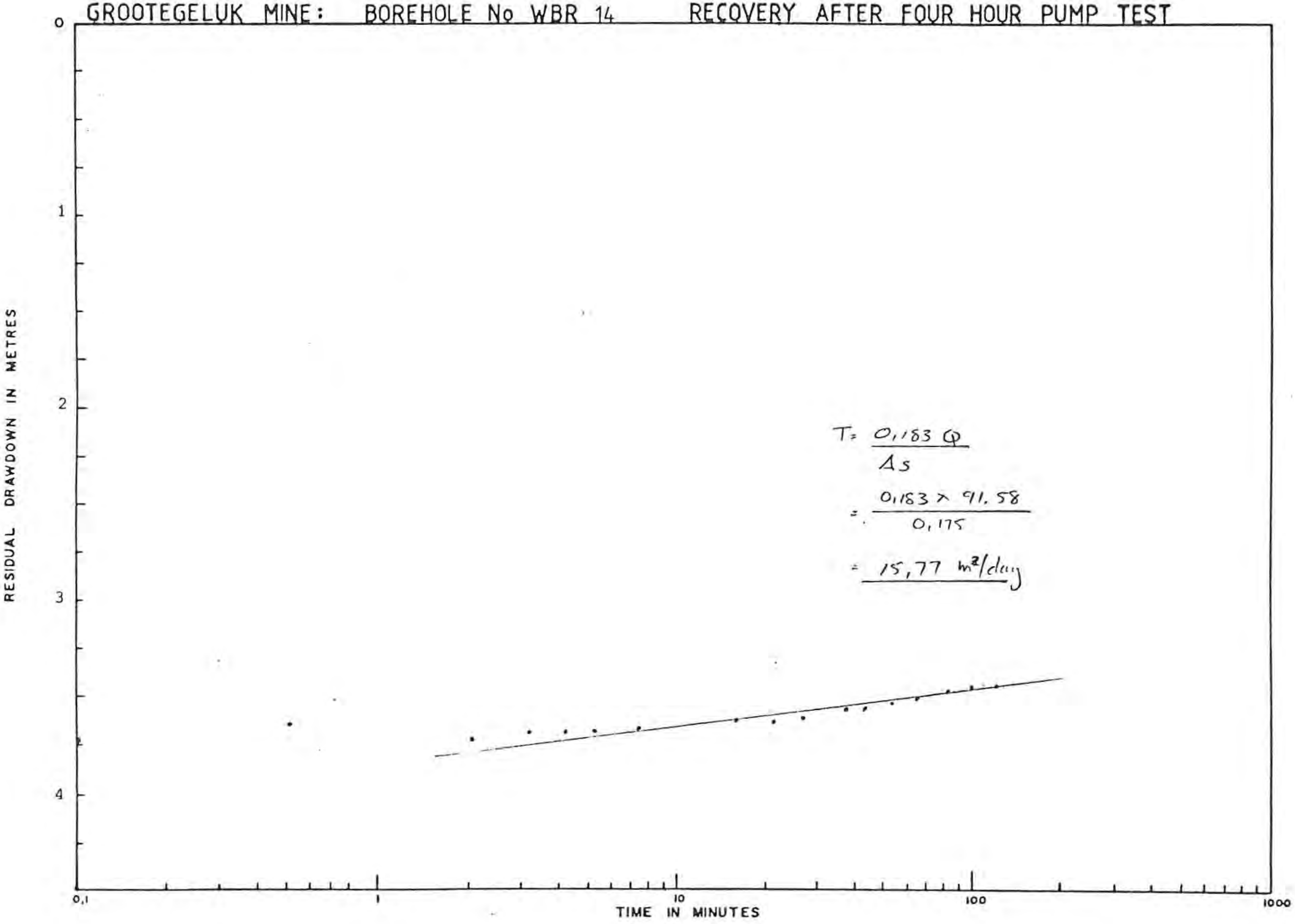
PUMPING RATES : TIME min	Q l/sec
0 - 4	1.12
4 - 7	1.09
7 - 12	1.08
12 - 240	1.08

$$T = \frac{0,183\,Q}{\Delta s}$$

$$= \frac{0,183 \times 1,08 \times 86,4}{1,53}$$

$$= \underline{10,95 \ m^2/day}$$

GROOTEGELUK MINE: BOREHOLE No WBR 14 RECOVERY AFTER FOUR HOUR PUMP TEST

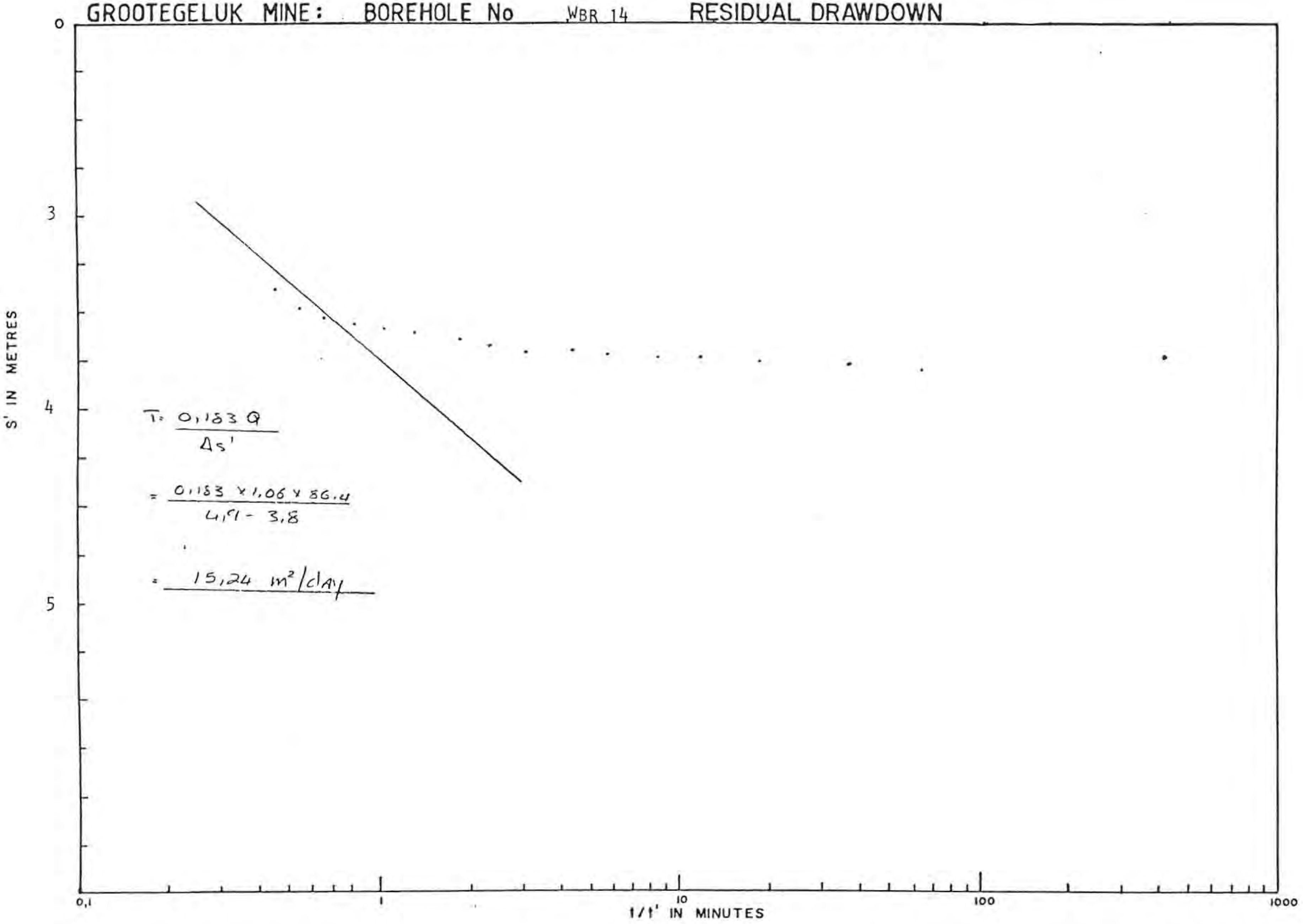


$$T = \frac{0{,}183\ Q}{\Delta s}$$

$$= \frac{0{,}183 \times 91{,}58}{0{,}175}$$

$$= 15{,}77\ m^2/day$$

GROOTEGELUK MINE: BOREHOLE No WBR 14 RESIDUAL DRAWDOWN

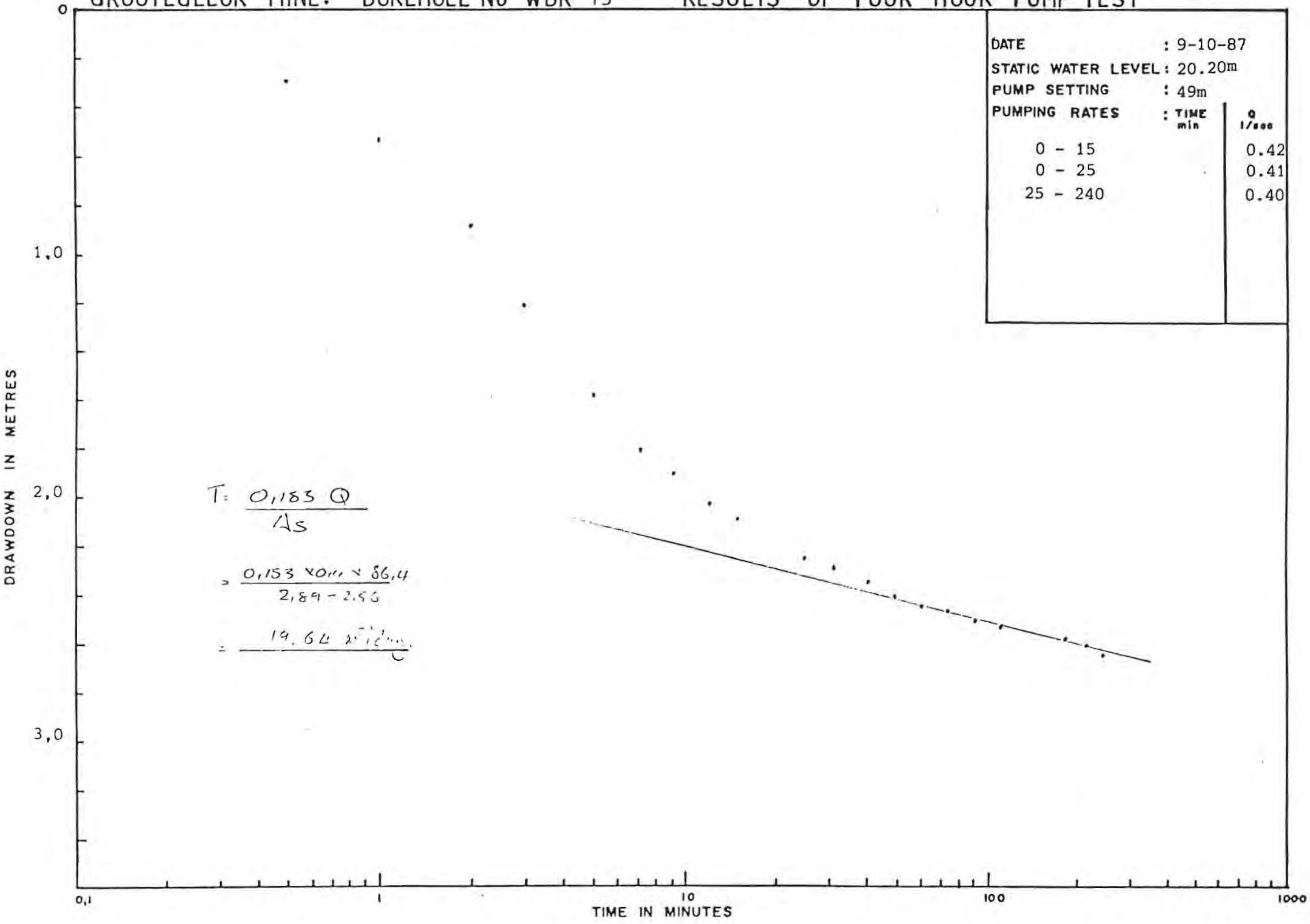


$$T = \frac{0{,}183\,Q}{\Delta s'}$$

$$= \frac{0{,}183 \times 1{,}06 \times 86{,}4}{4{,}91 - 3{,}8}$$

$$= \underline{15{,}24\ m^2/day}$$

GROOTEGELUK MINE: BOREHOLE No WBR 15 RESULTS OF FOUR HOUR PUMP TEST



DATE : 9-10-87
STATIC WATER LEVEL : 20.20m
PUMP SETTING : 49m

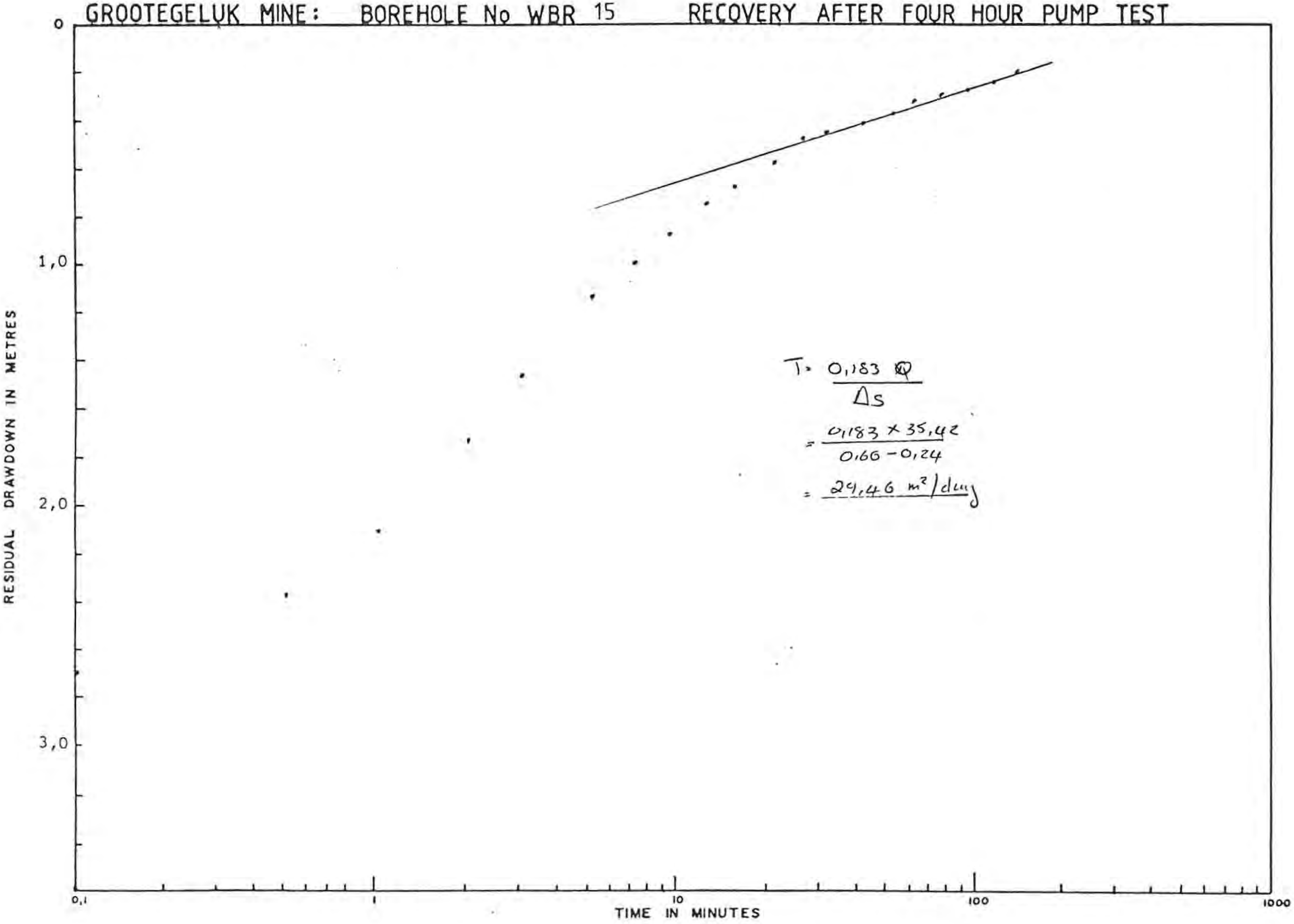
PUMPING RATES : TIME min	Q l/sec
0 - 15	0.42
0 - 25	0.41
25 - 240	0.40

$$T = \frac{0,183\ Q}{\Delta s}$$

$$= \frac{0,153 \times 0,4 \times 86,4}{2,89 - 2,56}$$

= 19.64 [illegible]

GROOTEGELUK MINE: BOREHOLE No WBR 15 RECOVERY AFTER FOUR HOUR PUMP TEST

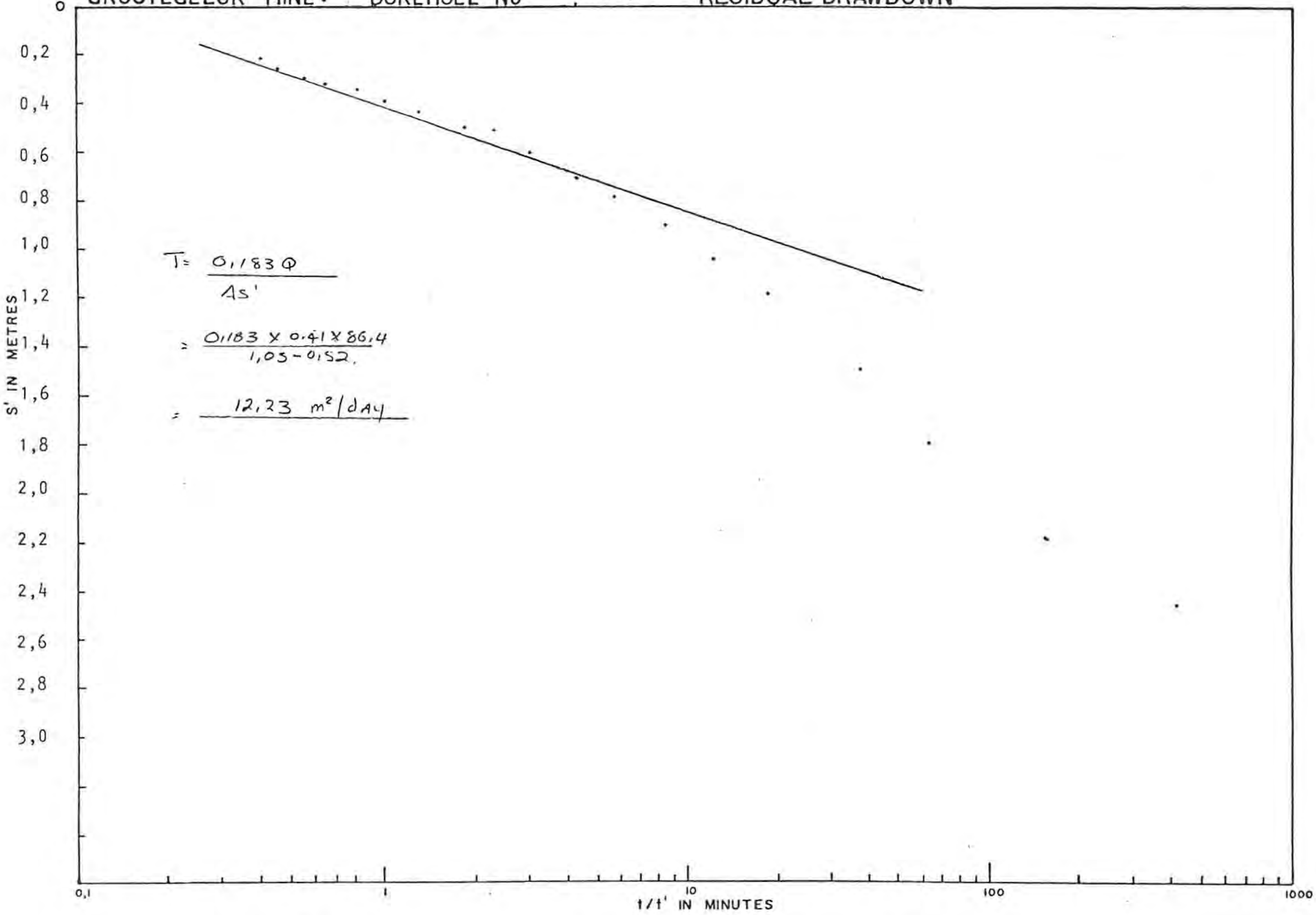


$$T = \frac{0,183\, Q}{\Delta s}$$

$$= \frac{0,183 \times 35,42}{0,66 - 0,24}$$

$$= \underline{29,46 \text{ m}^2/\text{day}}$$

GROOTEGELUK MINE: BOREHOLE No WBR 15 RESIDUAL DRAWDOWN

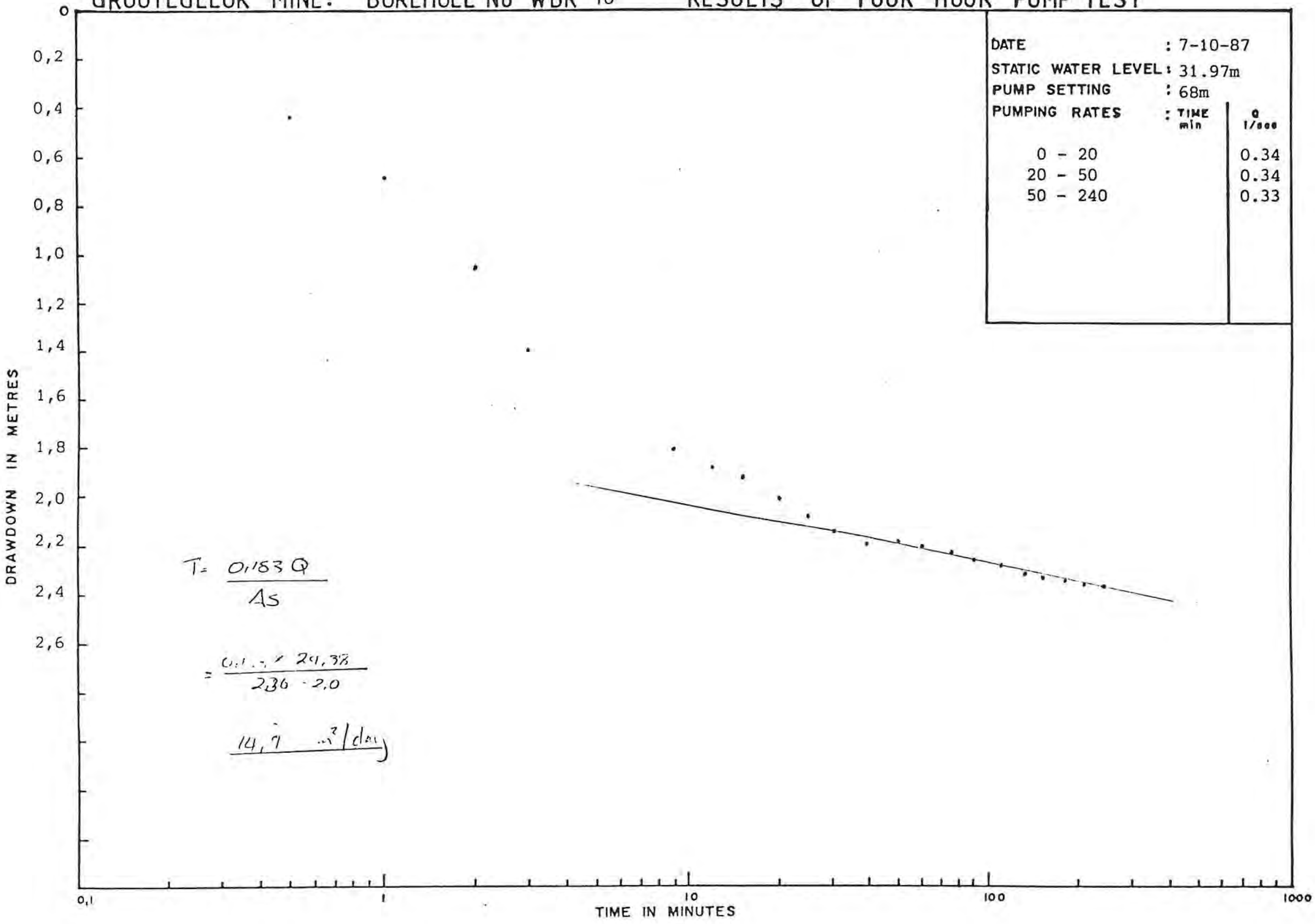


$$T = \frac{0,183\,Q}{\Delta s'}$$

$$= \frac{0,183 \times 0.41 \times 86,4}{1,03 - 0,52}$$

$$= 12,23 \ m^2/day$$

GROOTEGELUK MINE: BOREHOLE No WBR 16 RESULTS OF FOUR HOUR PUMP TEST



DATE : 7-10-87
STATIC WATER LEVEL : 31.97m
PUMP SETTING : 68m
PUMPING RATES :

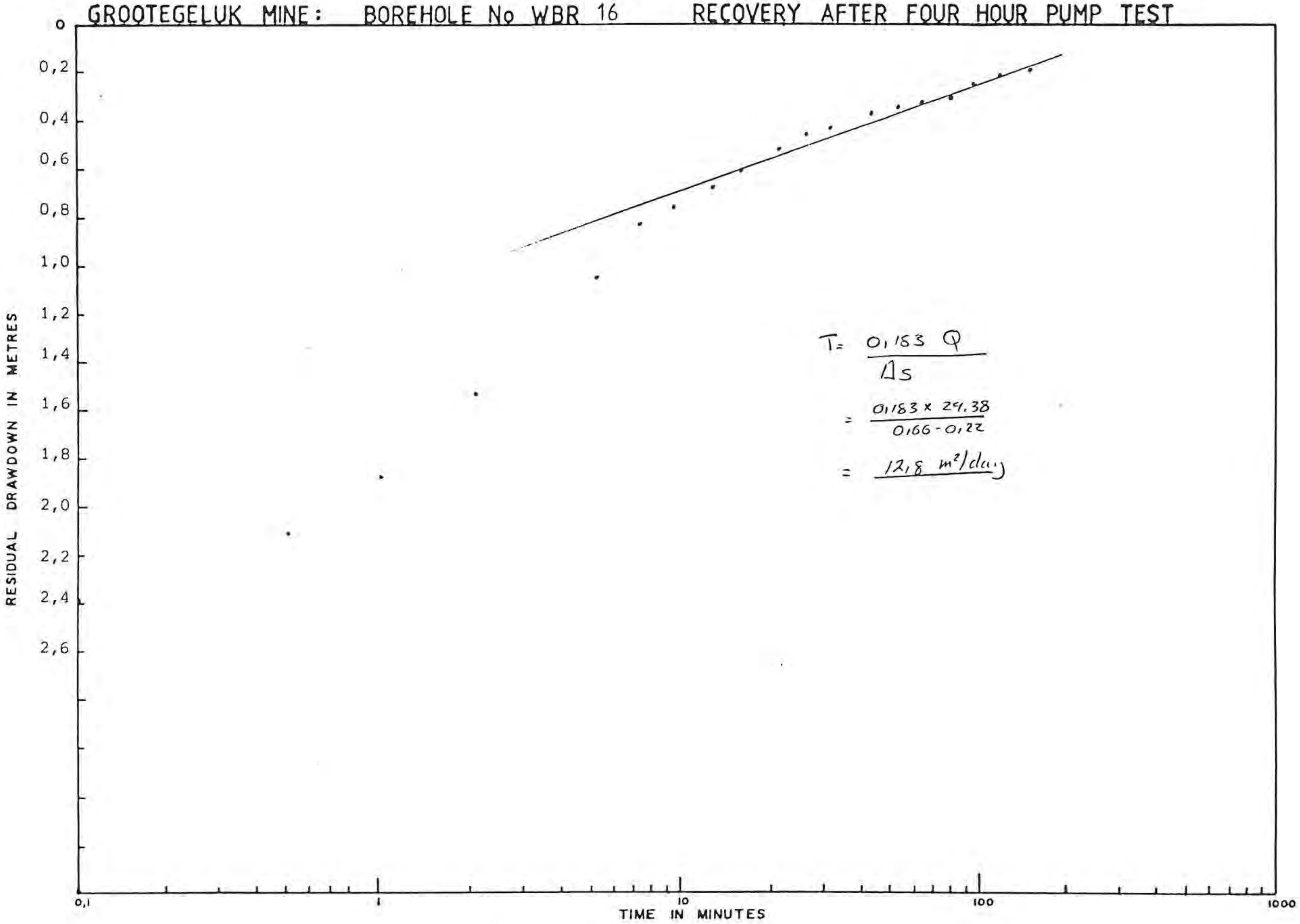
TIME min	Q l/sec
0 - 20	0.34
20 - 50	0.34
50 - 240	0.33

$$T = \frac{0,183\,Q}{\Delta s}$$

$$= \frac{0,183 \times 29,38}{2,36 - 2,0}$$

14,7 m³/day

GROOTEGELUK MINE: BOREHOLE No WBR 16 RECOVERY AFTER FOUR HOUR PUMP TEST

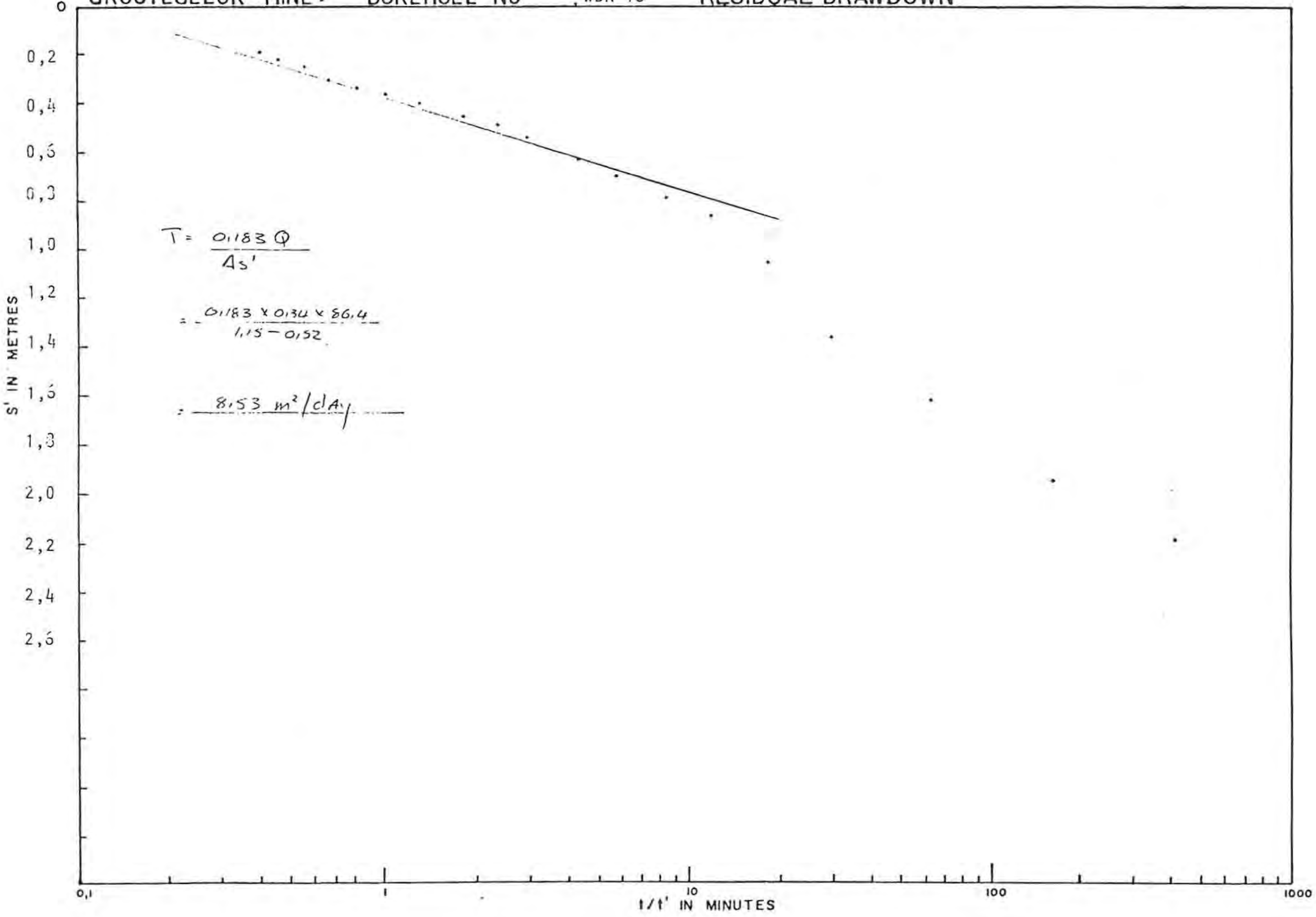


$$T = \frac{0{,}183\ Q}{\Delta s}$$

$$= \frac{0{,}183 \times 29.38}{0{,}66 - 0{,}22}$$

$$= \underline{12{,}8\ m^2/day}$$

GROOTEGELUK MINE: BOREHOLE No WBR 16 RESIDUAL DRAWDOWN

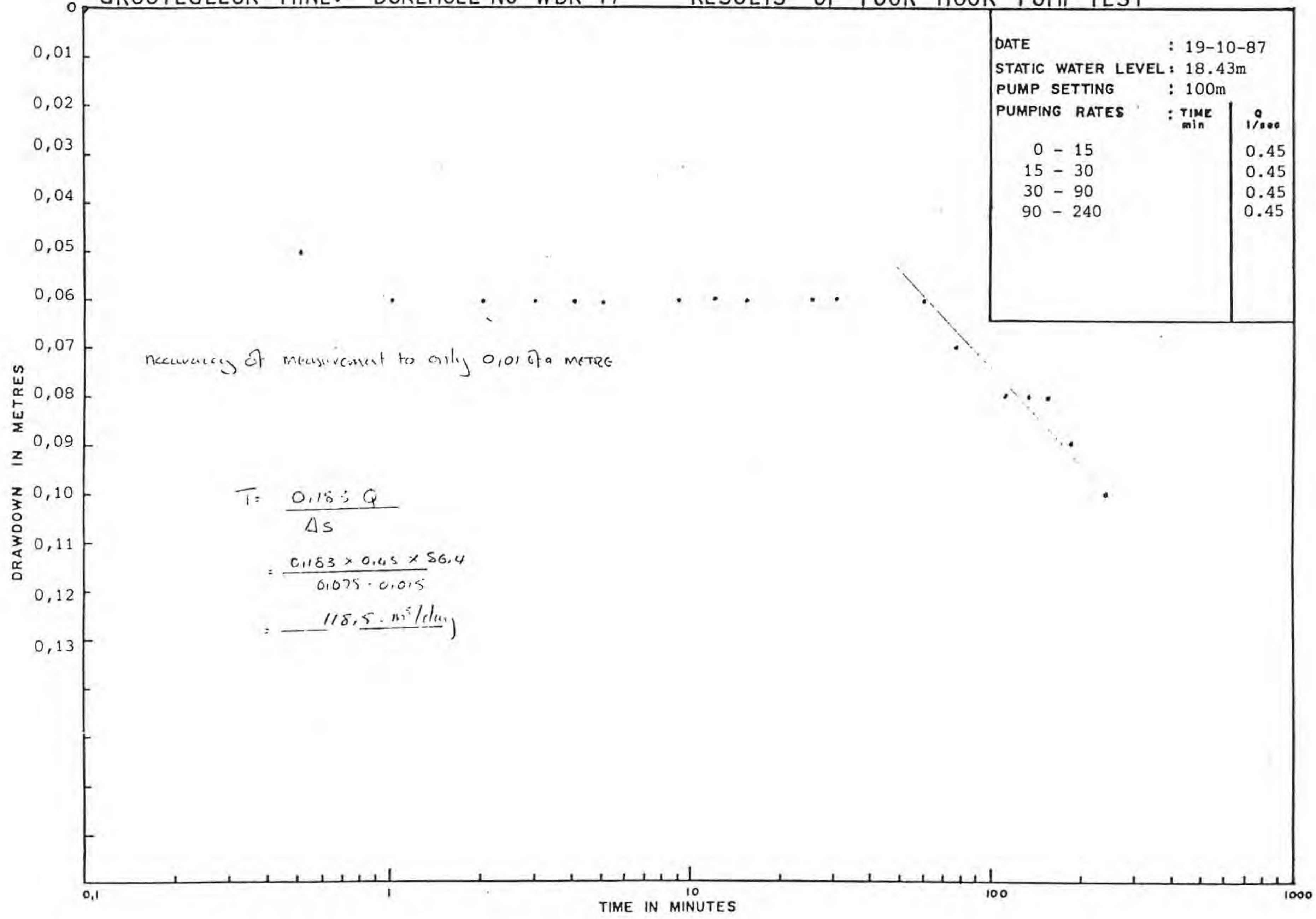


$$T = \frac{0{,}183\,Q}{\Delta s'}$$

$$= \frac{0{,}183 \times 0{,}34 \times 86{,}4}{1{,}15 - 0{,}52}$$

$$= 8{,}53 \ m^2/day$$

GROOTEGELUK MINE: BOREHOLE No WBR 17 RESULTS OF FOUR HOUR PUMP TEST



DATE : 19-10-87
STATIC WATER LEVEL : 18.43m
PUMP SETTING : 100m
PUMPING RATES :

TIME min	Q l/sec
0 - 15	0.45
15 - 30	0.45
30 - 90	0.45
90 - 240	0.45

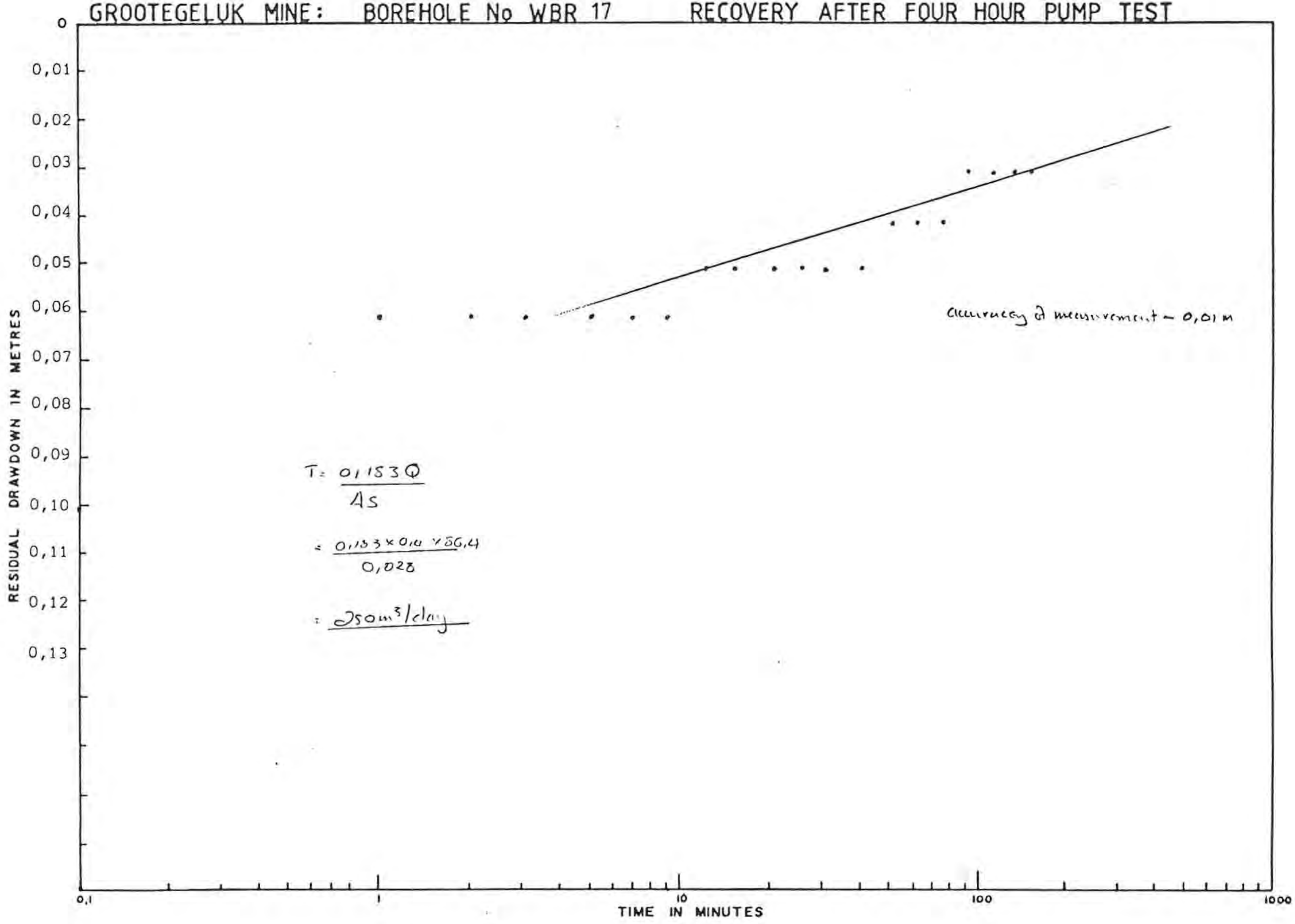
accuracy of measurement to only 0,01 of a METRE

$$T = \frac{0{,}183\ Q}{\Delta s}$$

$$= \frac{0{,}183 \times 0{,}45 \times 86{,}4}{0{,}075 - 0{,}015}$$

$$= \underline{118{,}5\ m^3/day}$$

GROOTEGELUK MINE: BOREHOLE No WBR 17 RECOVERY AFTER FOUR HOUR PUMP TEST



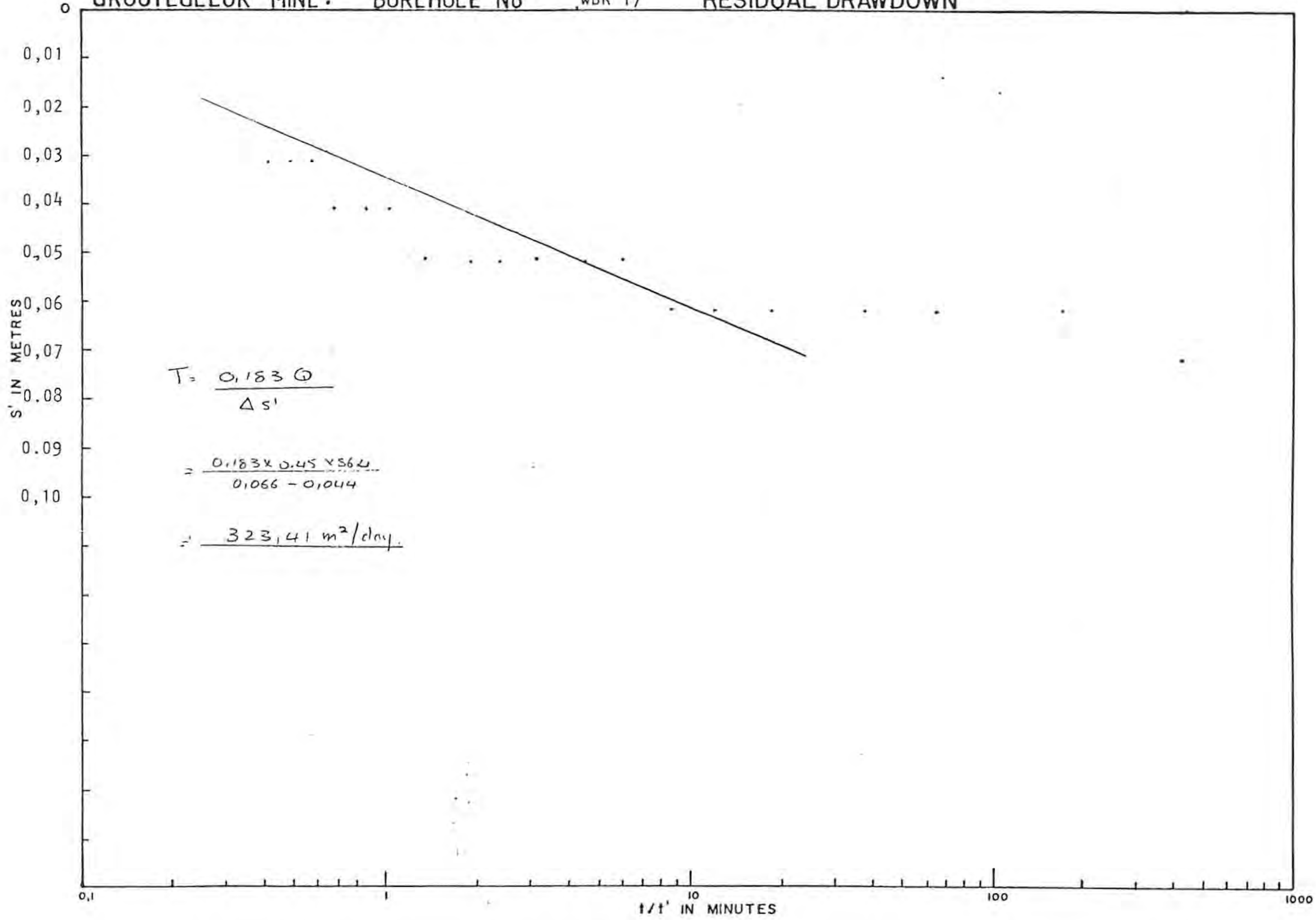
accuracy of measurement ~ 0,01 m

$$T = \frac{0{,}183\,Q}{\Delta s}$$

$$= \frac{0{,}183 \times 0{,}44 \times 86{,}4}{0{,}028}$$

= 250 m³/day

GROOTEGELUK MINE: BOREHOLE No WBR 17 RESIDUAL DRAWDOWN

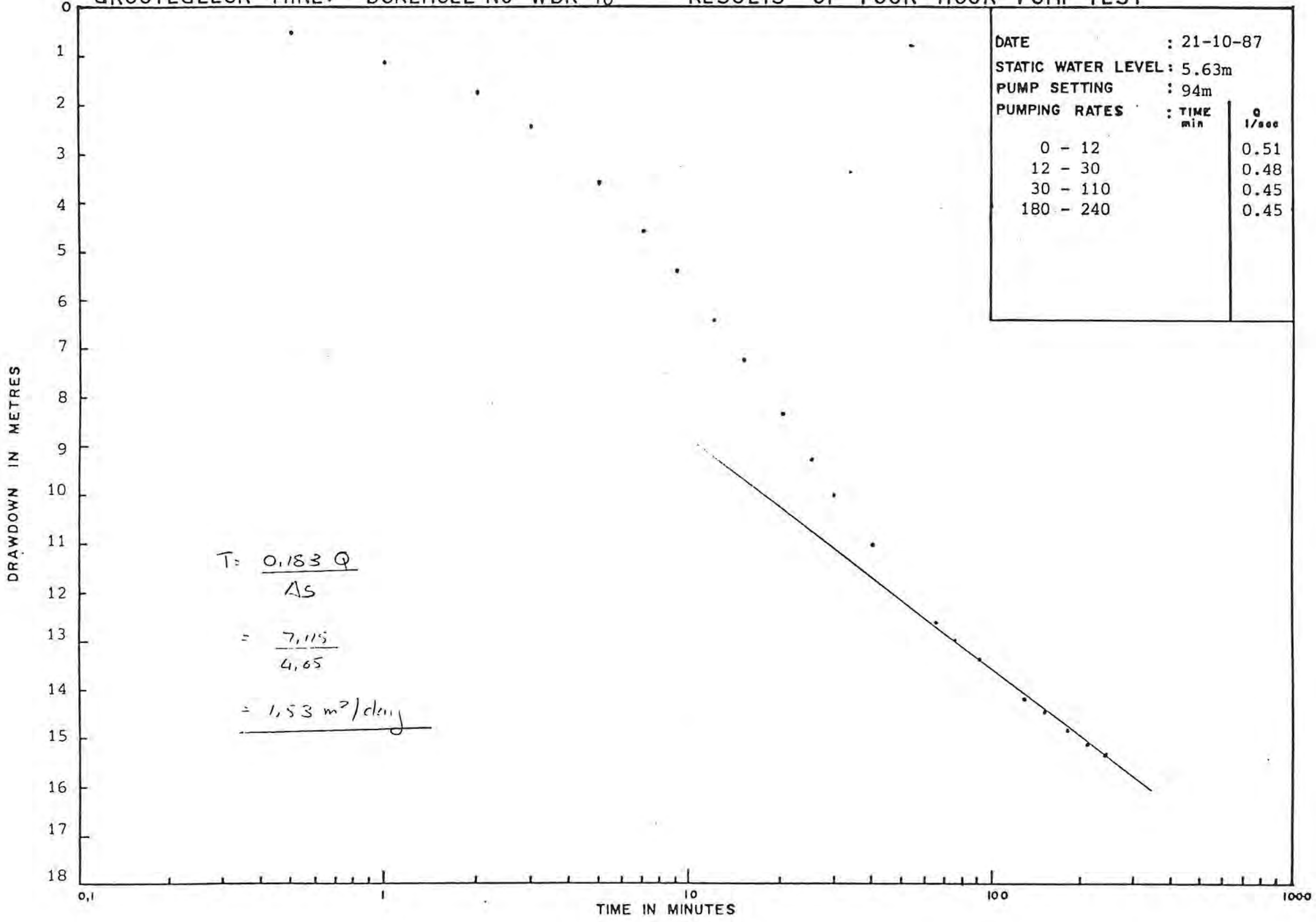


$$T = \frac{0{,}183\,Q}{\Delta s'}$$

$$= \frac{0{,}183 \times 0.45 \times 864}{0{,}066 - 0{,}044}$$

$$= \underline{323{,}41 \text{ m}^2/\text{day}}$$

GROOTEGELUK MINE: BOREHOLE No WBR 18 RESULTS OF FOUR HOUR PUMP TEST



DATE : 21-10-87
STATIC WATER LEVEL : 5.63m
PUMP SETTING : 94m
PUMPING RATES :

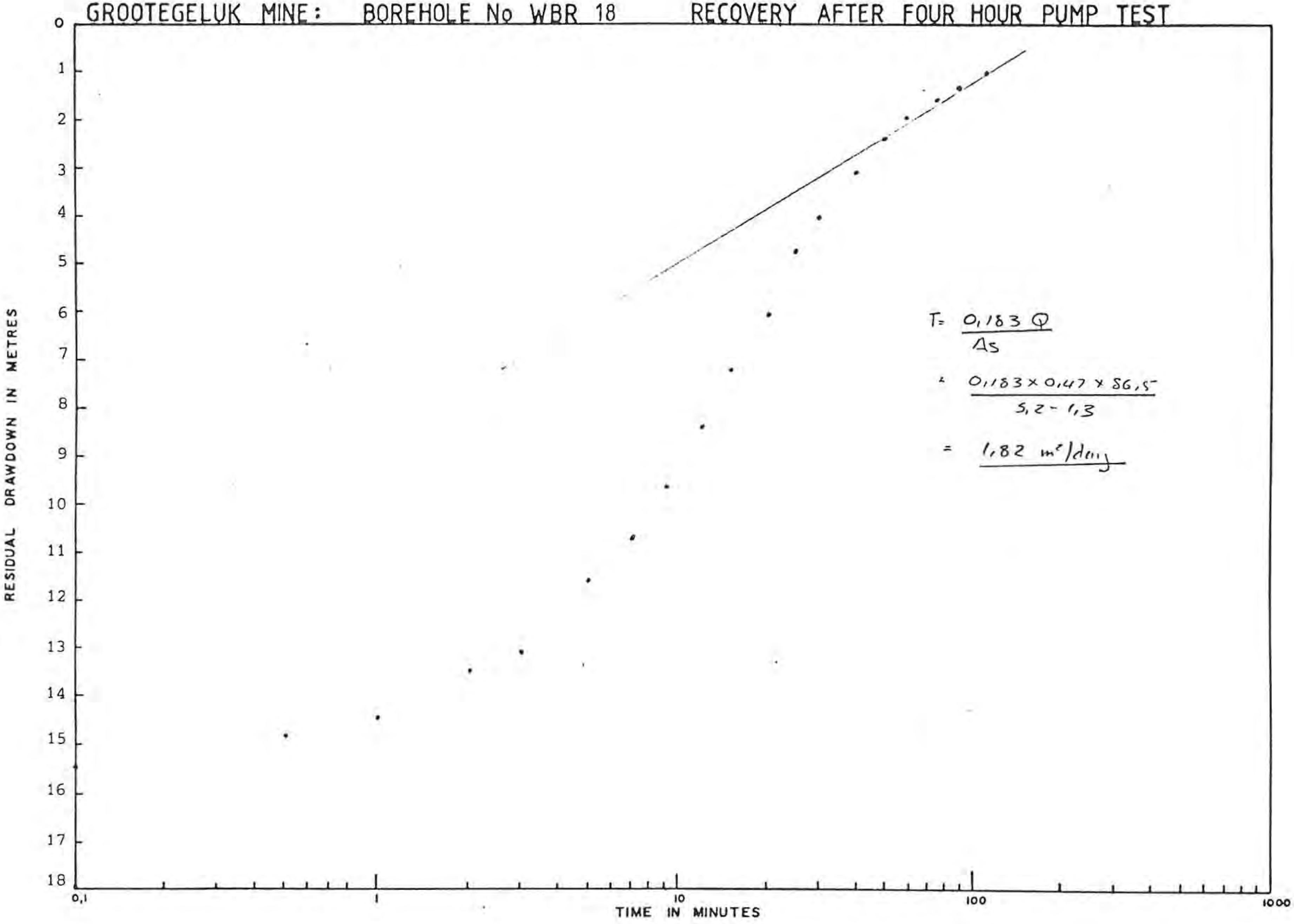
TIME min	Q l/sec
0 - 12	0.51
12 - 30	0.48
30 - 110	0.45
180 - 240	0.45

$$T = \frac{0{,}183\ Q}{\Delta s}$$

$$= \frac{7{,}115}{4{,}65}$$

$$= 1{,}53\ m^2/day$$

GROOTEGELUK MINE: BOREHOLE No WBR 18 RECOVERY AFTER FOUR HOUR PUMP TEST

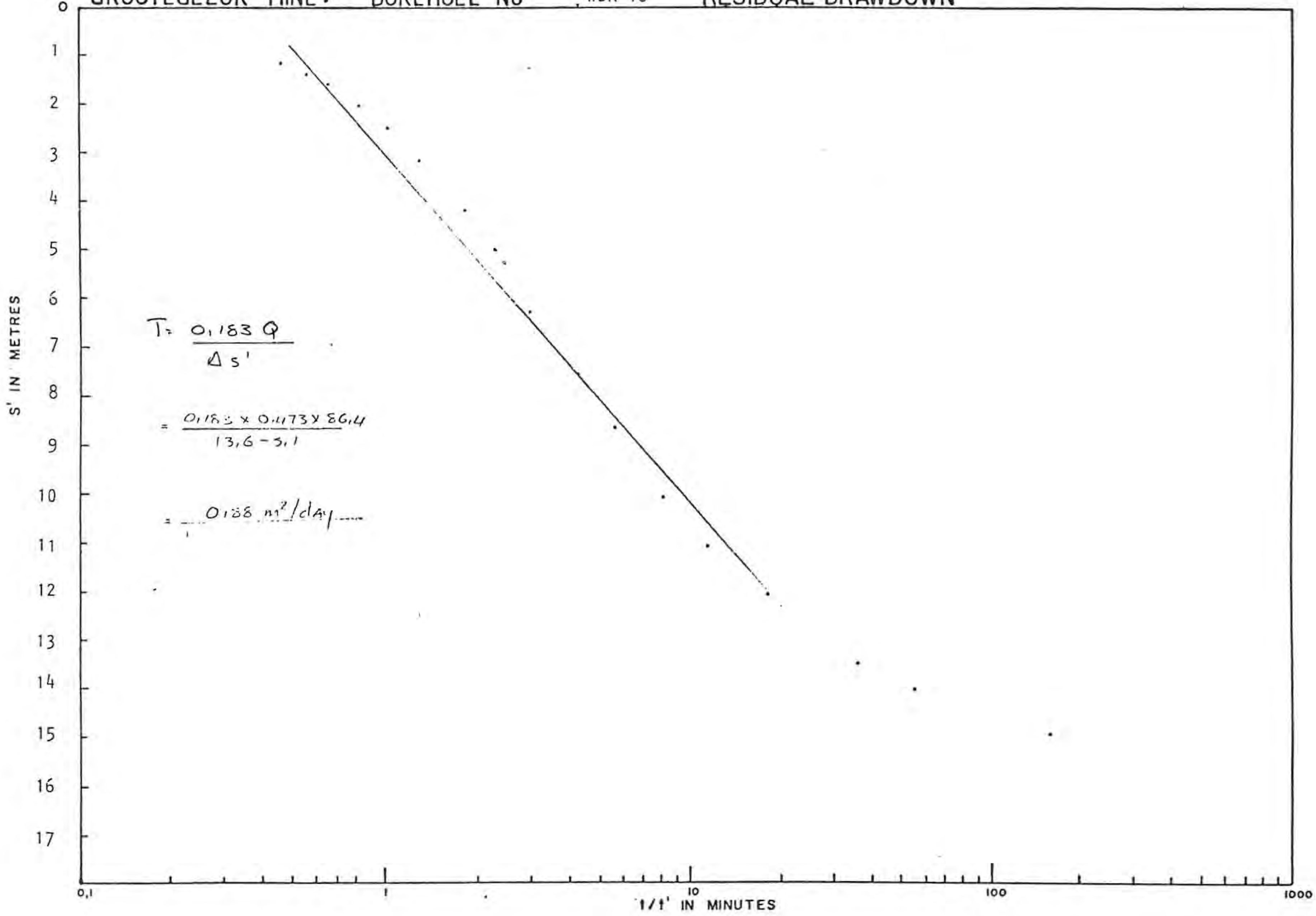


$$T = \frac{0,183\ Q}{\Delta s}$$

$$= \frac{0,183 \times 0,47 \times 86,5}{5,2 - 1,3}$$

$$= \underline{1,82\ m^2/day}$$

GROOTEGELUK MINE: BOREHOLE No WBR 18 RESIDUAL DRAWDOWN

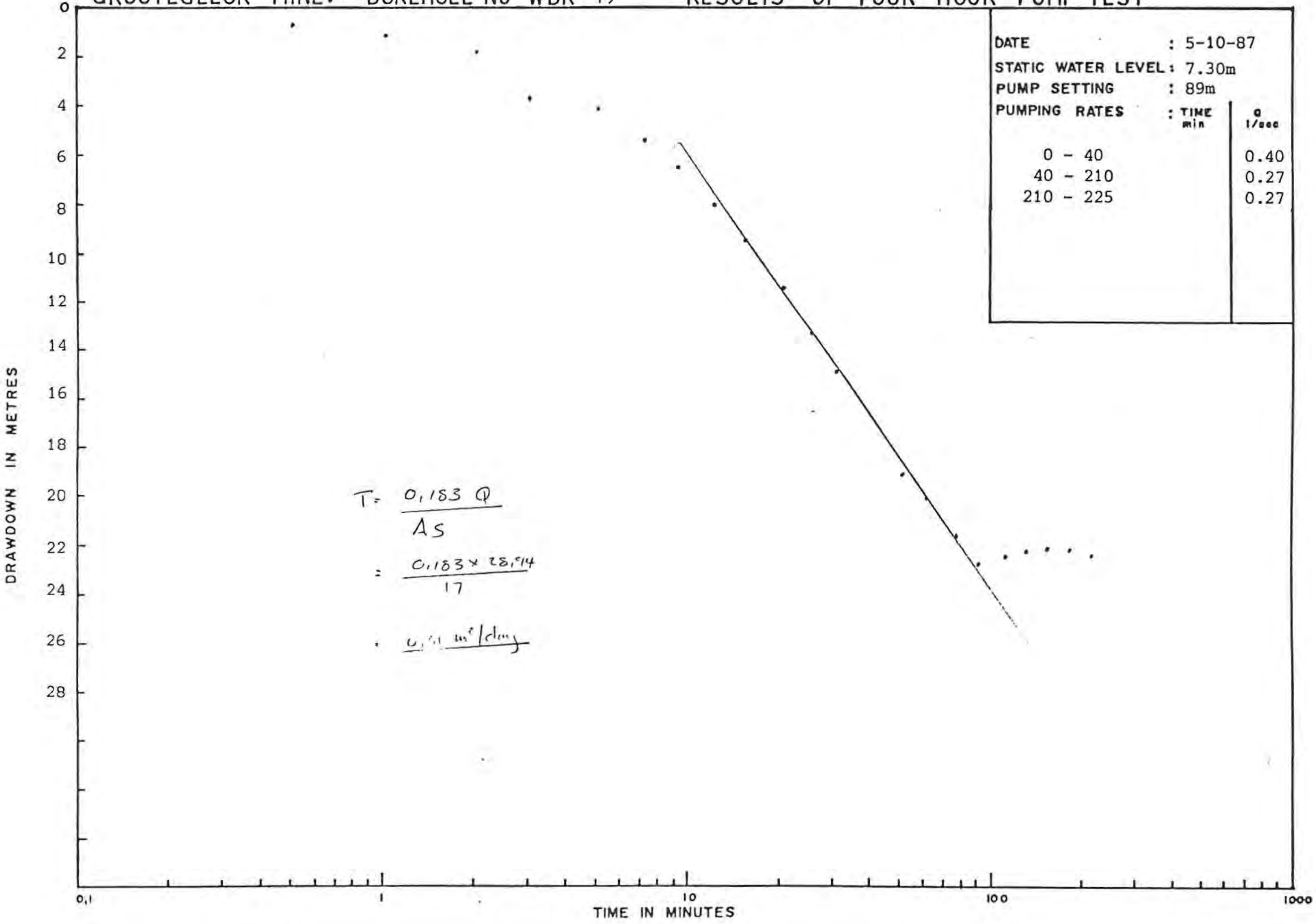


$$T = \frac{0,183\ Q}{\Delta s'}$$

$$= \frac{0,183 \times 0,473 \times 86,4}{13,6 - 3,1}$$

$$= 0,188\ m^2/day$$

GROOTEGELUK MINE: BOREHOLE No WBR 19 RESULTS OF FOUR HOUR PUMP TEST



DATE : 5-10-87
STATIC WATER LEVEL : 7.30m
PUMP SETTING : 89m

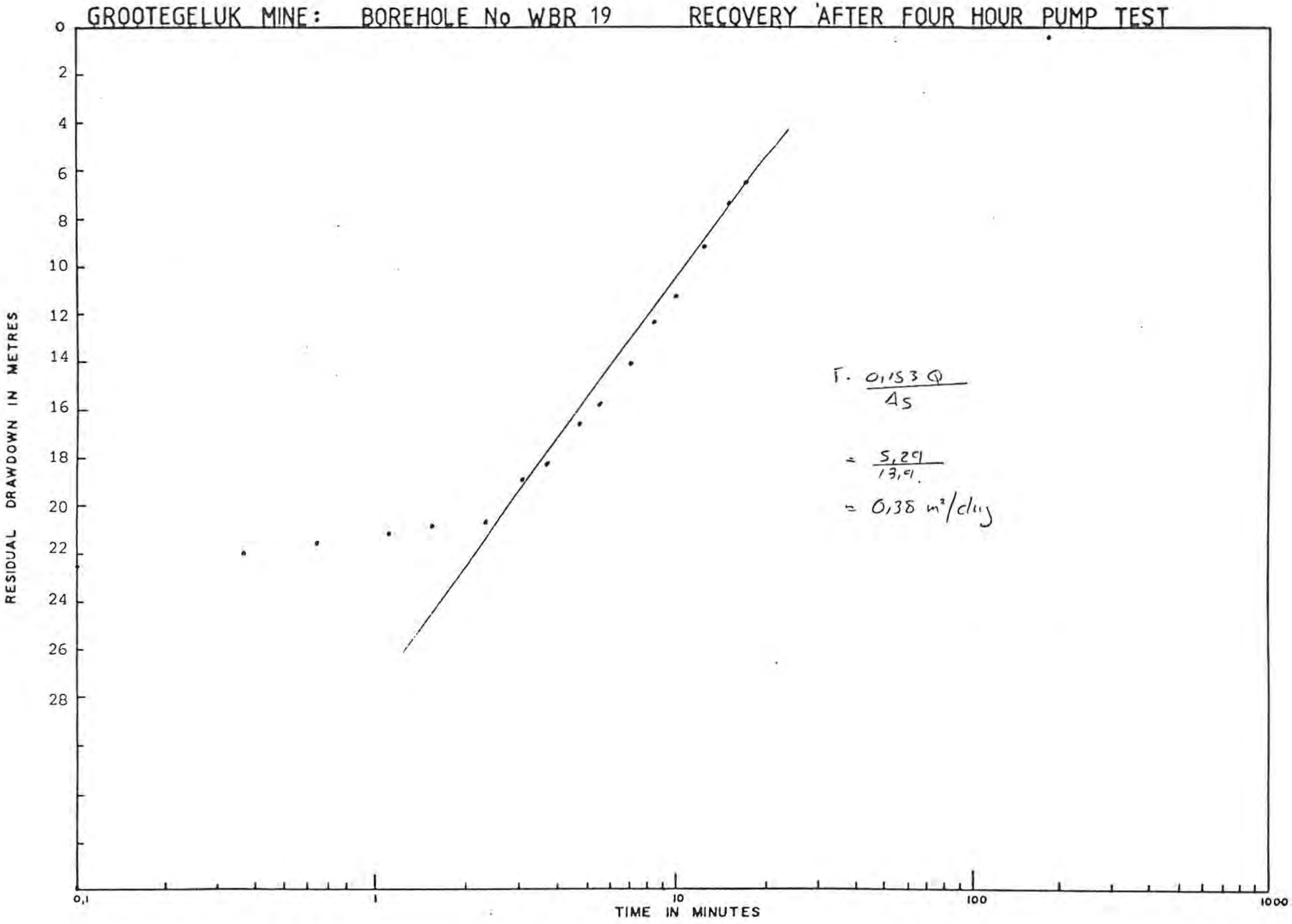
PUMPING RATES : TIME min	Q l/sec
0 - 40	0.40
40 - 210	0.27
210 - 225	0.27

$$T = \frac{0,183\ Q}{\Delta s}$$

$$= \frac{0,183 \times 28,94}{17}$$

$$= 0,31\ m^2/day$$

GROOTEGELUK MINE: BOREHOLE No WBR 19 RECOVERY AFTER FOUR HOUR PUMP TEST

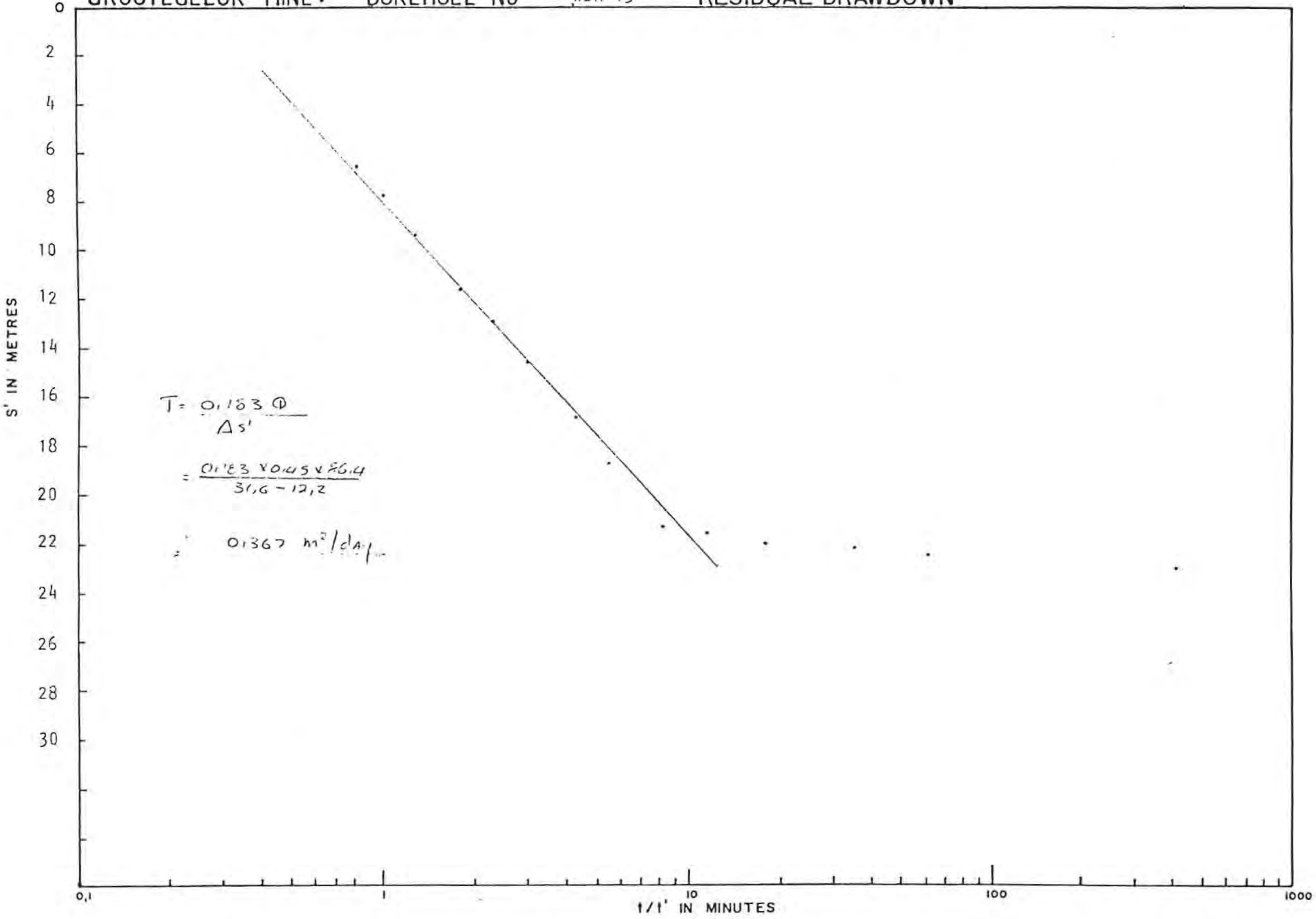


$T = \frac{0,153 Q}{\Delta s}$

$= \frac{5,29}{13,9}$

$= 0,38 \text{ m}^2/\text{day}$

GROOTEGELUK MINE: BOREHOLE No WBR 19 RESIDUAL DRAWDOWN

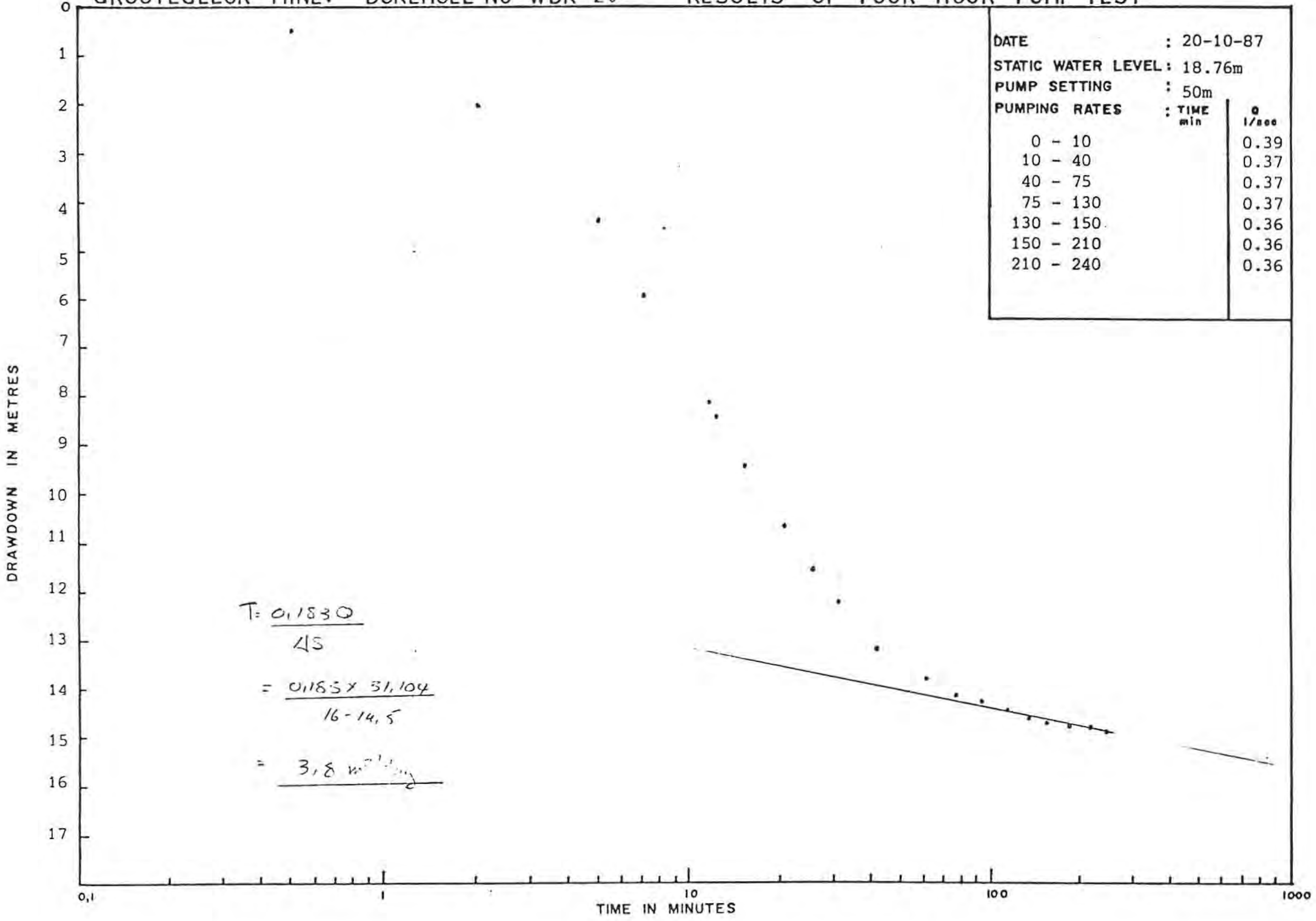


$$T = \frac{0,183\ Q}{\Delta s'}$$

$$= \frac{0,183 \times 0,45 \times 86,4}{31,6 - 12,2}$$

$$= 0,367\ m^2/day$$

GROOTEGELUK MINE: BOREHOLE No WBR 20 RESULTS OF FOUR HOUR PUMP TEST



DATE : 20-10-87

STATIC WATER LEVEL : 18.76m

PUMP SETTING : 50m

PUMPING RATES :

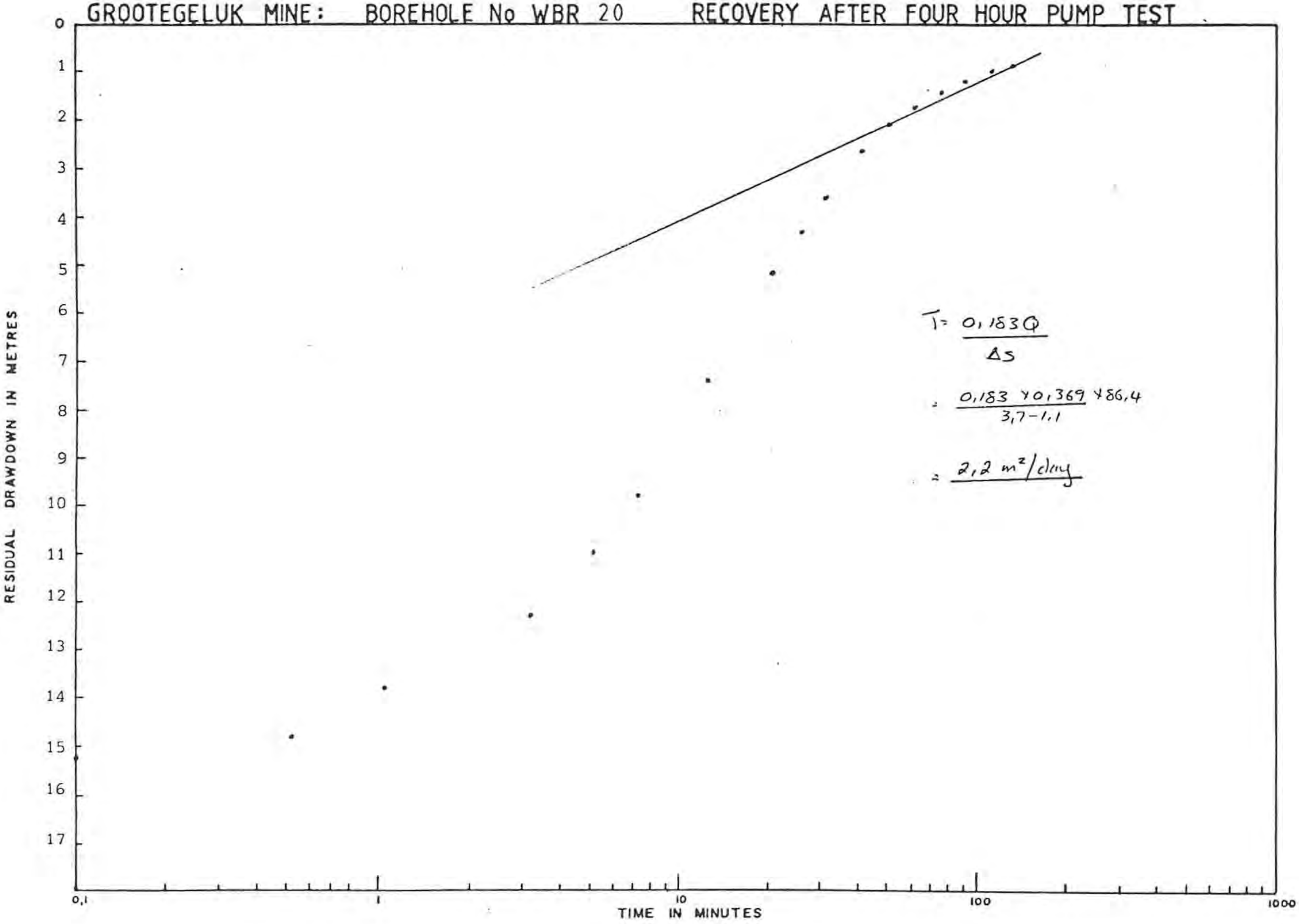
TIME min	Q l/sec
0 - 10	0.39
10 - 40	0.37
40 - 75	0.37
75 - 130	0.37
130 - 150	0.36
150 - 210	0.36
210 - 240	0.36

$$T = \frac{0,183Q}{\Delta S}$$

$$= \frac{0,183 \times 31,104}{16 - 14,5}$$

$$= \underline{3,8\ m^2/day}$$

GROOTEGELUK MINE: BOREHOLE No WBR 20 RECOVERY AFTER FOUR HOUR PUMP TEST

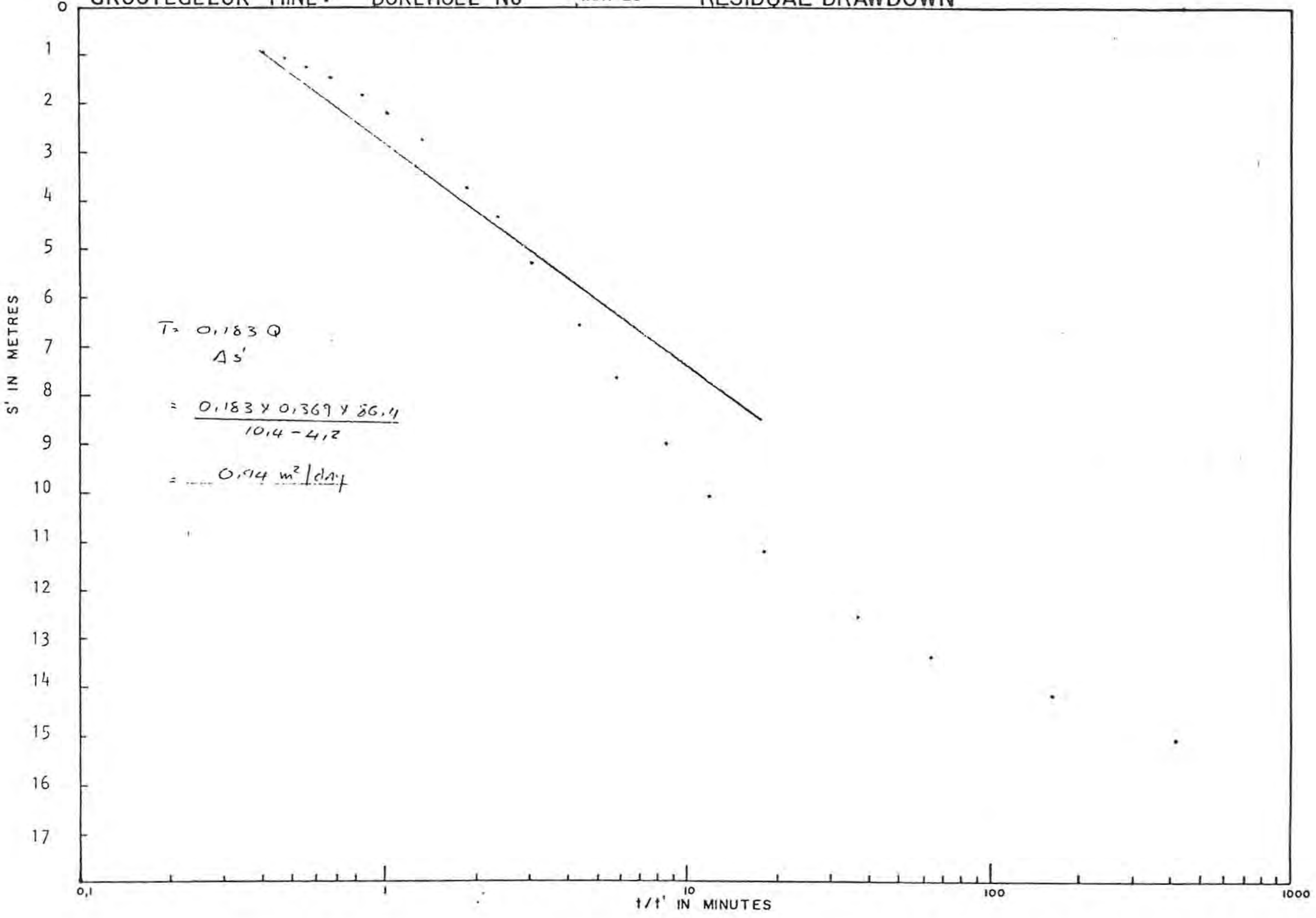


$T = \frac{0,183Q}{\Delta s}$

$= \frac{0,183 \times 0,369 \times 86,4}{3,7-1,1}$

$= \underline{2,2\ m^2/day}$

GROOTEGELUK MINE: BOREHOLE No WBR 20 RESIDUAL DRAWDOWN

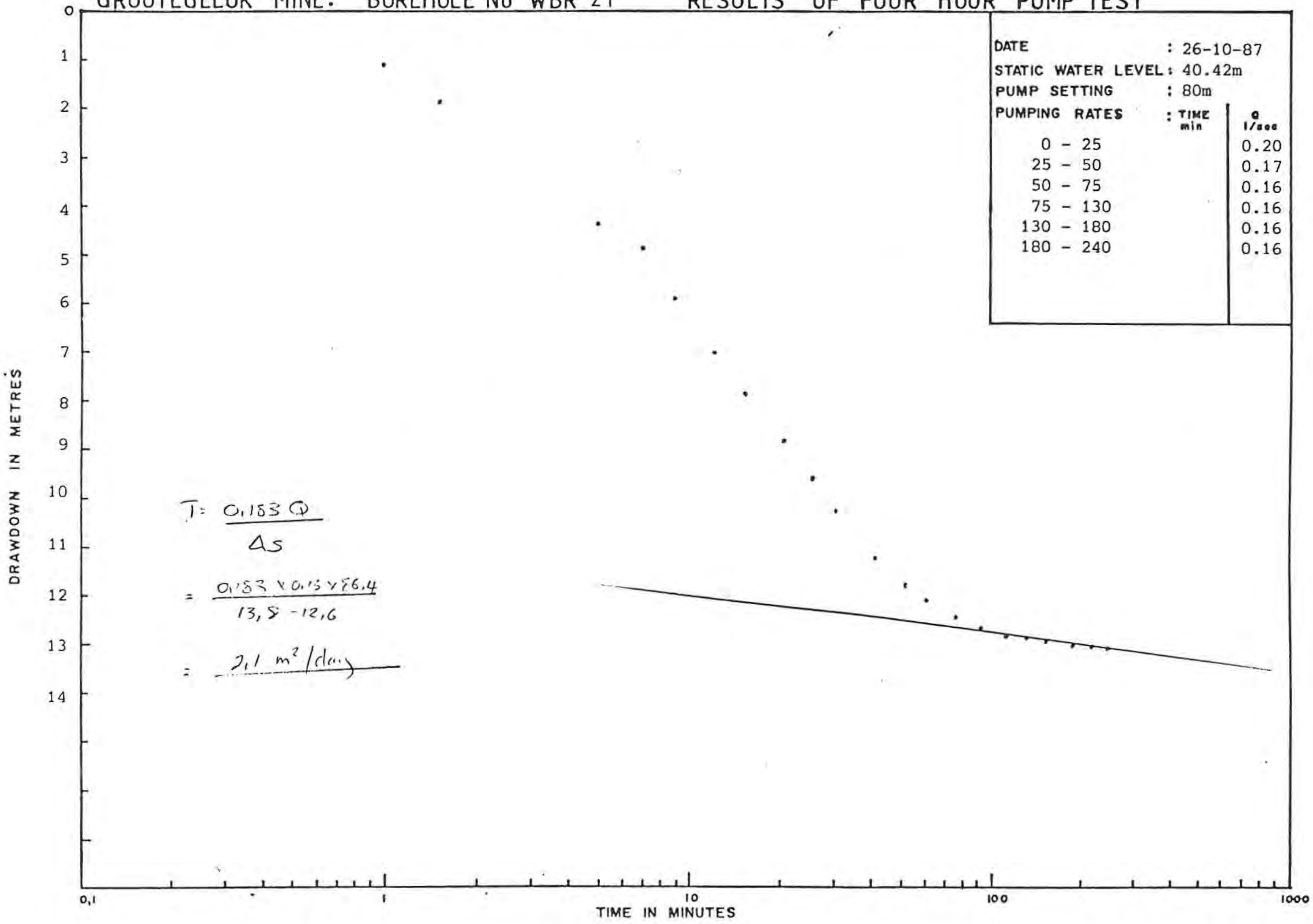


$T = \frac{0{,}183\,Q}{\Delta s'}$

$= \frac{0{,}183 \times 0{,}369 \times 86{,}4}{10{,}4 - 4{,}2}$

$= 0{,}94\ m^2/day$

GROOTEGELUK MINE: BOREHOLE No WBR 21 RESULTS OF FOUR HOUR PUMP TEST



DATE : 26-10-87
STATIC WATER LEVEL : 40.42m
PUMP SETTING : 80m
PUMPING RATES :

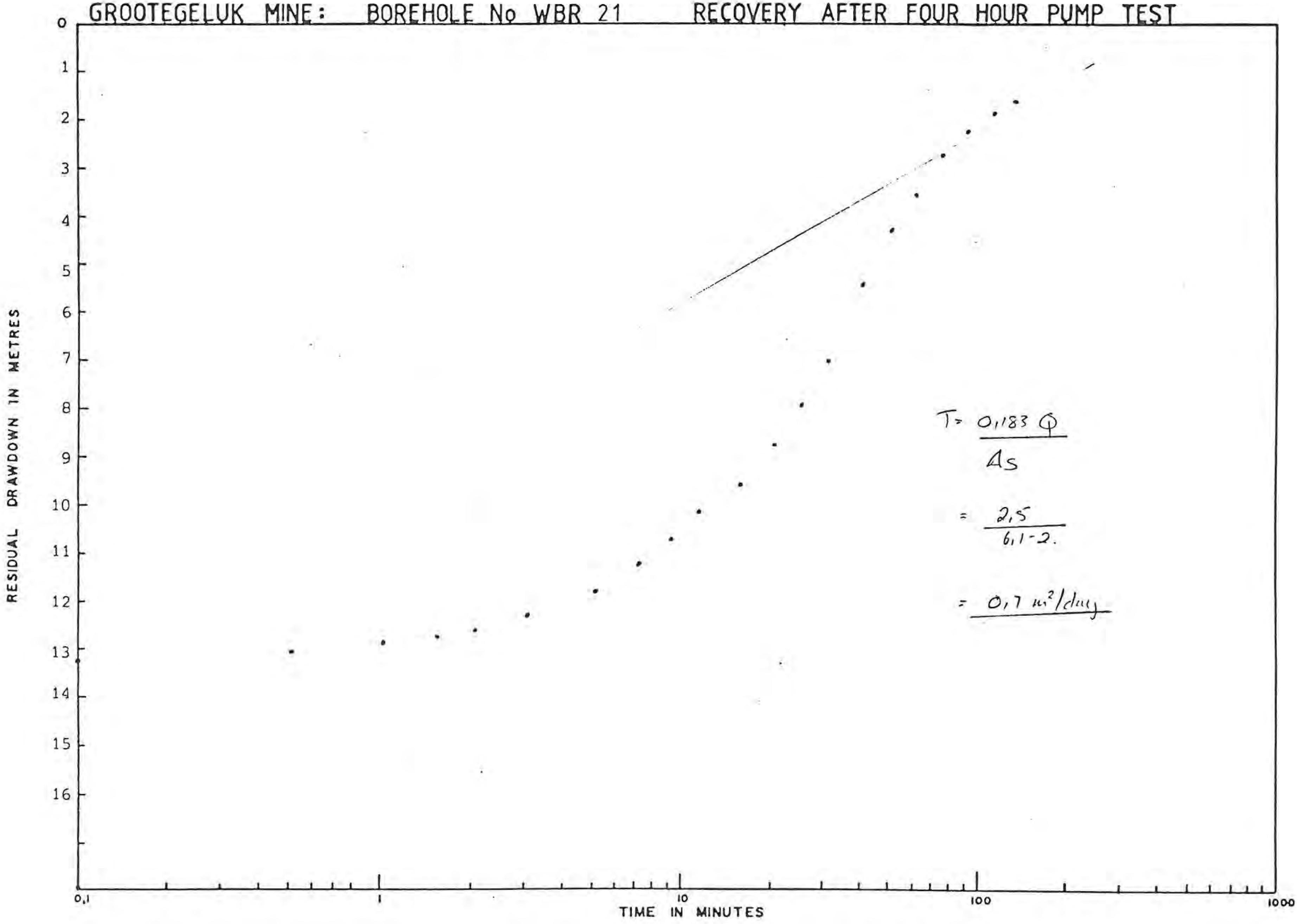
TIME min	Q l/sec
0 - 25	0.20
25 - 50	0.17
50 - 75	0.16
75 - 130	0.16
130 - 180	0.16
180 - 240	0.16

$$T = \frac{0,183\,Q}{\Delta s}$$

$$= \frac{0,183 \times 0,15 \times 86,4}{13,8 - 12,6}$$

$$= 2,1\ m^2/day$$

GROOTEGELUK MINE: BOREHOLE No WBR 21 RECOVERY AFTER FOUR HOUR PUMP TEST

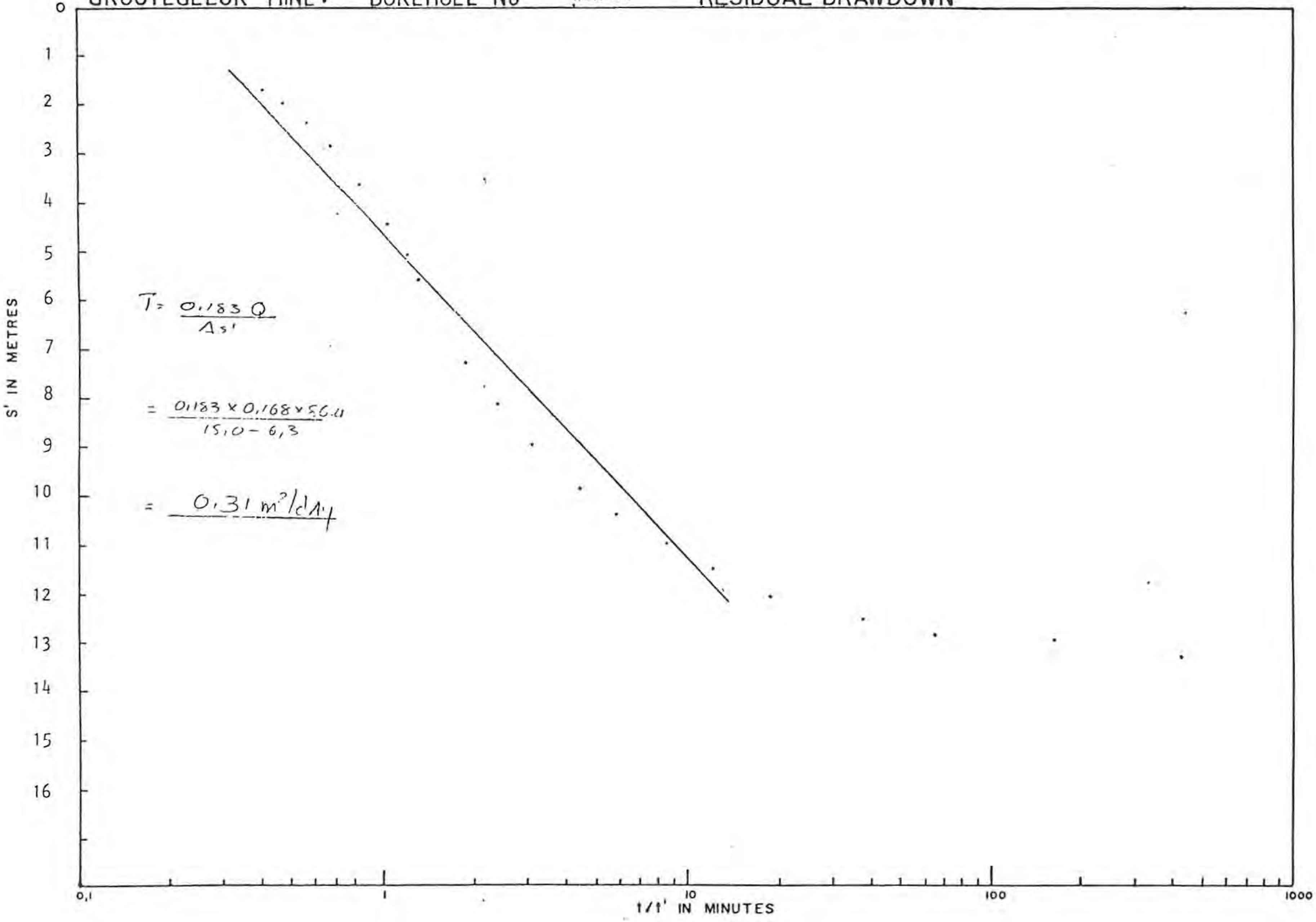


$$T = \frac{0{,}183\,Q}{\Delta s}$$

$$= \frac{2{,}5}{6{,}1-2.}$$

$$= \underline{0{,}7\ m^2/day}$$

GROOTEGELUK MINE: BOREHOLE No WBR 21 RESIDUAL DRAWDOWN

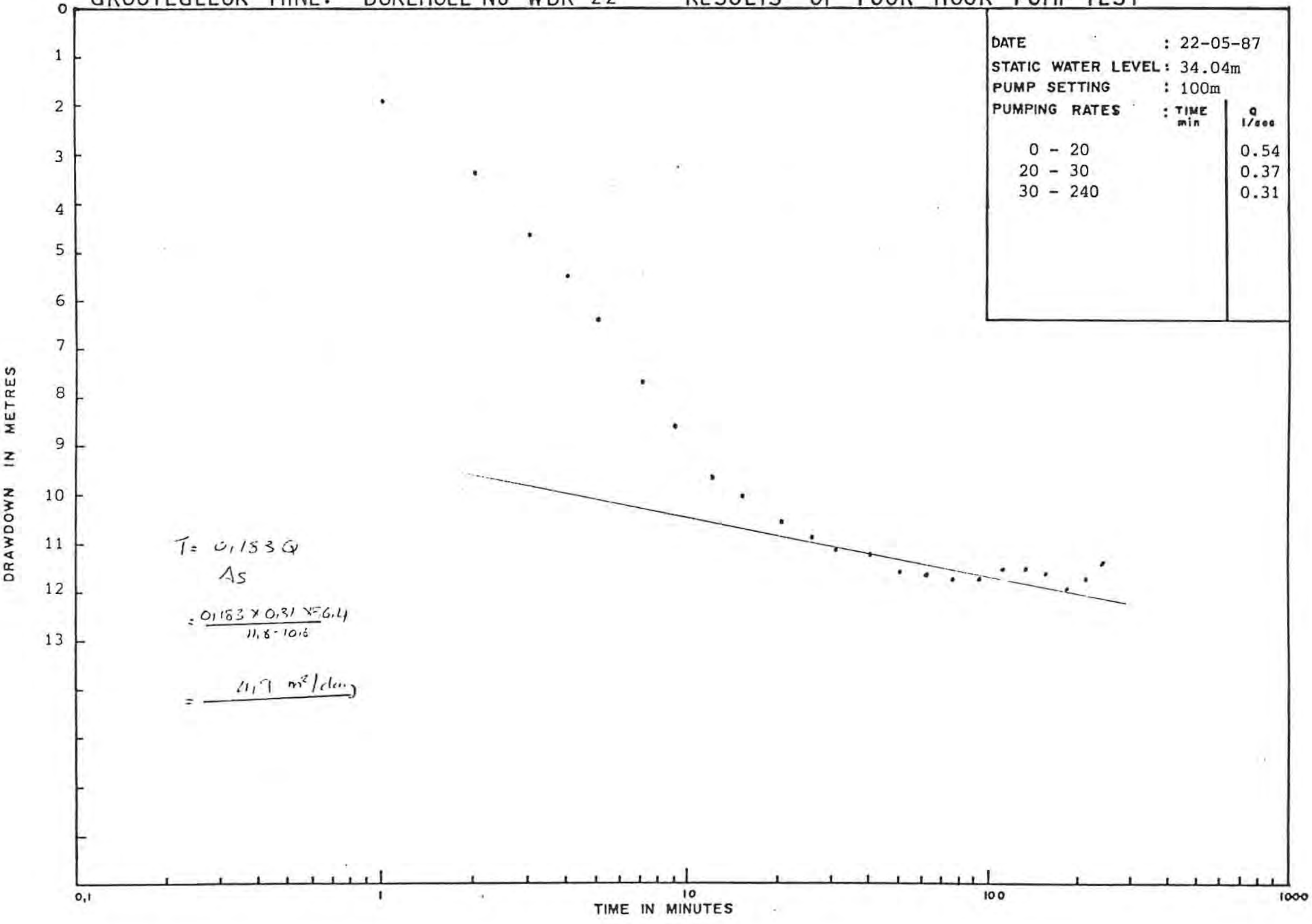


$$T = \frac{0{,}183\,Q}{\Delta s'}$$

$$= \frac{0{,}183 \times 0{,}168 \times 56{,}4}{15{,}0 - 6{,}3}$$

$$= \underline{0{,}31\ m^2/day}$$

GROOTEGELUK MINE: BOREHOLE No WBR 22 RESULTS OF FOUR HOUR PUMP TEST



DATE : 22-05-87
STATIC WATER LEVEL : 34.04m
PUMP SETTING : 100m
PUMPING RATES :

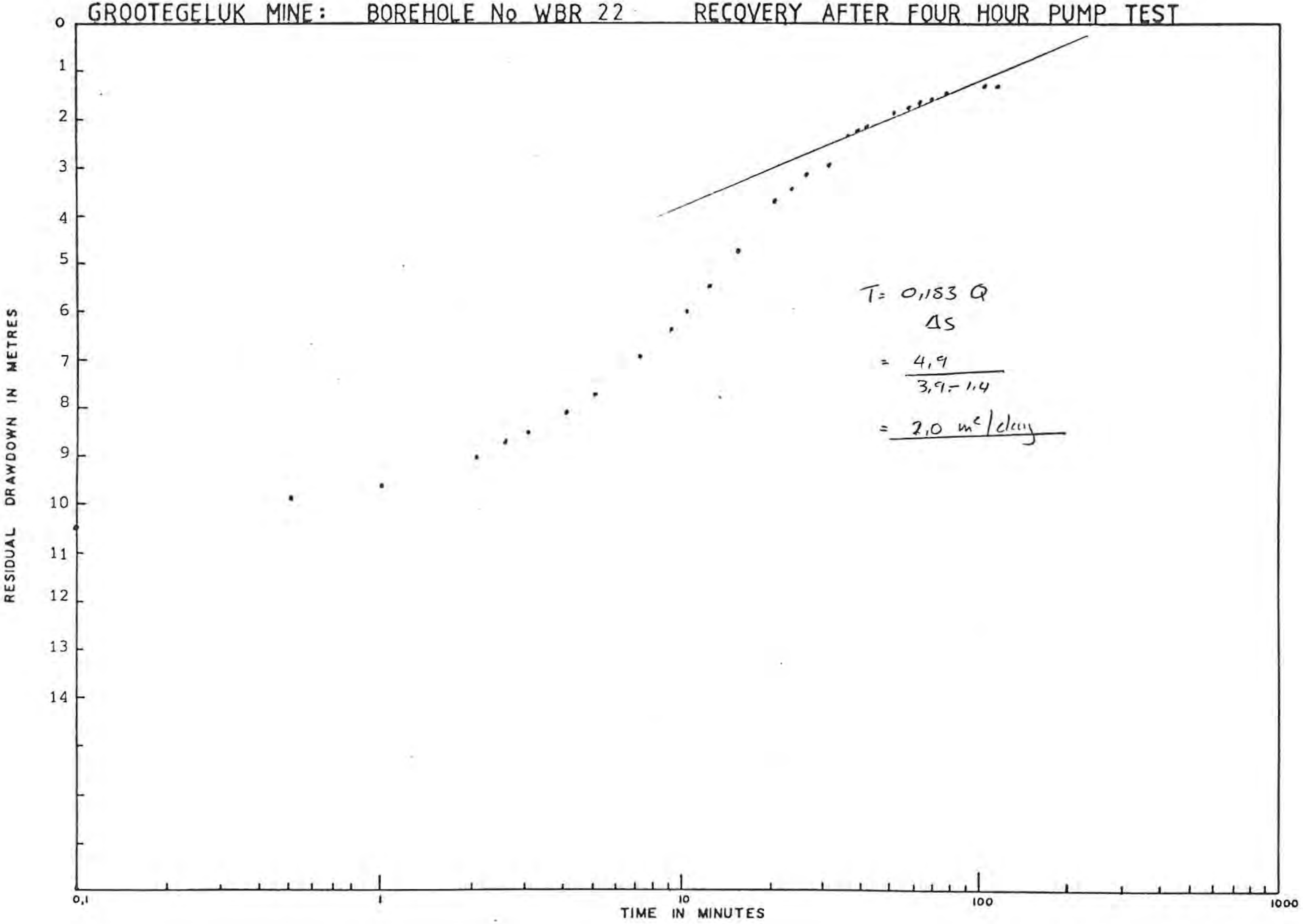
TIME min	Q l/sec
0 - 20	0.54
20 - 30	0.37
30 - 240	0.31

$$T = \frac{0,153 Q}{\Delta s}$$

$$= \frac{0,153 \times 0,31 \times 86,4}{11,8 - 10,6}$$

$$= \underline{4,7 \ m^2/day}$$

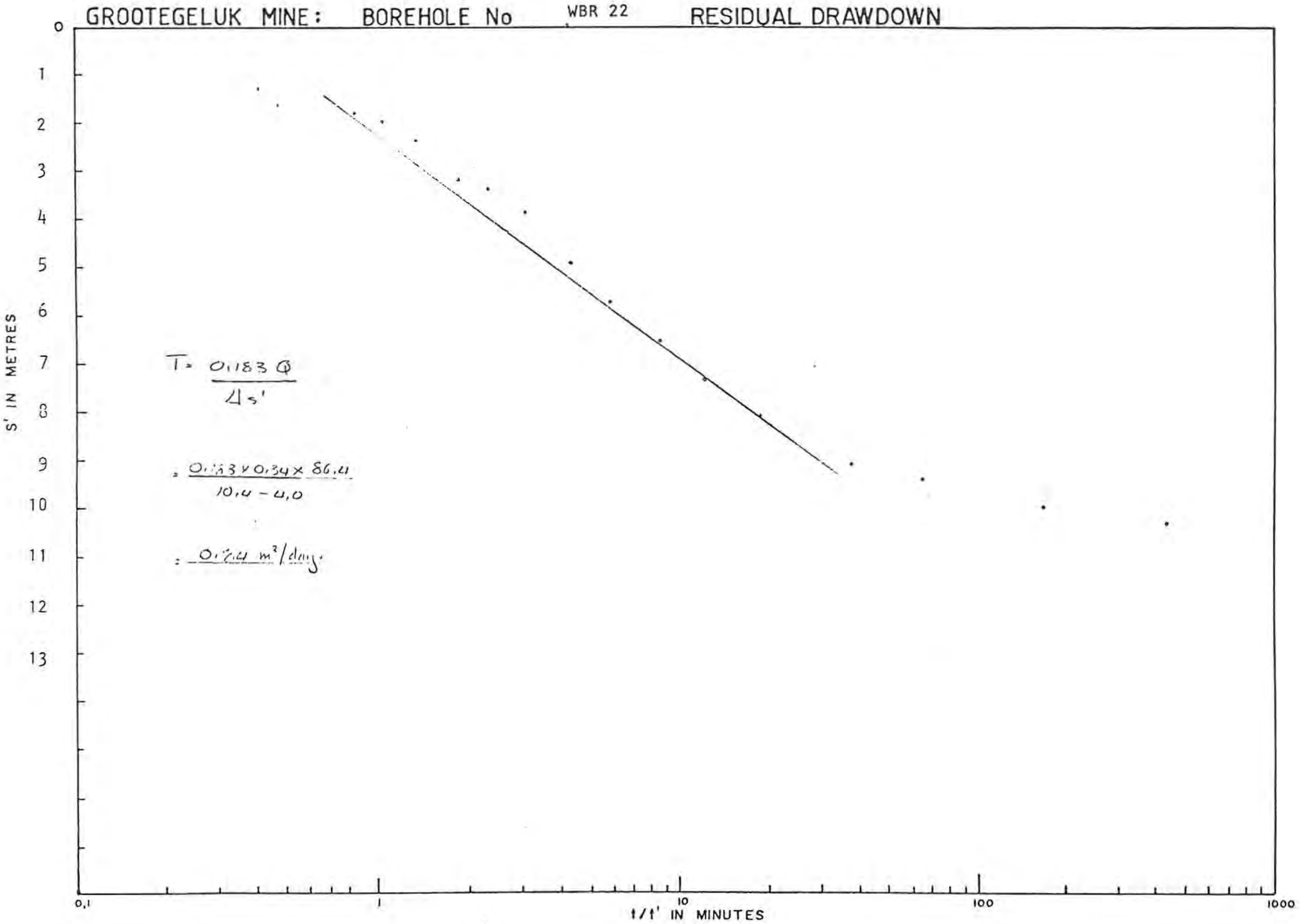
GROOTEGELUK MINE: BOREHOLE No WBR 22 RECOVERY AFTER FOUR HOUR PUMP TEST



$$T = \frac{0{,}183\,Q}{\Delta s}$$

$$= \frac{4{,}9}{3{,}9 - 1{,}4}$$

$$= \underline{2{,}0\ m^2/day}$$



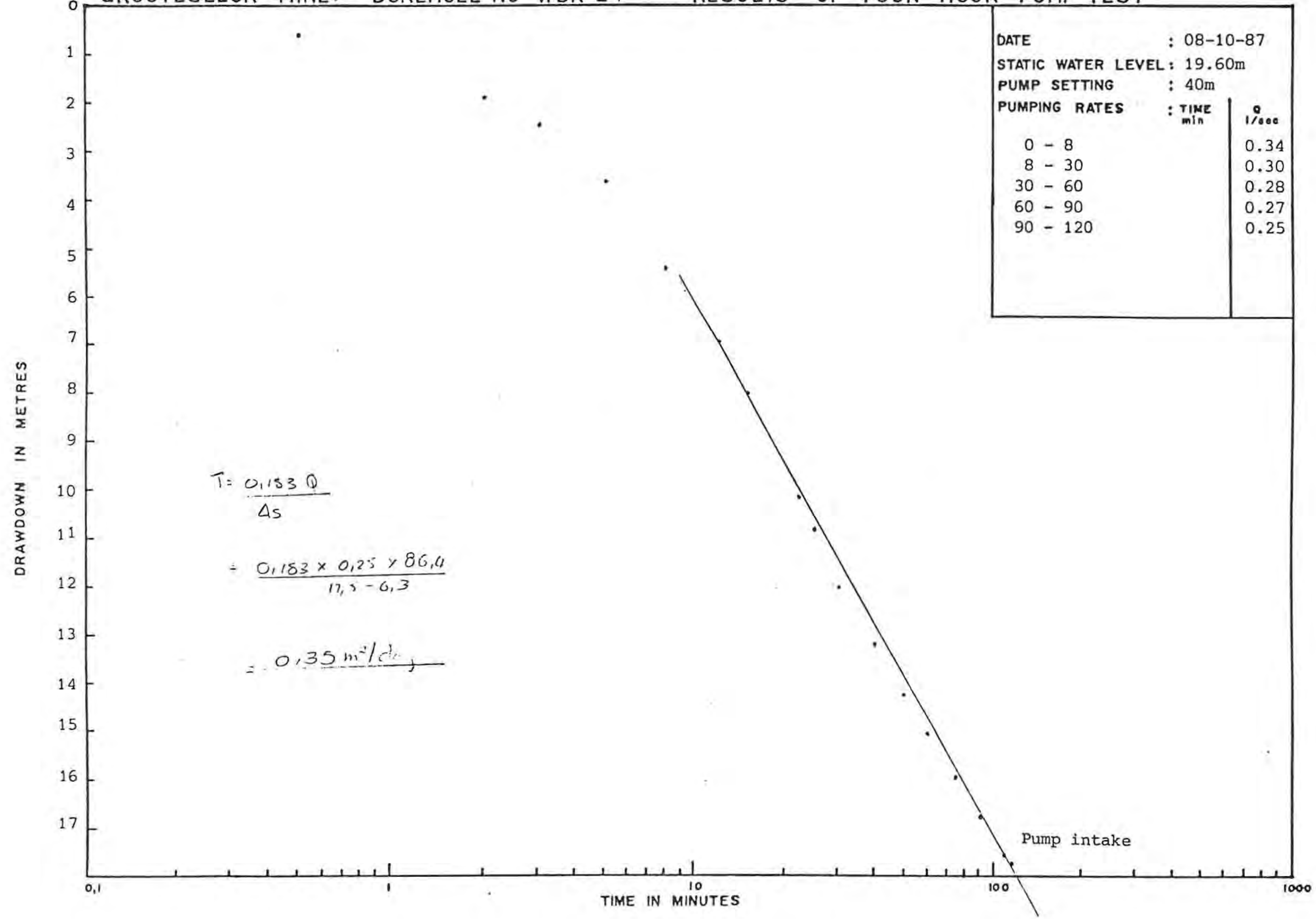
GROOTEGELUK MINE: BOREHOLE No WBR 22 RESIDUAL DRAWDOWN

$$T = \frac{0{,}183\ Q}{\Delta s'}$$

$$= \frac{0{,}183 \times 0{,}34 \times 86{,}4}{10{,}4 - 4{,}0}$$

$$= 0{,}84\ m^2/day.$$

GROOTEGELUK MINE: BOREHOLE No WBR 24 RESULTS OF FOUR HOUR PUMP TEST



DATE : 08-10-87

STATIC WATER LEVEL : 19.60m

PUMP SETTING : 40m

PUMPING RATES

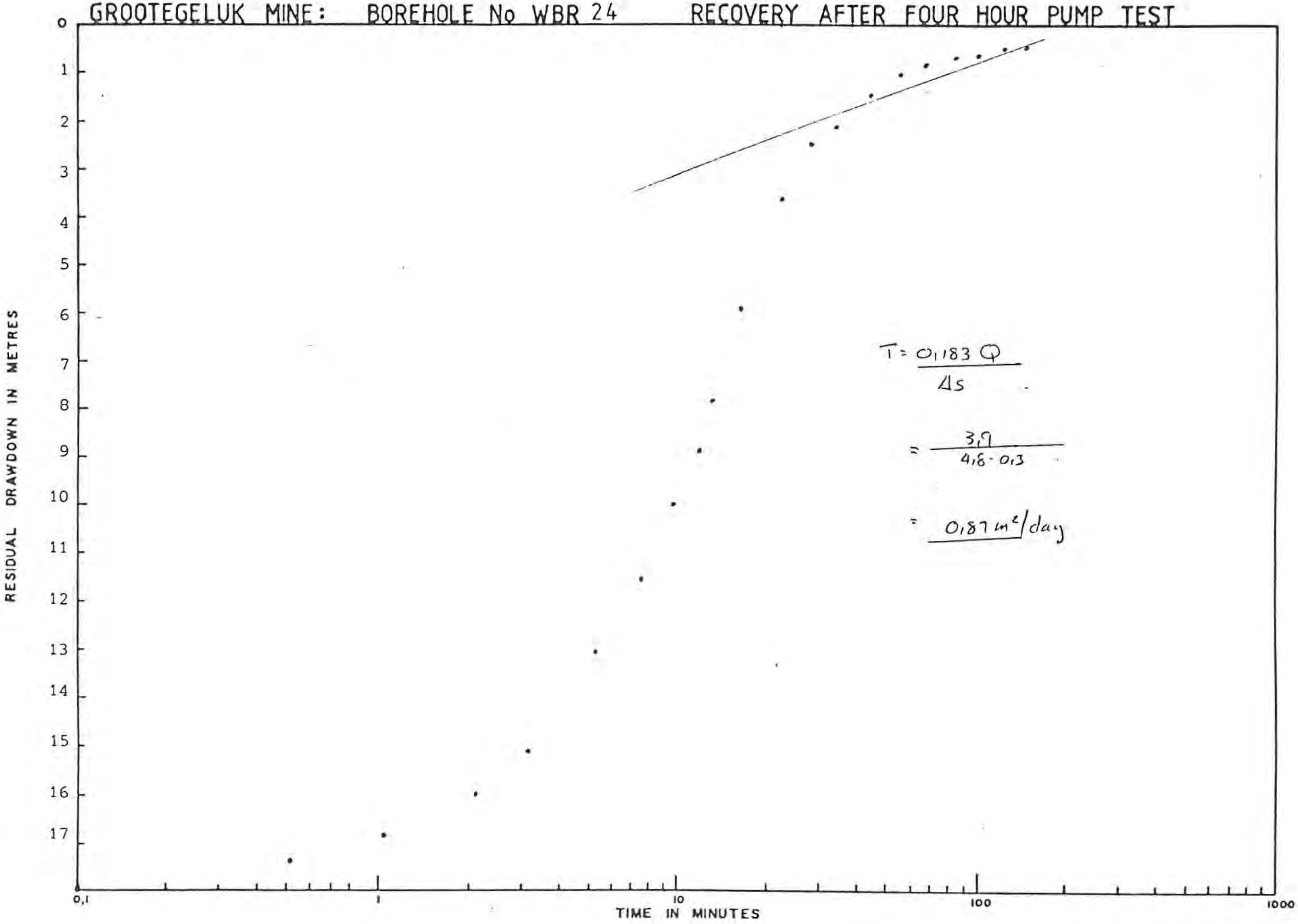
TIME min	Q l/sec
0 - 8	0.34
8 - 30	0.30
30 - 60	0.28
60 - 90	0.27
90 - 120	0.25

$$T = \frac{0,183\ Q}{\Delta s}$$

$$= \frac{0,183 \times 0,25 \times 86,4}{17,5 - 6,3}$$

$$= 0,35\ m^2/day$$

GROOTEGELUK MINE: BOREHOLE No WBR 24 RECOVERY AFTER FOUR HOUR PUMP TEST

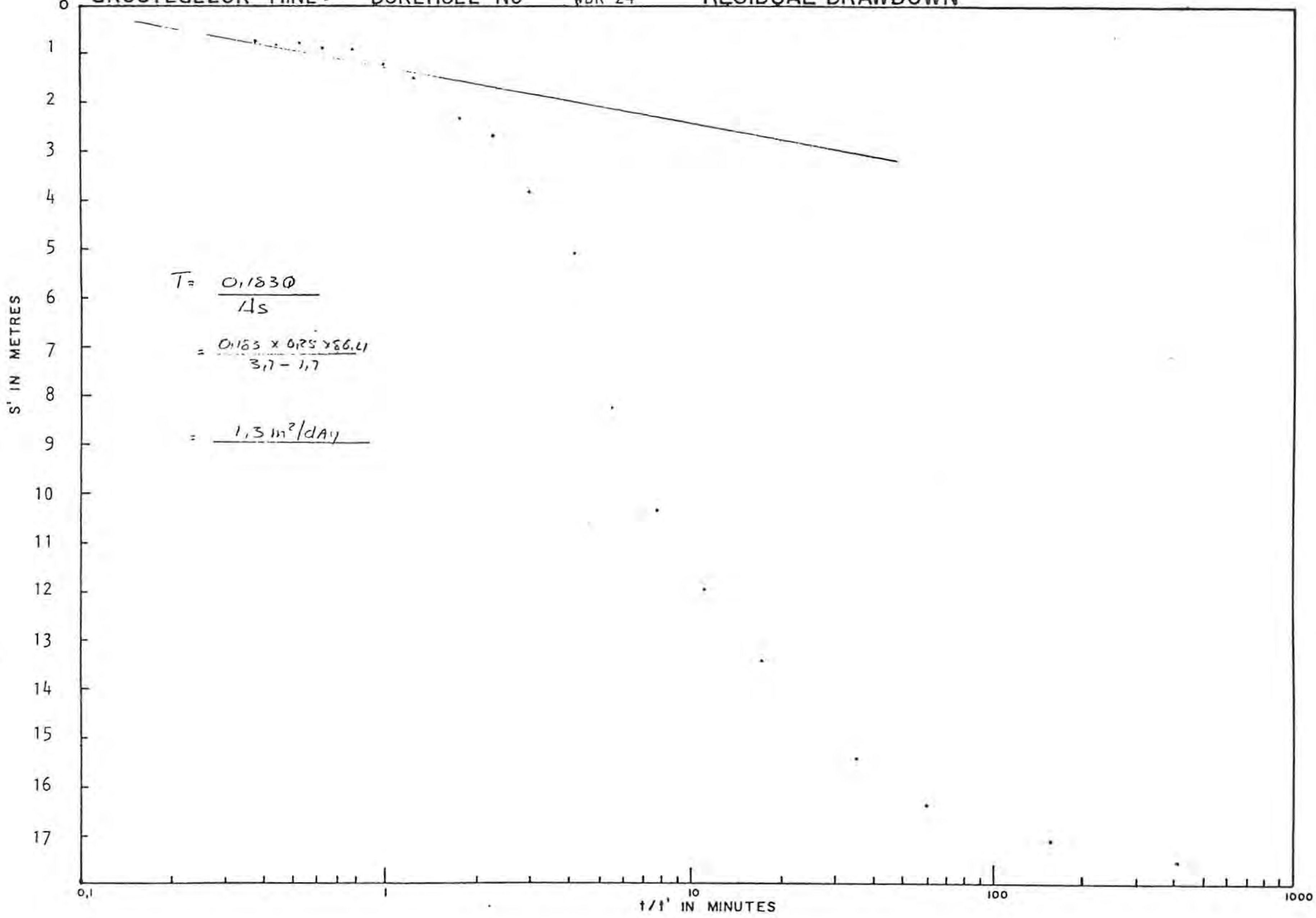


$$T = \frac{0{,}183\ Q}{\Delta s}$$

$$= \frac{3{,}9}{4{,}8 - 0{,}3}$$

$$= \underline{0{,}87\ m^2}/day$$

GROOTEGELUK MINE: BOREHOLE No WBR 24 RESIDUAL DRAWDOWN

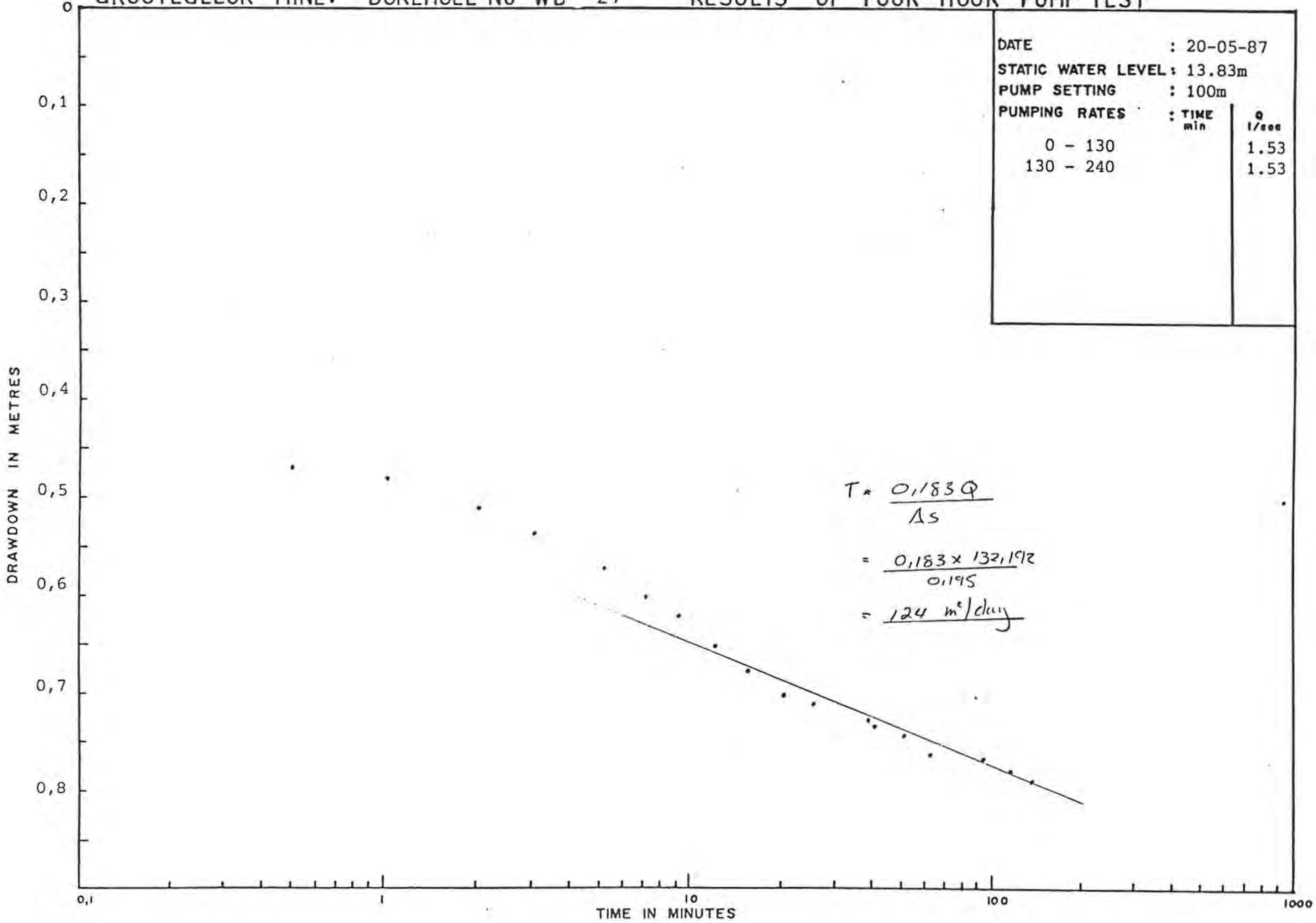


$T = \frac{0,183Q}{\Delta s}$

$= \frac{0,183 \times 0,25 \times 86,4}{3,7 - 1,7}$

$= 1,3\ m^2/day$

GROOTEGELUK MINE: BOREHOLE No WB 27 RESULTS OF FOUR HOUR PUMP TEST



DATE : 20-05-87
STATIC WATER LEVEL : 13.83m
PUMP SETTING : 100m
PUMPING RATES

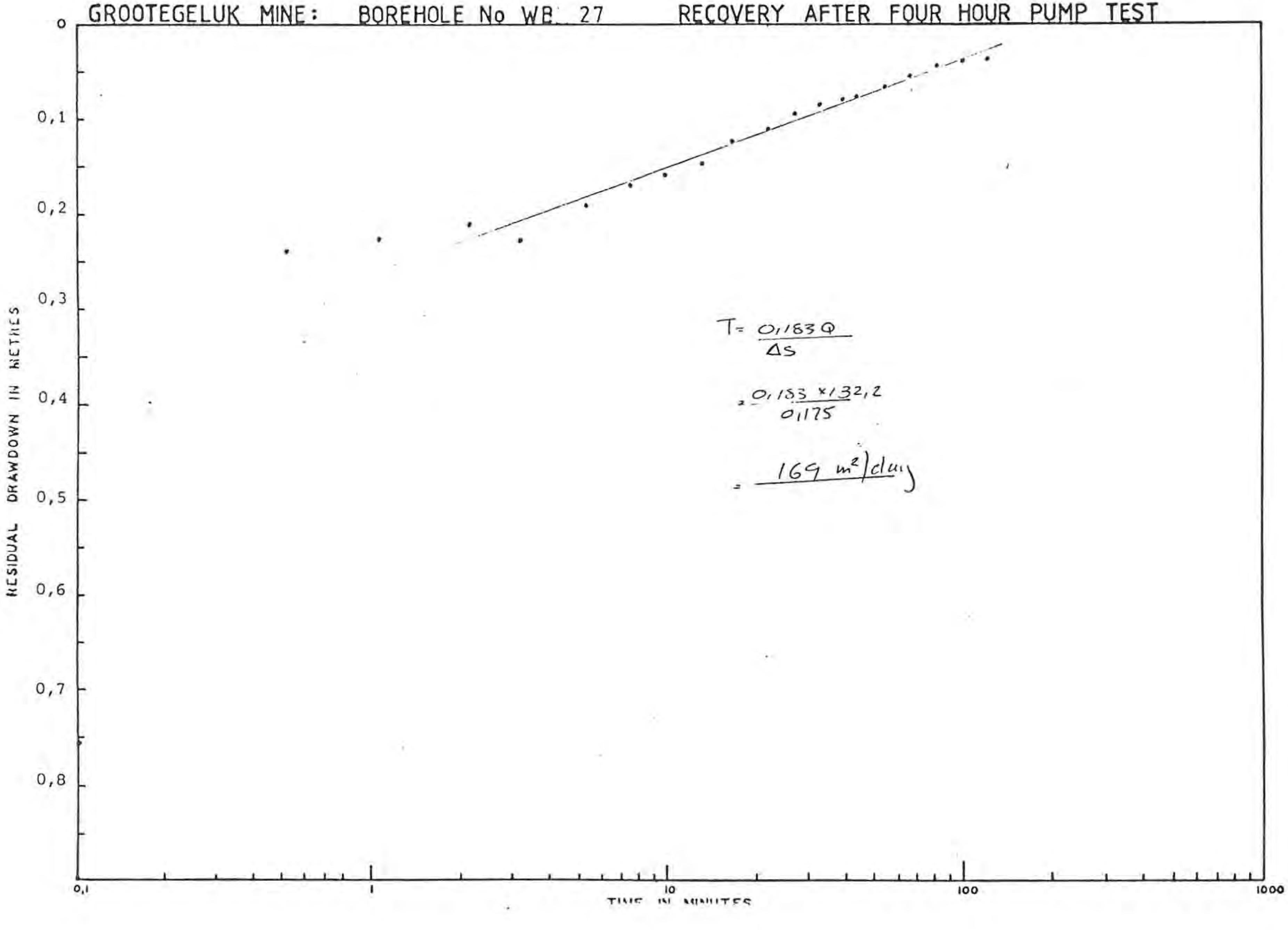
TIME min	Q l/sec
0 - 130	1.53
130 - 240	1.53

$$T = \frac{0,183Q}{\Delta s}$$

$$= \frac{0,183 \times 132,192}{0,195}$$

$$= 124 \text{ m}^2/\text{day}$$

GROOTEGELUK MINE: BOREHOLE No WB 27 RECOVERY AFTER FOUR HOUR PUMP TEST

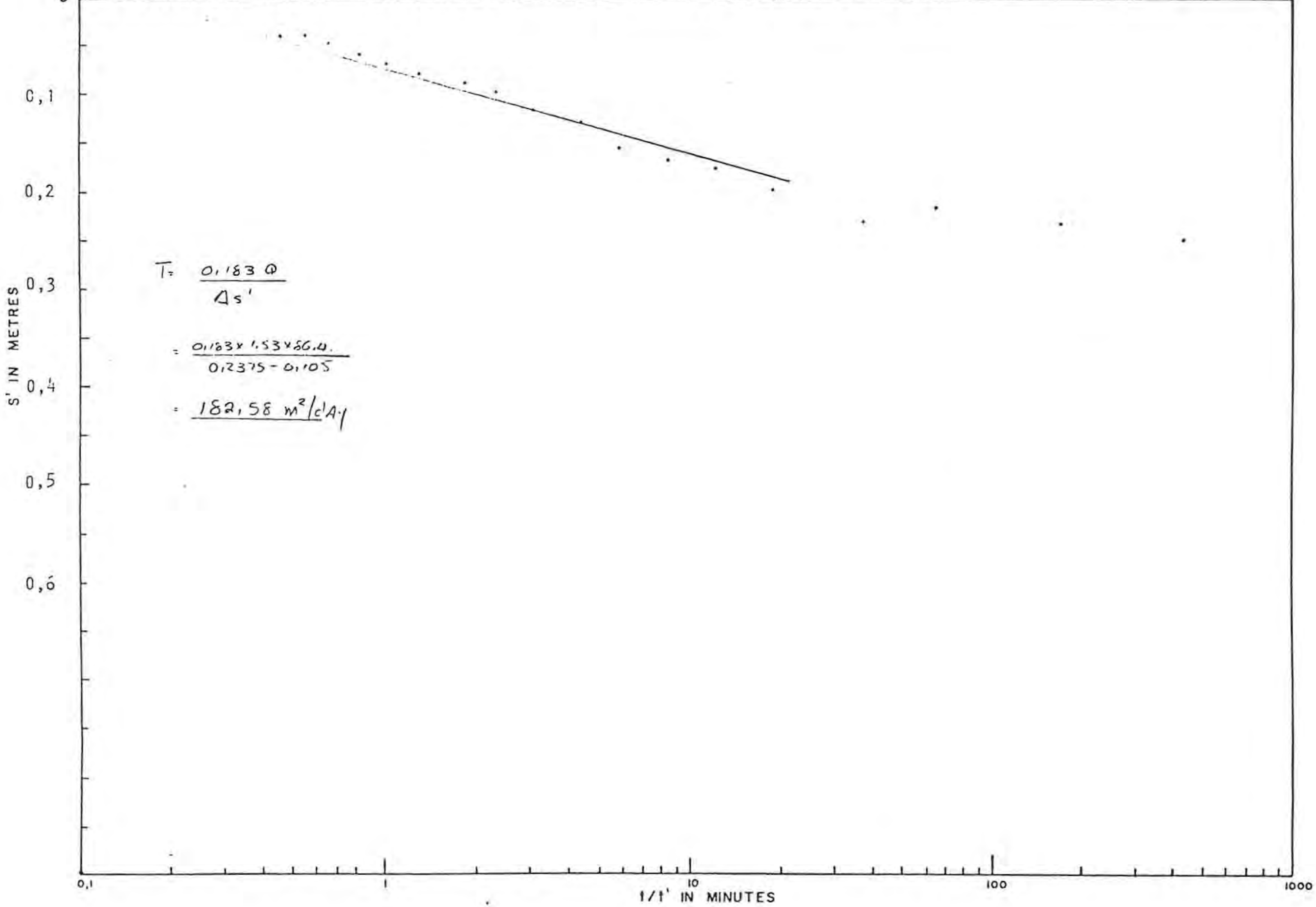


$$T = \frac{0{,}183\,Q}{\Delta s}$$

$$= \frac{0{,}183 \times 132{,}2}{0{,}175}$$

$$= \underline{169\ m^2/day}$$

GROOTEGELUK MINE: BOREHOLE No WB 27 RESIDUAL DRAWDOWN

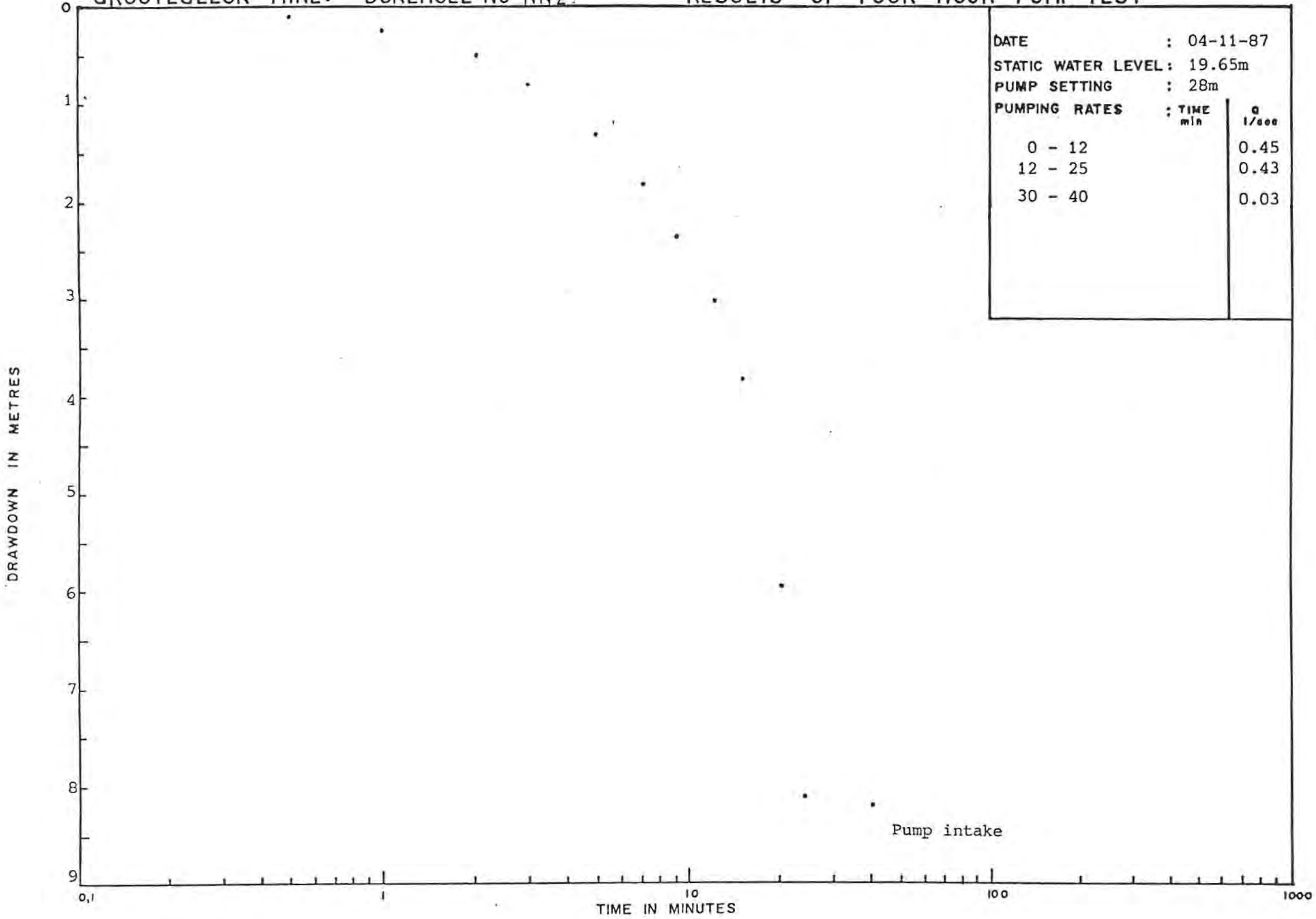


$$T = \frac{0{,}183\ Q}{\Delta s'}$$

$$= \frac{0{,}183 \times 1{,}53 \times 56{,}4}{0{,}2375 - 0{,}105}$$

$$= \underline{182{,}58\ m^2/d}$$ A·/

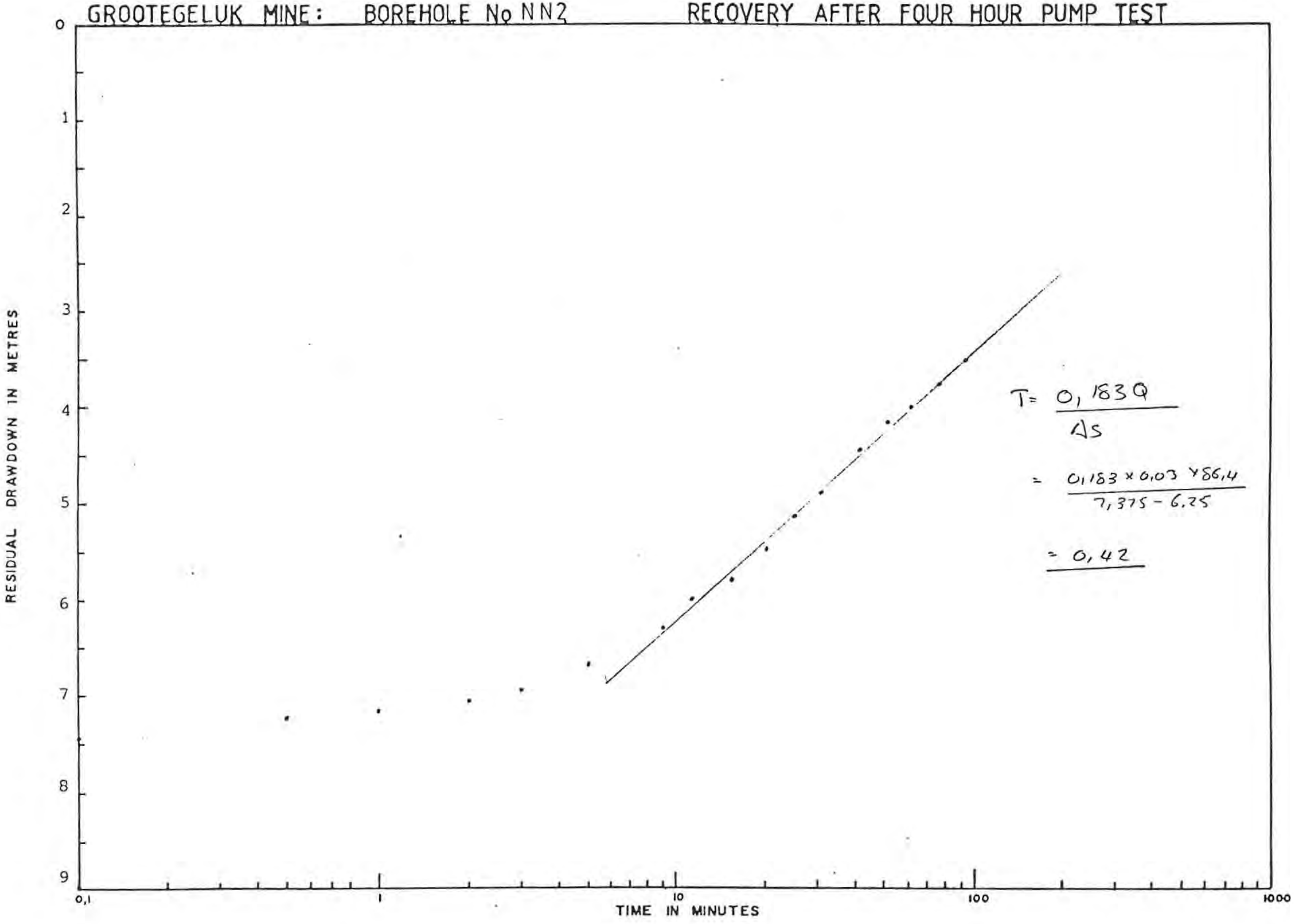
GROOTEGELUK MINE: BOREHOLE No NN2 RESULTS OF FOUR HOUR PUMP TEST



DATE : 04-11-87
STATIC WATER LEVEL : 19.65m
PUMP SETTING : 28m
PUMPING RATES :

TIME min	Q l/sec
0 - 12	0.45
12 - 25	0.43
30 - 40	0.03

GROOTEGELUK MINE: BOREHOLE No NN2 RECOVERY AFTER FOUR HOUR PUMP TEST

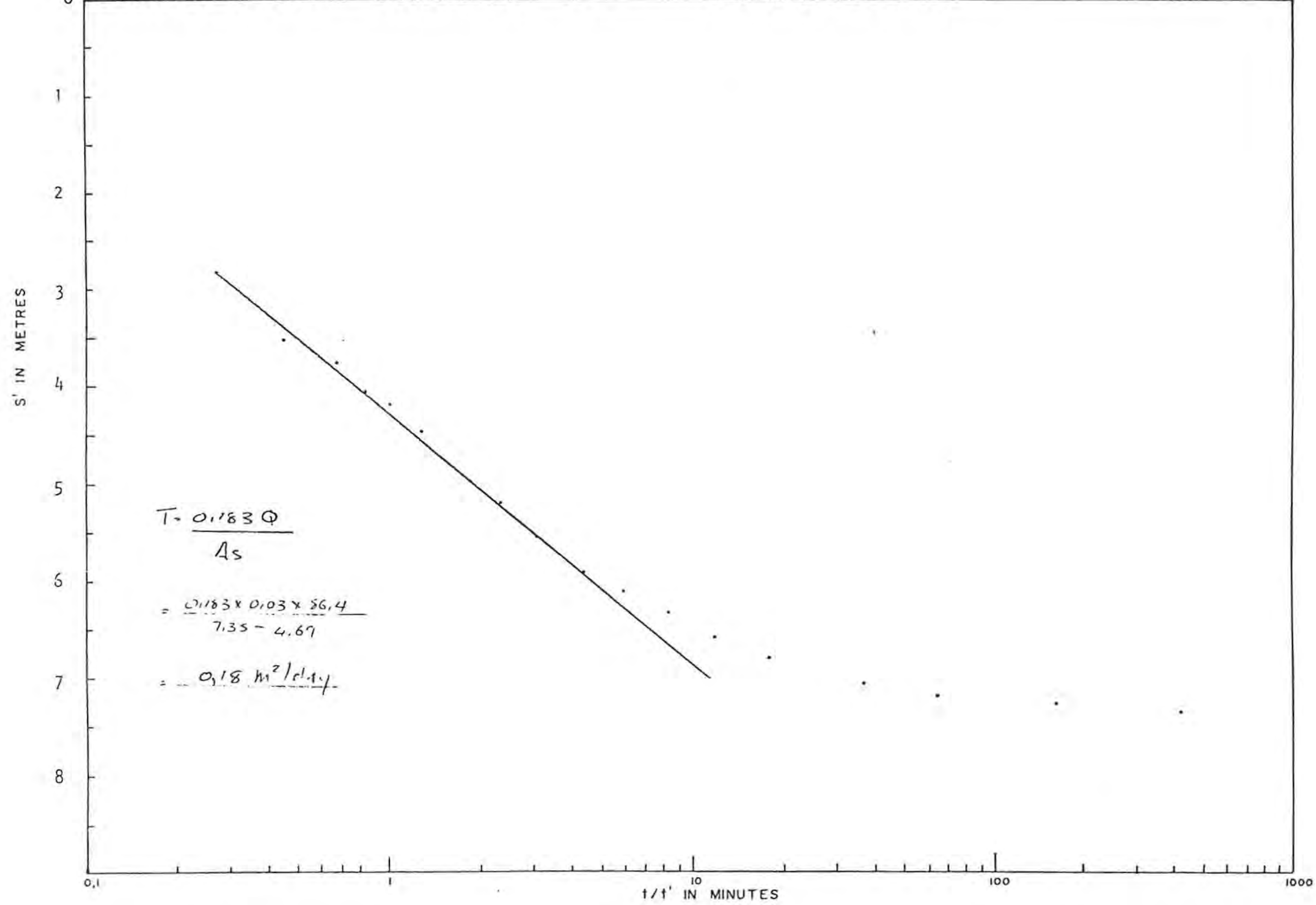


$$T = \frac{0,183Q}{\Delta s}$$

$$= \frac{0,183 \times 0,03 \times 86,4}{7,375 - 6,25}$$

$$= \underline{0,42}$$

GROOTEGELUK MINE: BOREHOLE No NN 2 RESIDUAL DRAWDOWN



$$T = \frac{0{,}183\,Q}{\Delta s}$$

$$= \frac{0{,}183 \times 0{,}03 \times 86{,}4}{7{,}35 - 4{,}67}$$

$$= 0{,}18\ m^2/day$$

APPENDIX 6

THE RESULTS OF THE CHEMICAL ANALYSES OF WATER SAMPLES FROM THE WBR BOREHOLES

CHEMICAL ANALYSIS OF GROUNDWATER SAMPLES FROM WBR BOREHOLES

BOREHOLE NO.	WBR1	WBR2	WBR3	WBR4	WBR5	WBR6	WBR7	WBR8	WBR9	WBR10	WBR11	WBR12
TDS Evap mg/l	285	410	2822	1125	1435	940	250	340	730	215	800	N
Cond ms/m	407	595	3280	71	192	109	386	502	757	297	77	o
pH lab	7,43	7,43	6,21	6,30	7,20	7,40	6,54	6,65	6,84	8,59	7,30	t
Grootegeluk	7,50	7,50	7,00	6,60	7,10	7,60	6,80	6,50	0,00	9,10	7,00	
												P
Major Cations												u
in meq/l												m
Ca^{2+}	1,88	3,22	10,23	5,43	6,40	6,96	1,60	1,29	2,74	0,70	5,39	p
Mg^{2+}	1,04	2,26	12,27	5,28	5,67	2,84	0,68	0,60	1,46	0,42	1,70	e
Na^{1+}	1,61	1,61	6,49	1,52	6,96	2,13	1,87	3,05	2,30	0,57	1,10	d
K^+	60,08	0,05	0,67	0,18	0,28	0,87	0,23	0,20	0,33	0,18	0,38	
Major Anions												
in meq/l												
$CO_3{}^{2-}$	2,70	5,30	3,60	1,60	4,96	5,64	2,30	0,70	0,60	1,70	6,56	
Cl^-	1,27	0,56	20,47	1,86	14,27	2,99	0,85	2,16	4,73	0,56	1,30	
$SO_4{}^{2-}$	0,21	0,10	3,60	9,26	0,69	4,48	0,27	0,19	0,27	0,27	1,39	
$NO_3{}^{-}$-N	0,02	0,00	0,05	0,03	0,03	0,02	0,00	0,02	0,05	0,00	0,00	
Trace Elements in mg/l												
SiO_2	27,00	30,00	78,00	28,00	21,00	23,00	13,00	24,00	18,00	6,50	12,00	
F	0,13	0,14	0,22	0,17	0,23	0,40	0,07	0,13	0,09	0,16	0,45	
Fe	0,20	0,10	2,50	2,80	1,60	0,20	0,90	0,40	0,50	0,30	2,80	
Mn	0,10	0,10	0,20	1,70	0,40	0,60	0,50	0,20	1,00	0,10	0,50	
Pb	0,10	0,10	0,10	0,10	0,10	0,10	0,10	0,10	0,10	0,10	0,10	
Zn	0,10	0,10	0,10	0,10	0,10	0,10	0,10	0,10	0,10	0,10	0,20	
Cd	0,10	0,10	0,30	0,30	0,30	0,30	0,10	0,10	0,10	0,10	0,30	
Fe^{++} (Acidized)	0,40	0,60	7,90	0,00	6,60	1,00	3,70	3,20	5,00	0,90	33,00	

WBR13	WBR14	WBR15	WBR16	WBR17	WBR18	WBR19	WBR20	WBR21	WBR22	WBR23	WBR24	WBR25	WBR26	WB 27	NN2
505	1125	692	786	1695	1040	940	960	1030	2200	N	288	3300	2200	1650	13204
845	116	747	946	1886	1440	1369	1420	151	122	o	360	364	249	185	15100
6,99	7,30	6,79	6,44	6,32	7,10	1,08	7,01	6,87	6,90	t	6,89	4,60	5,20	7,10	5,70
7,20	7,30	7,10	7,00	6,40	7,70	7,60	7,20	7,10	5,20		7,20	4,60	5,20	7,40	6,40
5,36	8,47	3,40	3,08	10,55	7,19	5,12	11,27	9,11	5,28	P	1,30	6,79	4,40	9,83	21,98
1,94	1,12	1,77	3,32	7,00	3,84	3,80	7,91	3,56	3,08	u	1,02	9,67	6,48	6,75	47,37
1,35	2,09	0,95	1,35	4,52	4,39	5,22	2,78	1,87	4,79	m	1,22	17,40	12,60	4,35	76,82
0,56	0,08	0,26	0,61	0,49	0,41	0,56	0,07	0,46	0,38	p	0,21	0,18	0,49	0,15	2,07
										e					
										d					
6,50	0,64	3,24	1,72	2,80	7,20	8,40	3,40	6,10	7,64		1,92	0,16	0,24	7,48	1,56
1,97	5,64	4,00	6,50	4,51	3,95	3,50	1,83	3,24	4,50		0,90	31,58	22,28	1,24	141,00
0,50	5,83	0,29	0,19	11,91	3,96	0,44	14,86	4,69	1,58		0,67	1,58	0,96	12,49	4,35
0,00	0,02	0,02	0,02	0,08	0,00	0,00	0,11	0,00	0,02		0,00	0,05	0,05	0,32	0,32
6,10		21,00	25,00	16,00	19,00	60,00	36,00	5,70			18,00				33,00
0,39	0,12	0,20	0,13	0,53	0,95	0,73	0,22	0,59	0,10		0,14	0,10	0,10	0,10	1,68
2,40	0,10	0,10	0,10	0,10	1,20	1,90	0,10	0,10	0,10		0,90	3,60	0,60	0,10	7,30
0,20	0,10	0,10	0,20	0,10	0,40	0,30	0,10	0,50	0,20		0,10	3,90	2,70	0,10	4,50
0,10	0,10	0,10	0,10	0,10	0,10	0,10	0,10	0,10	0,10		0,10	0,10	0,10	0,10	0,30
0,10	0,10	0,10	0,10	0,10	0,10	0,10	0,10	0,10	0,10		0,10	0,20	0,70	0,10	0,60
0,20	0,40	0,10	0,10	0,30	0,30	0,20	0,40	0,30	0,20		0,10	0,30	0,20	0,40	0,50
14,00	0,40	2,30	1,20	2,40	6,50	4,80	1,00	8,90	7,10		1,60		2,20	0,40	24,00

LOCATION AND TOPOGRAPHY OF THE GROOTEGELUK AREA (COPY OF PORTIONS OF 1:250 000 TOPOCADASTRAL SHEET 2326 ELLISRAS)

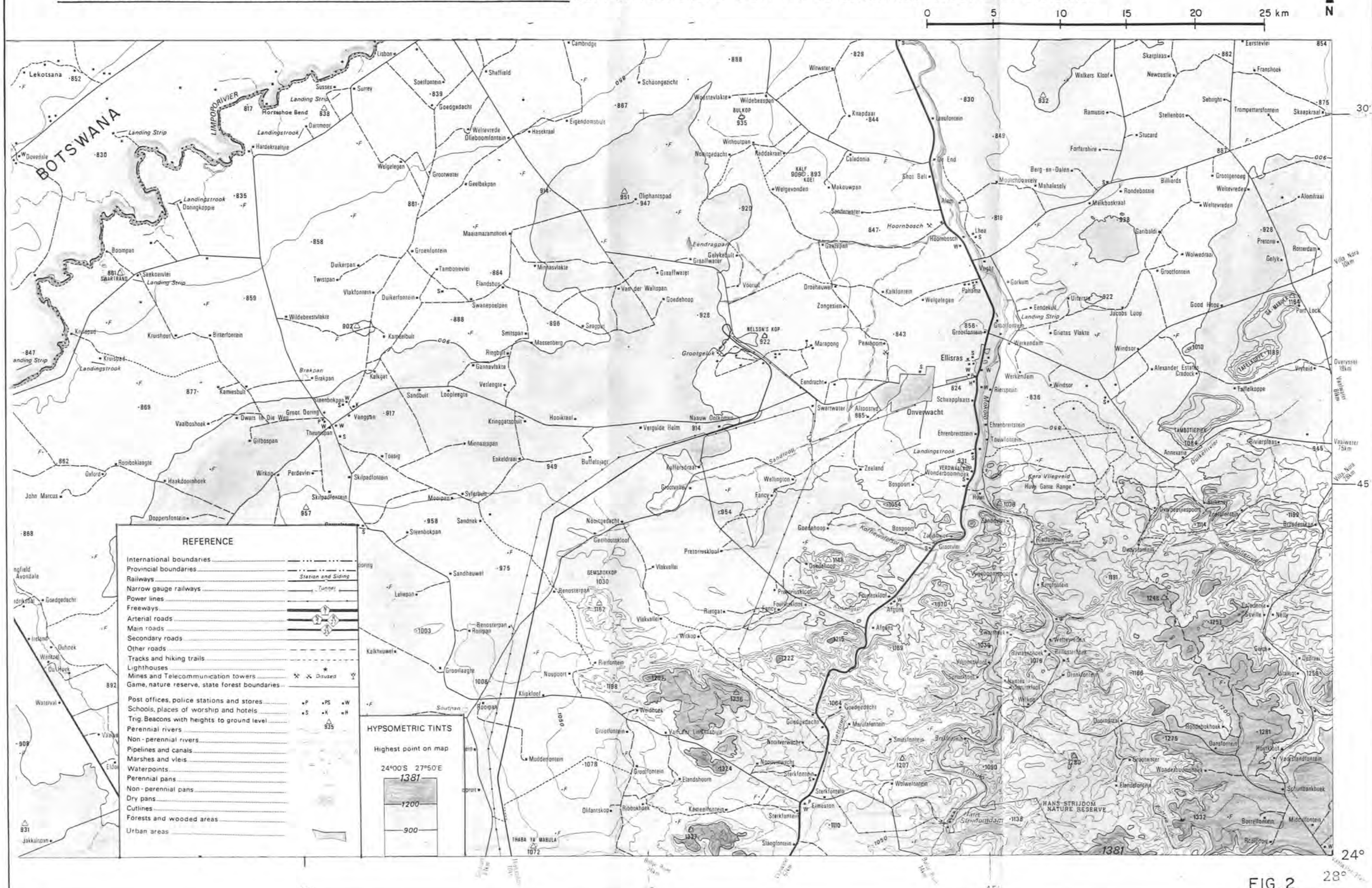


FIG. 2

TOPOGRAPHICAL MAP OF GROOTEGELUK and ISCOR OWNED FARMS (COPY OF PORTIONS OF 1:50 000 TOPOCADASTRAL SHEETS 2327DA & 2327CB)

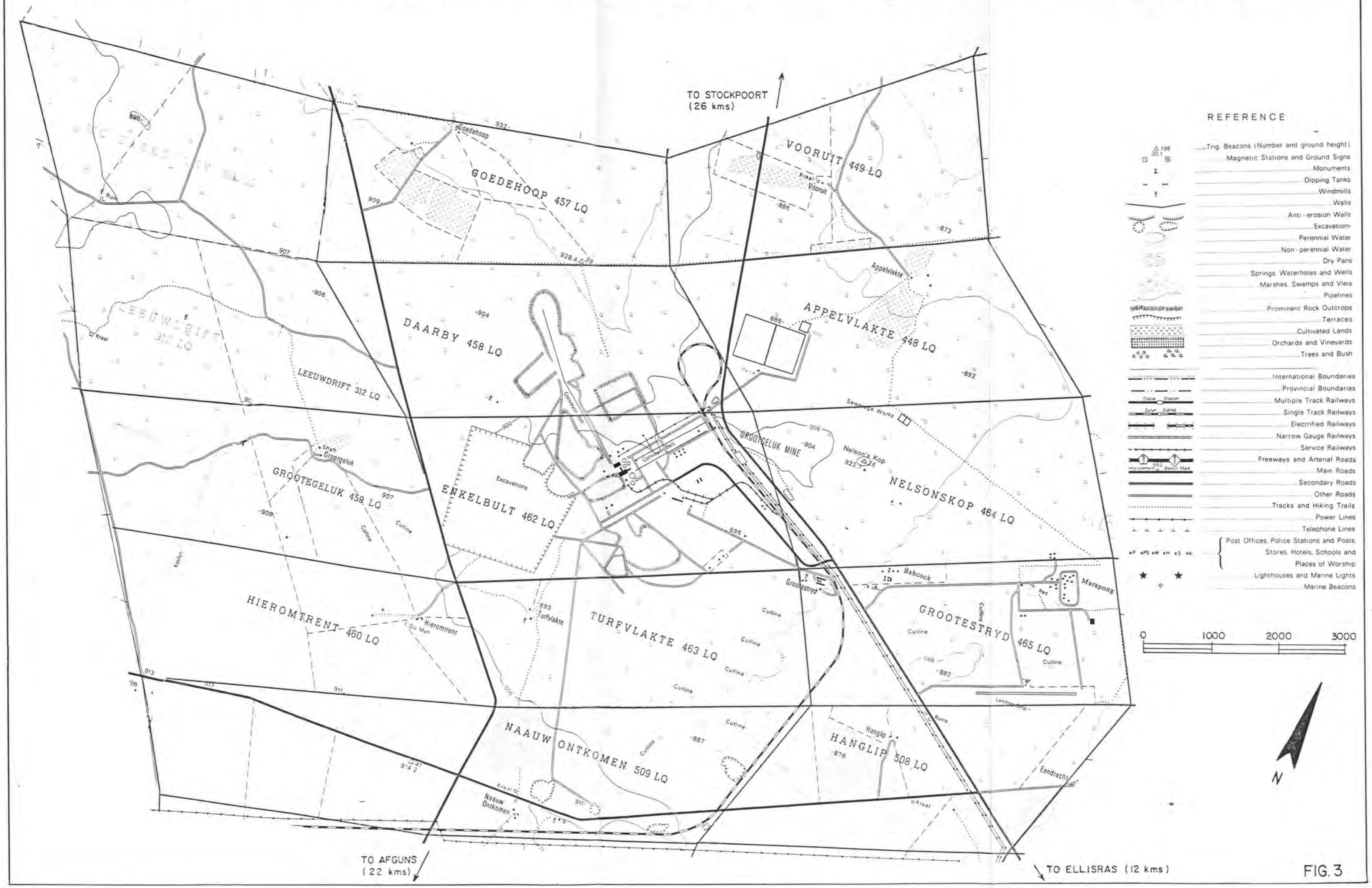


FIG. 3