Evaluation of the Crocodile River Stream - Aquifer Data by Finite Element Simulation

P J Hobbs, FDI Hodgson
GJ Van Tonder and JL Muller

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EVALUATION OF THE CROCODILE RIVER STREAM-AQUIFER DATA BY FINITE ELEMENT SIMULATION

by

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Research done by the Institute for Ground-water Studies
in conjunction with the Department of Water Affairs
under contract for the Water Research Commission

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EXECUTIVE SUMMARY

This research forms part of a threefold investigation into the applicability of ground-water models to South African Aquifers. The other two areas modelled were the Sishen and Atlantis Aquifers. All three investigations were done by the Institute for Ground-water Studies in conjunction with the Department of Water Affairs, under contract with the Water Research Commission.

This report deals only with the parameter identification and modelling of a conjunctive stream-aquifer system. The Crocodile River Valley, upstream of Thabazimbi, was selected for this exercise. Here, surface water is used in conjunction with ground water for intensive irrigation. The scheduled annual water requirement is presently in the order of 77×10^6 m^3.

During the drought of the past three years, the river has only flowed sporadically for short lengths of time. Prior to this, a prolonged period of river flow was evidenced in the wet period of the mid-seventies. One of the main concerns is to utilize the available water resources in the valley effectively. Ground-water utilization holds several advantages above water directly from the river. Some of these are:

- The alluvium and permeable rocks adjacent to river beds can be used for water storage during floods in the river. This water can be extracted during the dry months.
- The ground water is less prone to pollution than river water.
- Evaporation from ground-water systems is minimal.
- The cost of developing a ground-water supply is significantly less than that for surface water.

During this exercise, several modelling techniques were experimented with. The most successful of these makes use of the well-established finite element technique.

It allows detailed modelling of geometric features as well as variations in parameter values. A sensitivity analysis of the parameters involved indicated that specific parameters will have to be monitored more closely in the future, before a management model with a fair degree of confidence can be put forward. Conclusions from the computer simulations are as follows:

- The permeability distribution of the river bottom is perhaps the most important parameter which will have to be quantified by field observation. This can be ascertained in a number of ways, such as gauging losses from the river between weirs, or infiltration tests in the dry portions of the river.

- Abstraction from boreholes has not been monitored directly in the past. Many of the boreholes are presently being equipped with water meters and for future modelling an accurate record of abstraction will be available.

- The response of the aquifer to recharge especially from the river must be quantified. Although water levels have been measured in the past, continuous water-level recorders should be installed along several sections perpendicular to the river. This will allow the effect of recharge to be monitored as the flood wave moves through the aquifer. This will in turn allow calculation of permeabilities and storativities of the aquifers.

The conjunctive stream-aquifer model for the Crocodile River Valley is universally applicable. It can be applied to any stream-aquifer system. To illustrate the versatility of the model, two examples of the water-level response in the aquifer are presented here. They represent the response of the water table in the alluvium following a hypothetical flood lasting five days in the river. Contours were drawn of the ground-water levels immediately before the flood event and at the end of the flood.

The model can be used to great advantage to indicate the parameters which should be measured in the future, and the accuracy required. Continuous updating of the model as more information becomes available is essential. After several years of model refinement and validation, the stage will be reached where predictions of the water-table response will be sufficiently accurate to be of use for high-level management purposes.

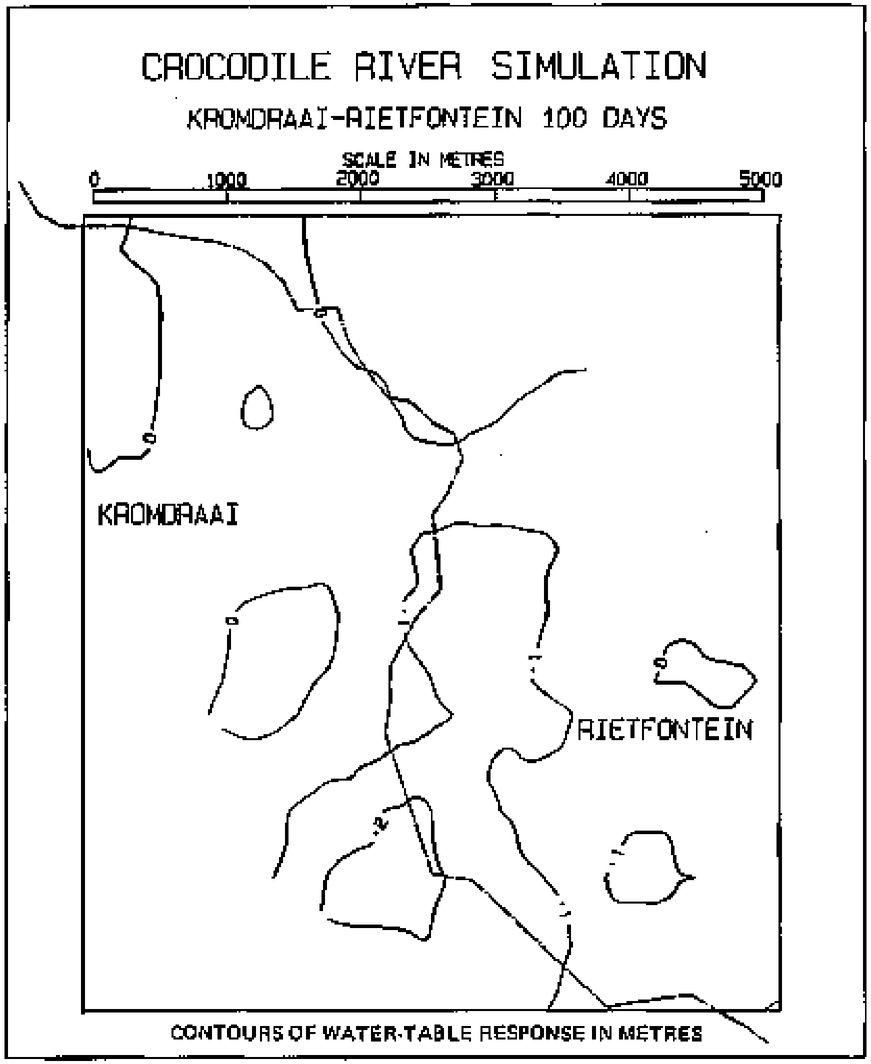

Figure 1. Response of the ground water level immediately before a period of flooding in the Crocodile River.

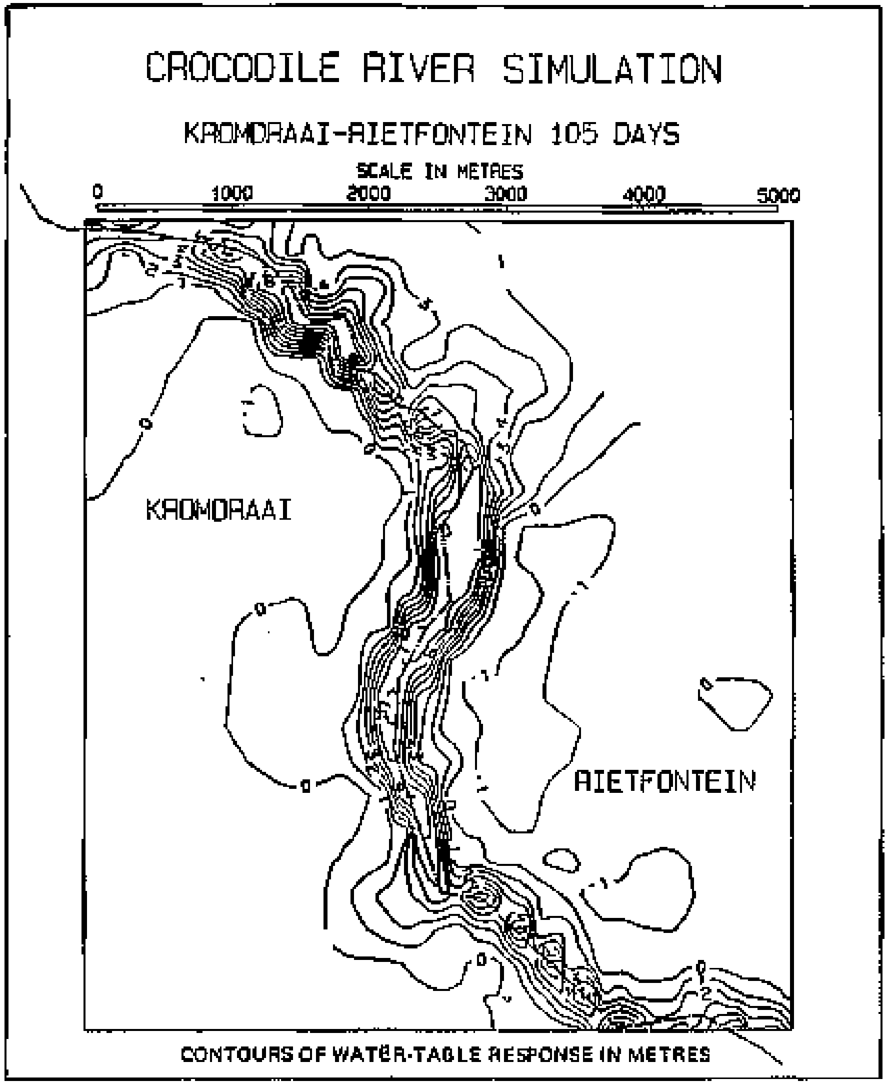

Figure 2. Response of the ground-water level immediately after a five day flood in the Crocodile River.

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CHAPTER 1

INTRODUCTION

1.1 PURPOSE AND SCOPE OF INVESTIGATION

This investigation into surface and ground-water aspects in the Crocodile River Valley forms part of a larger investigation into the applicability of ground-water models under South African conditions. The other investigations were:

- The dewatering effect caused by the Sishen Iron Ore Mine.
- The coastal aquifer at Atlantis.

In all three instances, geohydrological field investigations have been on-going for a number of years. The purpose of all three modelling exercises was:

- To construct a suitable model using existing mathematical and modelling techniques.
- To use these models to evaluate existing information in each of the areas.
- To identify necessary additional data required to create an operational management model.

This report deals only with the Crocodile River System. It is a joint effort between the Directorate of Geohydrology of the Department of Water Affairs and the Institute for Ground-water Studies at the University of the Orange Free State. The field work was carried out by the former, while the computer simulations were performed at the University of the Orange Free State.

1.2 GEOGRAPHIC SETTING

The study area is located immediately south of Thabazimbi in the North-Western Transvaal. It is framed by lines of latitude 24°40' and 25°17'S, and longitude 27°22' and 27°36'E. It encompasses a portion of the Crocodile River Valley some 50 km long, inclusive of all the riparian farms between Nooitgedacht 22 in the south and Wachteenbietjesdraai 350 in the north. Figure 1.1 is a locality map of the study area.

1.3 GENERAL BACKGROUND

Following successive drought and flood events in the early to mid-1960's, the local farming community made representations to the Department of Water Affairs in regard of an assured and stabilized surface-water supply. The area was subsequently proclaimed a Surface Water Control Area by Proclamation 111 of 10th May 1968. This action necessarily preceded the construction of surface reservoirs in 1970 (Klipvoor Dam) and 1971 (Vaalkop Dam), and was aimed at effecting control over the abstraction and usage of surface (public) water by means of statutory scheduling. A third reservoir, Roodekopjes Dam, is almost completed.

Subsequent development of irrigation farming was based primarily on the ground water available in the alluvial aquifer adjoining the river. This prompted concern regarding the possibly deleterious effect of large-scale ground-water abstraction on scheduled stream flow in the study area. Ground-water investigations confirmed that the aquifer and river are hydraulically connected. This necessitated that control be exercised over the ground-water resources of the study area, which was achieved by proclaiming the study area a Subterranean Water Control Area in 1981. The importance of ground water for irrigation in the study area is evident in the existence of some 300 irrigation boreholes in 1980. These represent a total ground-water allocation of 32×10^6 m^3 per year. The area under irrigation from surface water totals some 5600 ha, with a scheduled duty of 45×10^6 m^3 per year.

1.4 METHODS OF INVESTIGATION

1.4.1 PREVIOUS INVESTIGATIONS AND DATA COLLECTION

Previous investigations were helpful in evaluating the geohydrology and stream-aquifer relationship in the study area. Much of the geology of the region was mapped by Verwoerd (1963) and Iannello (1968). Bredenkamp and Porsasz (1967) investigated the

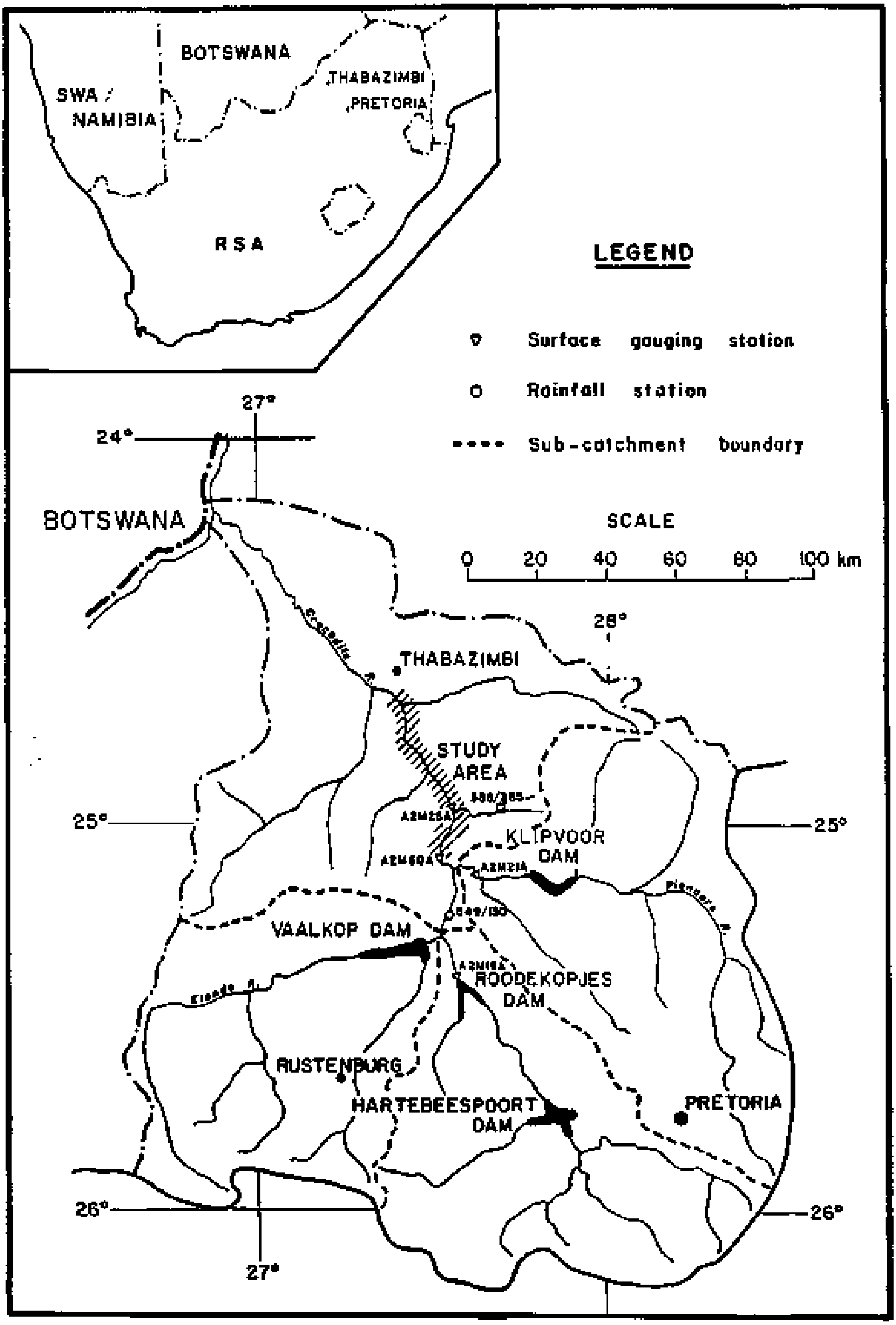


Figure 1.1. Locality map.

ground-water resources of the alluvial aquifer of the Crocodile River in the immediate vicinity of Thabazimbi. The "Bureau de Recherches Geologiques et Minières" (BRGM) (1977) conducted a geophysical, hydrologic and geohydrologic investigation that included the present study area.

More recently, Nel (1980) conducted a systems analysis for the operational strategy of the existing and proposed surface reservoirs that influence the regional hydrologic regime. Areas of surface-water irrigation, and the capacities and location of river pumps were obtained from a survey conducted by Murray, Biesenbach and Badenhorst Inc. (1984). Hobbs (1982) evaluated the ground-water reserves and better defined the stream-aquifer relationship in the study area. Data collection originating from his investigation is on-going and forms the basis of the present study.

Data collection activities have included:

(i) the inventory of all boreholes in the study area,

(ii) estimates of ground-water abstraction for irrigation,

(iii) collection of ground-water samples for chemical analysis, and

(iv) measurement of ground-water levels in 24 observation boreholes on a monthly basis and approximately 120 boreholes on an annual basis. The observation boreholes serve to monitor the response of the aquifer system to stream flow and ground-water abstraction. Stream flow data were provided by the Directorate of Hydrology of the Department of Water Affairs.

1.4.2 COMPUTER SIMULATION

Ground-water management and the proper conjunctive use of surface and ground water in the Crocodile River Valley are becoming increasingly important. This, however, requires that the dynamics of the stream-aquifer system be simulated rapidly and relatively inexpensively. This requirement can best be met by a mathematical model.

The computer model of the Crocodile River Valley stream-aquifer system was developed under the premise that, once shown to effectively simulate the hydrologic response of the aquifer to stream flow in a locality for which sufficient input data are available, the model can then be used to:

(i) extend the simulation either to part or the whole of the rest of the stream-aquifer system in the study area, and

(ii) extend the simulation into the future as a means of gauging the hydrologic response of the system to proposed or anticipated changes therein.

Especially the latter use of the model is integral to the proper conjunctive use of the water resources available to the study area.

1.5 ACKNOWLEDGEMENTS

The Water Research Commission and the Department of Water Affairs funded this investigation. This assistance is hereby gratefully acknowledged.

Appreciation and thanks are expressed to the many people who have contributed towards this report. This includes the property owners in the study area who permitted access to their properties and supplied information, and Mr. P.J. Beukes, resident Water Control Officer, who collected much information beyond the scope dictated by his post.

Thanks are also due to Mrs. C. le Roux for preparing some of the illustrations, and Mrs. M.J. Botha for word processing.

CHAPTER 2

ENVIRONMENTAL SETTING

2.1 PHYSIOGRAPHY

2.1.1 MORPHOLOGY AND DRAINAGE

The Crocodile River rises on the Witwatersrand north of Johannesburg, and flows in a north-westerly direction to eventually discharge into the Limpopo River. Main tributaries include the Elands and Pienaars Rivers. These rivers drain the western and eastern subcatchment basins respectively (Fig. 1.1).

The gentle topography of the valley floor varies in elevation between 900 and 950 metres above mean sea level. Isolated ridges and hills mark the presence of harder less weathering geologic formations such as banded ironstone and quartzite. Ephemeral surface drainages along the sloping flanks of the valley generally do not reach the river. Most are truncated by the alluvial flood plain.

2.1.2 VEGETATION AND CLIMATE

The rapid development of irrigation farming has resulted in the large-scale deforestation of arable land in the study area. The natural vegetation, which is of the Mixed Bushveld type (Acocks, 1975), covers those areas relatively far removed from the river where the soil cover is shallow and outcrops of bed rock are in evidence. Only the river banks remain very densely vegetated with invasive syringa trees and reeds.

The climate of the study area is characterized by abundant sunshine, moderate rainfall and high rates of evaporation. The summers are hot with average maximum temperatures of 35°C during the warmest month. The minimum temperatures during the cold winters ranges from -2,5°C to -5°C. The study area experiences a summer rainfall regime with an average precipitation of some 600 mm per annum, 80% thereof occurring in the months November through to March. The potential evaporation rate for the study area approaches 2500 mm per annum. Representative long-term annual precipitation is illustrated in Figure 2.1.

2.1.3 LAND USE

Land use in the study area is dominated by irrigation farming, although mixed farming (irrigation and cattle) is a general practice. The fertile clay and sandy loam soils of the alluvial flood plain support the intensive irrigation farming. Although only some 20% of the yearly rainfall occurs in the dry winter months, the region is able to produce two crops per year. Water for irrigating the winter crop is normally provided by:

(i) reservoir releases on demand, and
(ii) ground water obtained from boreholes tapping the alluvial aquifer.

Wheat is the principal winter crop and maize, soya-beans and sunflowers are the main summer crop types. Cotton, tobacco, lucerne and vegetables are also cultivated on a smaller scale.

Conventional sprayer irrigation is the most common technique applied, but centre-pivot and linear systems are becoming increasingly popular because of their higher degree of efficiency. Murray, Biesenbach and Badenhorst (1984) report that a typical sprayer irrigation system in the study area provides a duty of 60 to 70 mm per ha per 10 day irrigation cycle.

2.2 GEOLOGY

The study area is located in the centre of the Bushveld Complex. Sediments of the Transvaal Sequence (dolomite, quartzite, shale and banded ironstone) outcrop over a large area termed the Crocodile River Fragment (Hall, 1932), which is almost

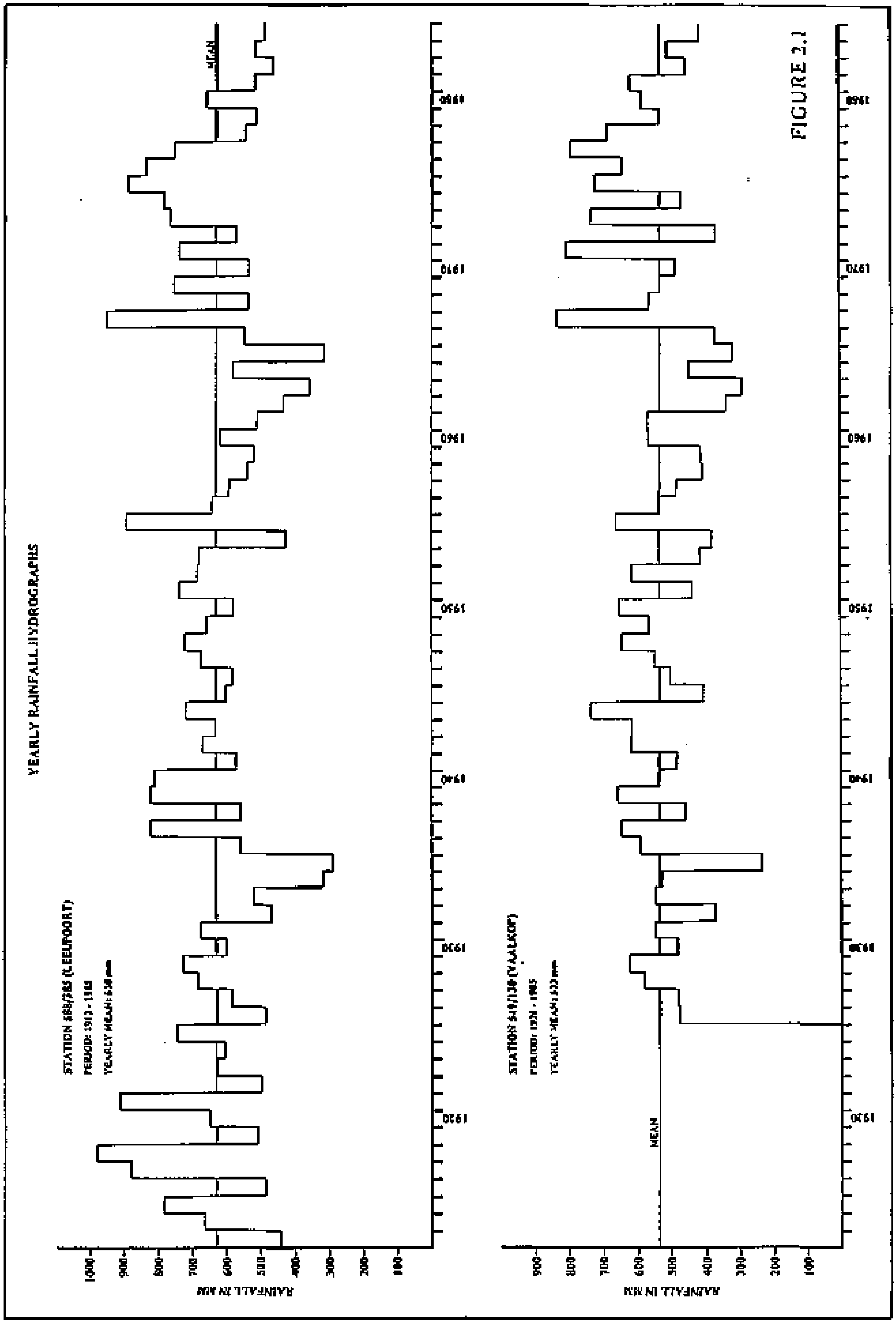

YEARLY RAINFALL HYDROGRAPHS
RAINFALL IN MM
MEAN
1920
1930
1940
1950
1960
1970
1980
RAINFALL IN MM
MEAN

FIGURE 2.1

entirely encircled by granite of the Lebowa Granite Suite. Figure 2.2 represents a generalized geological map of the study area after Verwoerd (1963).

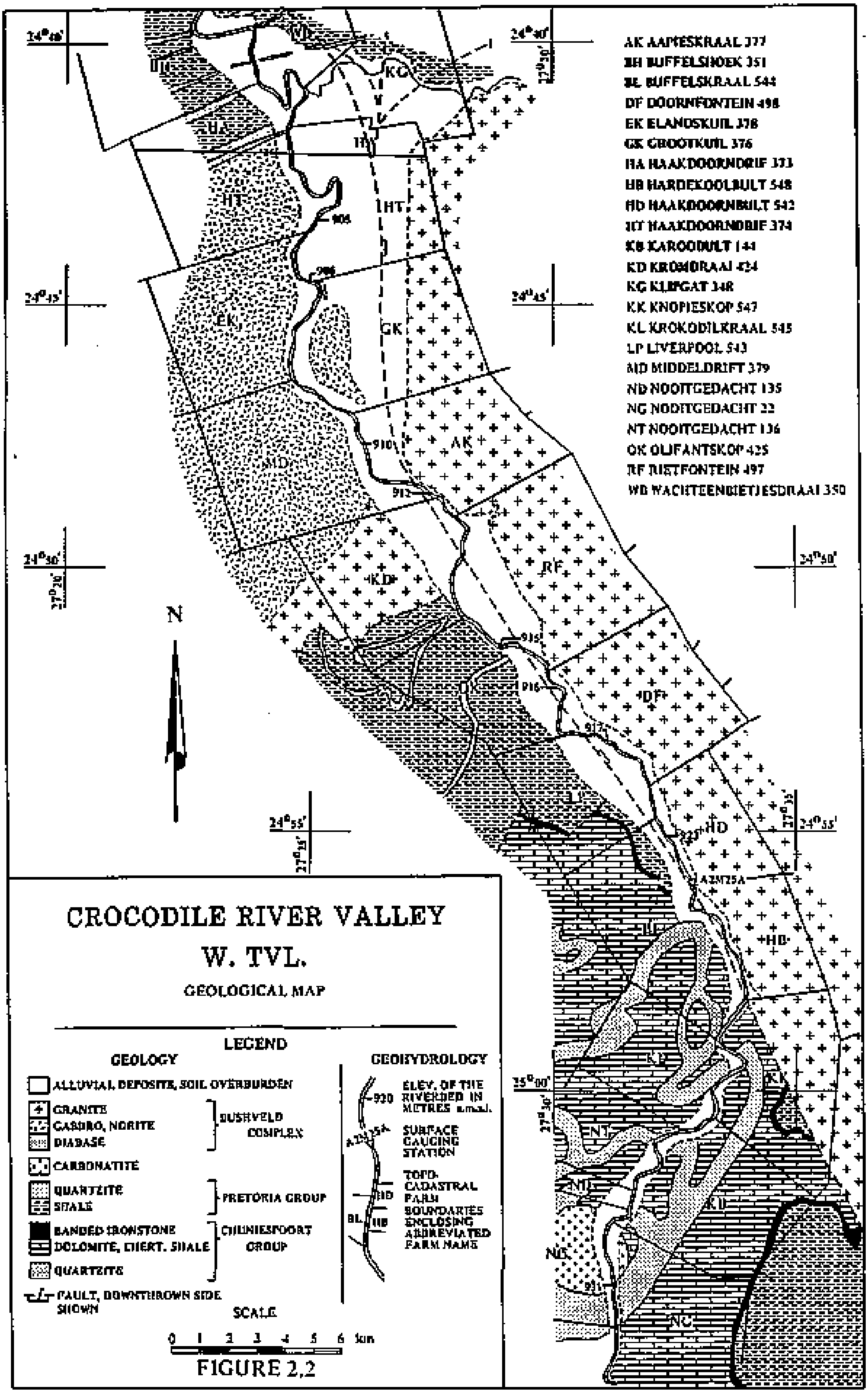
The most prominent geological feature is a large normal fault striking in a NNW - SSE direction. It forms the eastern boundary of the Crocodile River Fragment, entering the valley on the farm Knopieskop 547, from where it largely determines the course of the river northwards up to the farm Kromdraai 424. From here the fault assumes a more northerly strike direction, veering to the west in the extreme north. South of the farm Kromdraai 424, the fault brings Bushveld Granite on the east to lie against the sediments of the Transvaal Sequence on the west. From Kromdraai 424 northwards to the farm Haakdoorndrift 373, gabbro/norite on its west lies against the granite along a strike length of approximately 12 km. Alluvium, on average 16 metres thick, effectively conceals the position of the fault throughout most of the study area.

Extensive outcrops of bed rock are generally only visible further away from the river, on average >500 metres in the south to >1000 metres in the extreme north. However, outcrops in the river bed are visible at a number of locations. On the farm Wachteenbietjesdraai 350 in the extreme north, quartzite ridges traverse the valley, effectively defining ground-water compartments (Bredenkamp and Porsasz, 1967). In the south, outcrops of granite are visible in the river bed at Buffelskraal Drift, site of surface gauging station A2M25A. Quartzite ridges outcrop in close proximity to the river on the farms Krokodilkraal 545 and Knopieskop 547.

The extensive outcrops of dolomite and, to a lesser extent granite, reasonably well-define the lateral extent of the alluvium in the southern part of the study area. The same cannot be said of the gabbro/norite and granite over extensive areas in the northern part of the study area. Here, a substantial overburden of weathered bed rock merges indistinguishably with the alluvium.

2.3 SURFACE HYDROLOGY

Two relatively large rivers discharge immediately south of the study area into the Crocodile River. Flow in the lower reaches of these rivers is regulated by two dams, namely Vaalkop (capacity 57,6 x 10^6 m^3) on the Elands River and Klipvoor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BH BUFFELSHOEK 351
BL BUFFELSKRAAL 544
DF DOORNFONTEIN 498
EK ELANDSKUIL 378
GK GROOTKUIL 376
HA HAAKDOORNDRIF 373
HB HARDEKOOLBULT 548
HD HAAKDOORNBULT 542
HT HAAKDOORNDRIF 374
KB KAROODULT 144
KD KROMDRAAI 424
KG KLIPGAT 348
KK KNOPIESKOP 547
KL KROKODILKRAAL 545
LP LIVERPOOL 543
MD MIDDELDRIFT 379
ND NOOITGEDACHT 135
NG NOOITGEDACHT 22
NT NOOITGEDACHT 136
OK OLIFANTSKOP 425
RF RIETFONTEIN 497
WB WACHTEENBIETJESDRAAI 350
N
CROCODILE RIVER VALLEY
W. TVL.
GEOLOGICAL MAP
LEGEND
GEOLOGY
ALLUVIAL DEPOSITS, SOIL OVERBURDEN
GRANITE
GABBRO, NORITE
DIABASE
BUSHVELD COMPLEX
CARBONATITE
QUARTZITE
SHALE
PRETORIA GROUP
BANDED IRONSTONE
DOLOMITE, CHERT. SHALE
QUARTZITE
CHUNIESPOORT GROUP
FAULT, DOWNTHROWN SIDE SHOWN
GEOHYDROLOGY
ELEV. OF THE RIVERBED IN METRES a.m.s.l.
SURFACE GAUGING STATION
TOPO-CADASTRAL FARM BOUNDARIES ENCLOSING ABBREVIATED FARM NAME
SCALE
0 1 2 3 4 5 6 km
FIGURE 2.2

(capacity 43,8 x 10^6 m^3) on the Pienaars River. These dams normally ensure the perennial flow of water in the Crocodile River through the study area.

River discharge in the study area is gauged at station A2M25A. This is an open-channel flow gauging station located some 15 km downstream from the southern extremity of the study area. Table 2.1 presents the complete monthly discharge record for this station. The questionable accuracy and incompleteness of the original discharge record has been improved by applying the regression equation derived in Appendix A. However, the flow record indicates an extremely variable discharge regime. Gauging station A2M60A located at the southern boundary of the study area was completed in 1982, and therefore has a very limited record. Table 2.2 presents the summed monthly upstream discharge.

Figure 2.3 depicts the monthly discharges from Tables 2.1 and 2.2. The discharge at A2M25A has recently (1983) for the first time dropped below some 2 x 10^6 m^3 per month since the commissioning of the dams. Further, discharges greater than approximately 10 x 10^6 m^3 per month at A2M25A generally exceed the summed upstream discharge for that month. This reflects the contribution of surface run-off to the river below the dams and station A2M19A.

The general deficit in monthly discharge at station A2M25A during the dry winter months is ascribed to:

(i) abstraction of river water for irrigation upstream of the station,
(ii) recharge to the alluvial aquifer,
(iii) losses due to evapotranspiration, and
(iv) inaccurate gauging.

The double-mass curve of river discharge (Fig. 2.4) reflects the changed discharge regime of the river following the commissioning of the surface reservoirs.

It is realized that many important factors influencing river discharge have been neglected in the above discussions. Furthermore, the results are derived for that portion of the study area that least well reflects the geohydrology of the stream-

TABLE 2.1. MONTHLY DISCHARGE AT STATION A2M25A (10^6 m^3)

(+) = Gauging capacity of station exceeded
(*) = Corrected discharge (see Appendix A)

MONTH YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1960	7,38	4,19	1,59	5,29	4,30	1,86	1,85	1,06	0,00	0,00	28,38	96,32
1961	17,08	9,37	21,72	74,70	11,52	9,65	4,60	2,78	0,58	0,13	3,80	8,91
1962	3,69	4,05	0,70	2,02	0,72	0,00	0,00	0,00	0,00	0,00	1,29	0,91
1963	0,66	0,91	0,00	0,03	0,00	0,00	0,00	0,00	0,00	0,67	4,10	3,83
1964	2,58	4,13	0,70	0,00	0,00	0,00	0,00	0,00	0,00	51,49	13,66	23,72
1965	11,19	2,56	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	1,13
1966	3,28	11,07	0,03	0,00	0,00	0,00	0,00	0,00	0,00	15,35	5,16	115,54
1967	185,37	46,98	227,55	302,61	59,64	19,97	9,86	8,72	2,96	1,26	5,87	2,14
1968	2,16	0,64	8,99	7,99	5,04	3,07	1,86	0,59	0,45	0,28	2,84	2,62
1969	0,30	1,53	41,95	7,51	4,65	2,15	0,72	0,41	0,02	1,41	2,54	11,37
1970	0,93	1,10	0,77	0,03	0,44	1,30	0,98	1,60	2,89	1,90	0,21	3,83
1971	55,20	80,60	15,20	78,50	7,30	1,59	2,38	1,30	1,87	3,09	5,35	62,70
1972	188,00	42,50	17,20	7,89	2,91	1,84	1,34	2,03	2,88	4,32	3,98	5,02
1973	3,04	5,37	2,10	4,08	1,66	0,91	10,47*	2,40	3,45	5,93	3,50	92,11
1974	75,94	71,06	25,21	44,85	11,24	3,26	4,12	3,17	4,37	3,49	18,66*	17,53*
1975	142,00+	380,00+	184,00	325,00+	70,74*	22,40	15,40	7,36	3,07	3,97	3,83	23,30
1976	236,00	118,74*	370,33*	133,57*	212,63*	49,46*	39,52*	21,90	13,56*	102,00	82,72*	31,47*
1977	29,81*	126,18*	166,10*	76,25*	29,08*	17,97*	20,90*	15,18*	16,96*	16,77*	13,03*	8,42
1978	328,00+	488,00+	283,00+	108,00	43,40	25,10	21,30	13,20	11,30	9,57	6,96	6,30
1979	8,66	4,80	5,57	3,25	2,14	1,80	3,36	4,15	4,40	6,29	75,10	33,40
1980	65,10	99,50	31,30	8,75	4,72	3,33	5,96	4,70	8,45	8,70	9,80	66,50
1981	101,00+	107,00	107,00	10,20	11,60	4,87	6,04	8,08	6,32	9,25	5,91	5,51
1982	13,90	6,50	8,57	4,78	3,49	3,41	7,65	6,94	10,40	9,74	4,40	4,74
1983	7,02	9,15	5,95	1,06	0,00	0,00	0,00	0,00	4,13	1,44	1,90	10,90
1984	8,30	5,51	0,06	0,00	0,00	0,00	0,00	0,00	4,24	1,61	0,90	3,86
1985	1,76	3,02	1,30	0,00	0,00	0,00						

TABLE 2.2. SUMMED MONTHLY UPSTREAM DISCHARGE (10^6 m^3)

(+) = Gauging capacity of station(s) exceeded
(*) = Gauged value includes period of no record
Gauging as follows: January, 1960 to May, 1971 = A2M19A + A2M20 + A2M21A; June, 1971 to September, 1982 = A2M19A + A2M21A + VAALKOP DAM RELEASES; October, 1982 to present = A2M60A

MONTH YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1960	8,21	3,96	7,85	5,43	4,56	2,49	2,46	1,79	0,67	0,61	25,00	117,51
1961	13,86	8,86	19,01	73,38	12,69	14,48	4,85	3,19	1,14	1,24	5,31	12,75
1962	2,89	4,95	1,59	2,86	1,41	0,85	0,77	0,51	0,05	0,06	4,79	2,14
1963	3,99	1,71	0,05	1,96	0,12	1,09	2,16	0,29	0,06	1,94	5,58	7,68
1964	6,06	7,24	0,77	0,82	0,12	0,21	0,58	0,42	0,11	51,25	14,01	28,16
1965	14,77	4,81	0,08	0,71	0,51	0,33	0,41	0,44	0,08	0,01	0,38	2,50
1966	12,52	30,78	0,14	0,00	0,00	0,03	0,10	0,12	0,10	22,90	7,19	120,48
1967	172,66	362,59	208,66	213,86	48,08	23,01	9,74	9,71	3,77	2,24	7,73	2,09
1968	2,14	1,65	10,69	8,31	4,40	3,08	2,90	1,97	0,38	0,68	2,99	3,60
1969	1,19	1,57	28,03	8,89	6,55	2,05	1,39	1,06	1,07	0,34	3,22	9,77
1970	2,40	1,73	2,24	1,11	2,16	2,24	2,53	3,89	3,55	4,30	1,34	3,58
1971	5,06	45,63	11,93	32,43	5,88	3,06	3,78	3,48	4,22	5,71	5,38	44,50
1972	68,75	11,27	13,07	5,14	2,56	2,08	2,47	4,51	6,32	9,12	6,04	6,53
1973	5,54	3,83	3,01	2,63	2,12	2,50	4,96	5,28	7,14	8,69	4,80	42,80
1974	36,46	35,02	16,32	24,60	7,05	3,87	5,50	5,86	7,04	8,78	9,80	10,48
1975	106,88	187,73	98,20	160,02	52,05	18,10	13,54	8,54	6,84	8,26	5,53	18,31
1976	109,36	89,55*	286,10*	101,13	162,90	35,42	27,66	13,59	7,39	66,70	61,41	21,37
1977	20,07	95,36	128,55	58,38	19,48	10,82	13,11	8,64	10,03	8,88	8,96	5,84
1978	398,66	384,00	181,20	67,92	30,19	25,25	24,63	17,34	18,07	14,78	11,08	10,77
1979	13.51	10,95	9,91	5,82	4,00	4,72	8,31	11,43	13,34	15,41	50,33	30,25
1980	52,60	67,60+	32,30	15,90	11,07	9,87	14,32	13,02	15,82	13,20	15,56	35,70*
1981	32,90+	48,10	49,20	15,23	17,16	12.49	15.27	17,38	18,17	17,11	9,23	7,14
1982	17,56	14,47	14,62	8,07	6,45	6,40	11,33	12,59	16,35	12,70	5,47	8,43
1983	9,93	13,20	8,98	1,35	0,00	0,00	0,00	0,01	8,19	3,15	3,64	13,40
1984	13,10	8,91	0,51	0,00	0,00	0,00	0,00	0,00	10,20	3,36	2,64	5,28
1985	5,58	6,92	3,47	0,00	0,00	0,00	0,00					

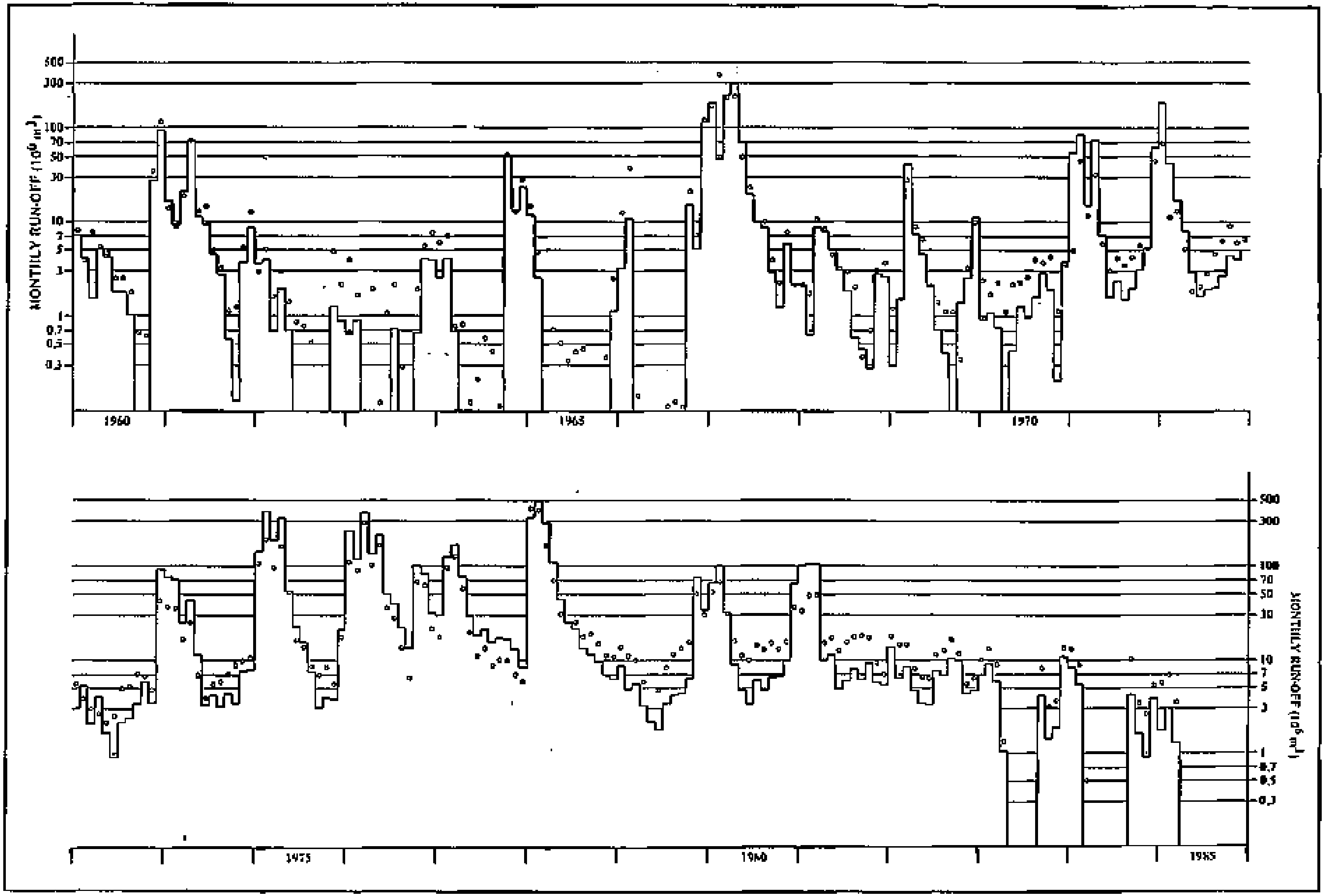


Figure 2.3. Monthly discharge at surface gauging station A2M25A, and summed upstream monthly discharge (open symbols).

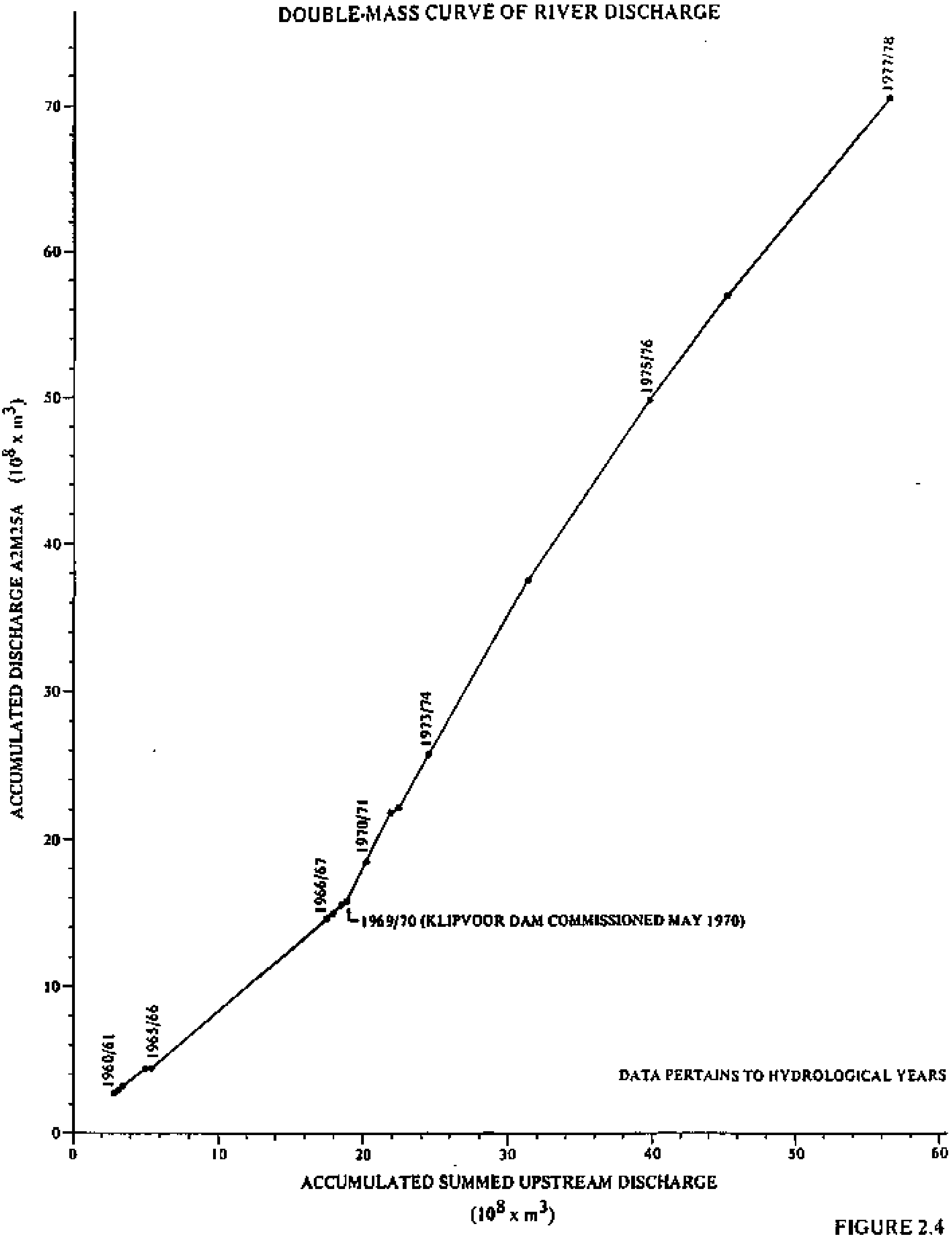

DOUBLE-MASS CURVE OF RIVER DISCHARGE
ACCUMULATED DISCHARGE A2M25A (10^8 x m^3)
ACCUMULATED SUMMED UPSTREAM DISCHARGE (10^8 x m^3)
0
10
20
30
40
50
60
70
1960/61
1965/66
1966/67
1969/70 (KLIPVOOR DAM COMMISSIONED MAY 1970)
1970/71
1973/74
1975/76
1977/78
DATA PERTAINS TO HYDROLOGICAL YEARS

FIGURE 2.4

aquifer system. This includes the extensive basin area located upstream of the study area.

Nevertheless, the base-flow component of discharge at station A2M25A is computed at 32% (on average) of the gauged discharge. In general, the analyses show this percentage to increase as gauged discharge decreases, and vice versa.

The foregoing discussion has stressed the need for a surface gauging station at the lower extremity of the study area. Such a facility is imperative if:

(i) the magnitude of base flow originating within the study area is to be quantified, and

(ii) stream losses recharging the alluvial aquifer are to be computed with reasonable accuracy.

APPENDIX A TO CHAPTER 2

RIVER DISCHARGE

To obtain a more representative record for the discharge at station A2M25A, it was assumed that a linear relationship existed between this discharge and the summed monthly upstream discharge. This assumption was tested for the period January, 1960 to April, 1970. This period preceded the commissioning of Klipvoor and Vaalkop Dams (in May, 1970 and May, 1971 respectively). Linear regression by the method of least squares yielded a correlation coefficient of 0,98. Linear regression applied to the data for the period May, 1970 to April, 1979 yielded a correlation coefficient of 0,92 (months containing incomplete data were excluded from this analysis). The linear relationship between the data contained in Table 2.1 and 2.2 is described by the regression equation

$$y = 1{,}28x + 4{,}12 \qquad \text{(A-1)}$$

where

y = monthly discharge at A2M25A in million m^3

x = summed monthly upstream discharge in million m^3

APPENDIX B TO CHAPTER 2

CORRELATION OF RAINFALL WITH RIVER DISCHARGE

Precipitation data for rainfall stations 549/130 (Vaalkop) and 588/385 (Leeupoort) were used to correlate rainfall with river discharge at station A2M25A. Rainfall data for each of the hydrological years 1960/61 to 1979/80 have been expressed as a ratio of the long-term mean yearly rainfall. This value is termed the "index of wetness" (Butler, 1957).

Figure B-1 graphically depicts the correlation of rainfall at Vaalkop with river discharge. In Figure B-2, the indices used are the mean indices for Vaalkop and Leeupoort.

Both these figures indicate that a reasonable correlation exists for the pre-1970/71 period. This correlation can be described by an exponential function of the form

$$y = ae^{bx} \qquad \text{(B-1)}$$

where

y = annual (water-year) discharge x 10^6 m^3 at station A2M25A
x = index of wetness for the corresponding period

In the case of Figure B-1, this function yields the equation

$$y = 3{,}05\ e^{(3{,}22x)} \qquad \text{(B-2)}$$

with a coefficient of determination (r^2) of 0,92.

Similarly, for Figure B-2

$$y = 2{,}35\ e^{(3{,}54x)} \qquad \text{(B-3)}$$

for which $r^2 = 0{,}91$.

The correlation for the post-1970/71 data is weak for both sets of data. This emphasizes the influence of the dams on the natural discharge regime of the river, and negates any further attempt to reasonably determine the influence of rainfall on river discharge following the commissioning of the dams.

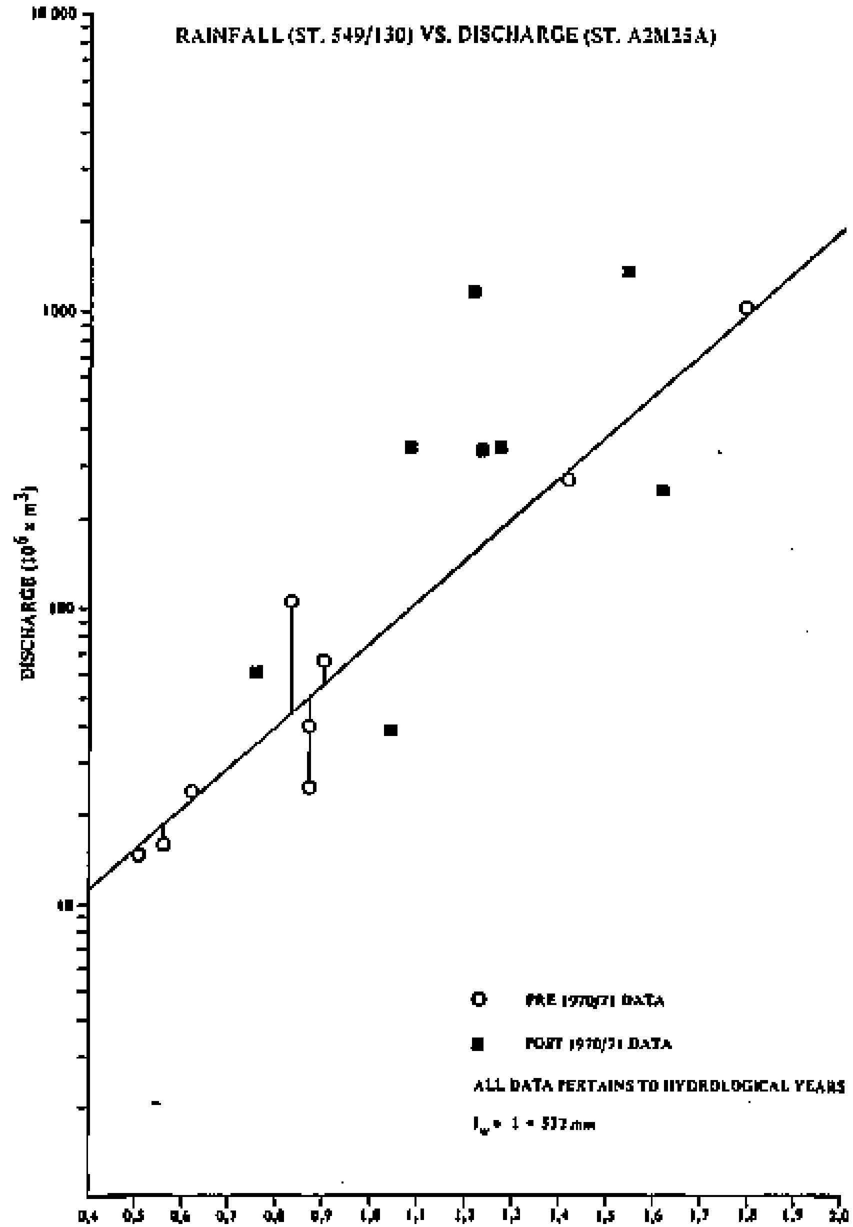


FIGURE B-1

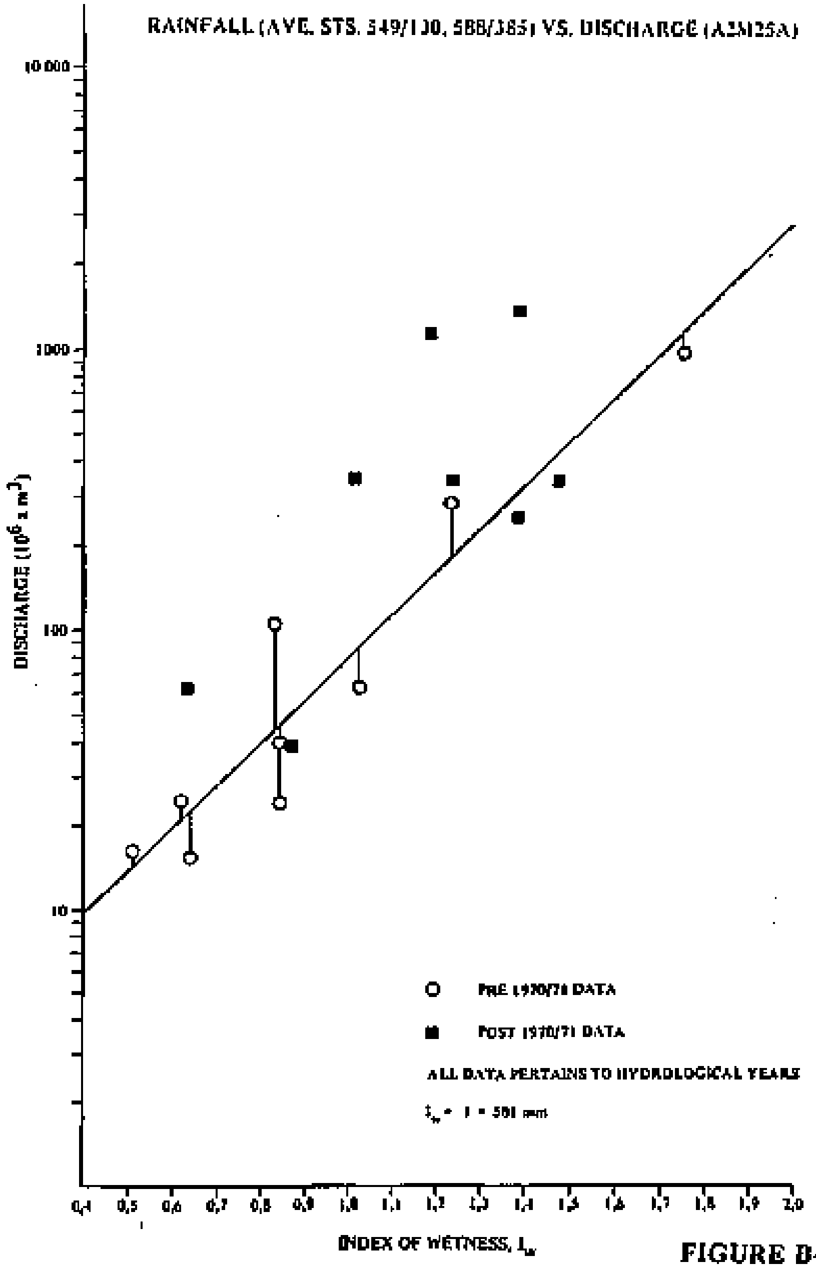


FIGURE B-2

APPENDIX C OF CHAPTER 2

ANALYSIS OF BASE FLOW

Base flow can contribute significantly to stream flow in any stream-aquifer system. To quantify base flow at station A2M25A, daily discharge hydrographs were compiled for two periods of time (Figures C-1 and C-2). Both periods were chosen for their complete data and represent:

(i) a period characteristic of the natural discharge regime of the river, i.e. pre-1970/71 (Fig. C-1), and

(ii) a period characteristic of discharge subsequent thereto (Fig.C-2).

METHOD OF ANALYSIS

Base flow was analysed using the technique described by Butler (1957, p. 214) and Meyboom (1961). The logarithm of discharge is plotted against time (linear), and the portion of the stream hydrograph representing base-flow recession plots as a straight line. This portion of the graph can be separated from the other components of run-off (Figures C-1 and C-2).

According to Butler (1957), the volume of base flow during a given time interval is given by the equation

$$Q = \int_{t_1}^{t_2} Q\,dt = \left[\frac{-K_1 K_2 / 2{,}3}{10^{t/K_2}} \right]_{t_1}^{t_2} \qquad \text{(C-1)}$$

where

K_1 = base-flow discharge at the start of the base-flow recession

K_2 = time increment corresponding to one log cycle change in discharge

$t_1 = t_0 = 0$

t_2 = time interval since t_1 preceding the following recharge period

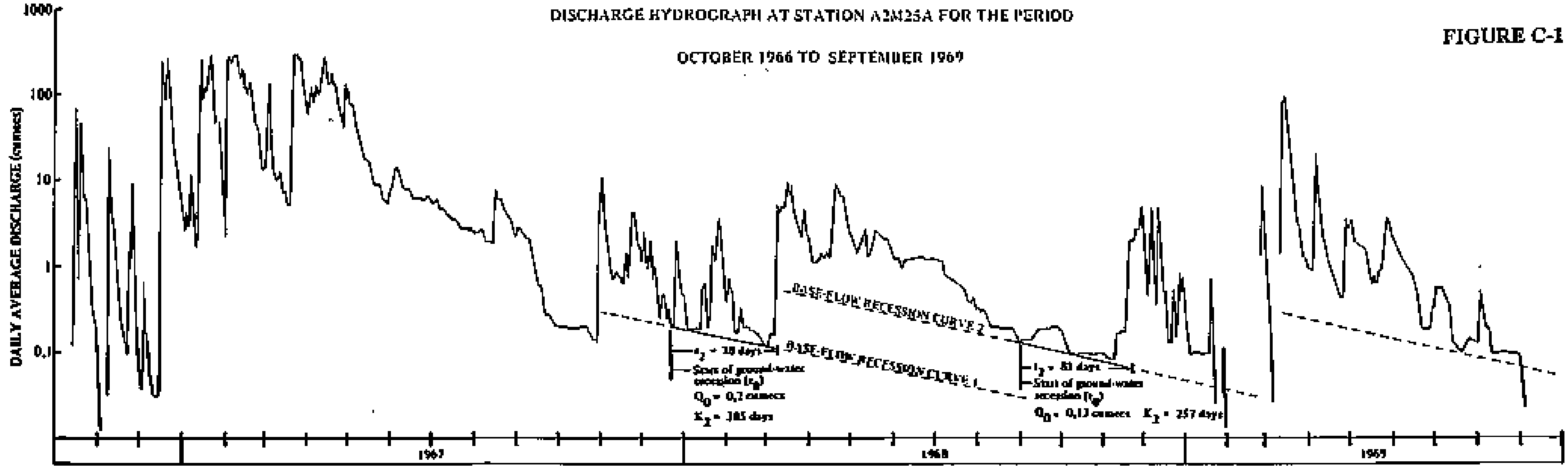


FIGURE C-1

DISCHARGE HYDROGRAPH AT STATION A2M25A FOR THE PERIOD OCTOBER 1966 TO SEPTEMBER 1969

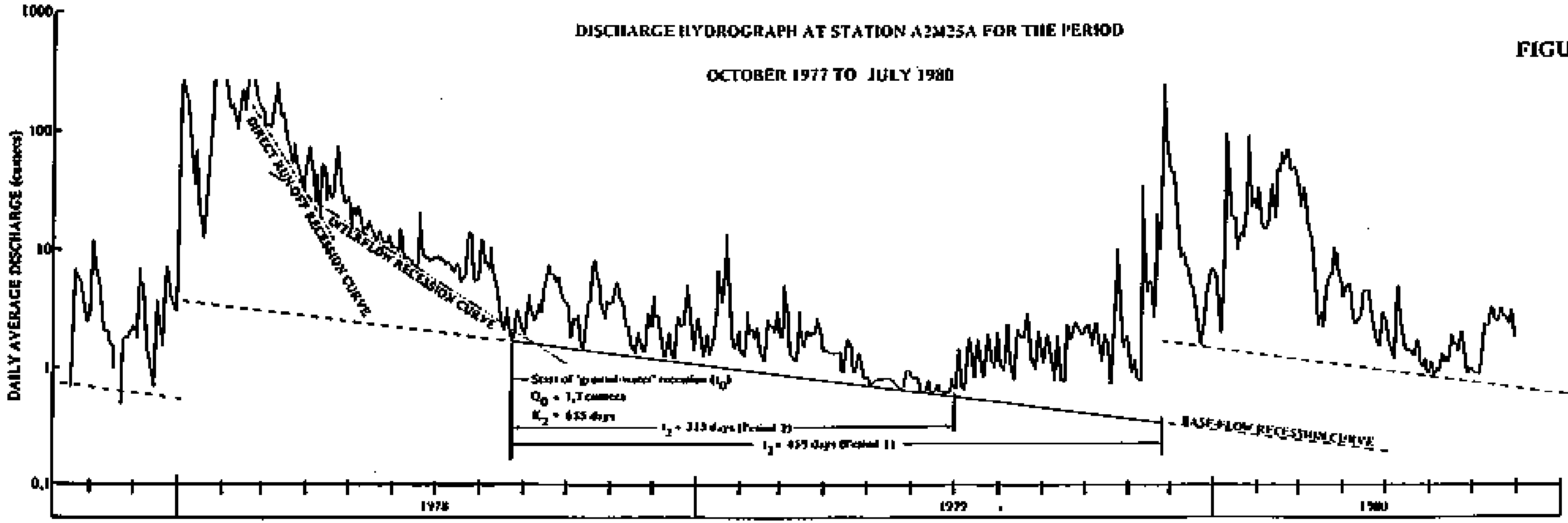


FIGURE C-2

DISCHARGE HYDROGRAPH AT STATION A2M25A FOR THE PERIOD OCTOBER 1977 TO JULY 1980

Similarly, the total volume of base flow held in storage corresponding to a given point on the base-flow recession curve is given by the equation

$$Q = \int_{t}^{\infty} Q \, dt \qquad \text{(C-2)}$$

Meyboom (1961) showed that integrating this equation from time t_0 to infinity enabled the computation of the total volume of base flow discharged during a complete base-flow recession. Meyboom termed this volume, given by the equation

$$Q_{tp} = \int_{t_0}^{\infty} Q \, dt \qquad \text{(C-3)}$$

the total potential ground-water discharge.

Equation (C-3) can be written as

$$Q_{tp} = \left[\frac{-K_1K_2/2,3}{10^{\infty/K_2}}\right] - \left[\frac{-K_1K_2/2,3}{10^{0/K_2}}\right] \qquad \text{(C-4)}$$

The first term of this equation becomes extremely small as t_2 approaches infinity. The factor $10^{0/K_2}$ in the second term equals unity.

Therefore

$$Q_{tp} = K_1K_2/2,3 \qquad \text{(C-5)}$$

in which K_1 and K_2 are as defined above.

ANALYSIS FOR THE PERIOD OCTOBER, 1966 TO SEPTEMBER, 1969

The daily discharge hydrograph (Fig. C-1) reflects large fluctuations during period October, 1966 to September, 1969. The preceding 19 months (March, 1965 to mid-October, 1966) witnessed zero daily discharge at station A2M25A. The large flow-losses caused by recharge of the dry river bed are reflected in the large fluctuations in discharge associated with the start of the first "wet" period (October/November, 1966). Daily average flow reverted to below 0,1 cumecs within days of discharges greater than 10 cumecs. The very low flows witnessed in February and September, 1969 are attributed to upstream abstraction for irrigation.

Figure C-1 indicates that all three components of stream flow, i.e. direct run-off, interflow (originating as bank storage) and base flow are manifested in the declining segments of the stream hydrograph.

Analysis of the base-flow recession yielded the following results:

RECESSION 1

$Q_{tp} = 2{,}29 \times 10^6\ m^3$ — K_1 - $0{,}2\ m^3/s$; $K_2 = 305$ days

$Q = 1{,}02 \times 10^6\ m^3$ — $t_1 = 0$; $t_2 = 78$ days

Gauged flow ~ $3{,}8 \times 10^6\ m^3$

RECESSION 2

$Q_{tp} = 1{,}26 \times 10^6\ m^3$ — $K_1 = 0{,}13\ m^3/s$; $K_2 = 257$ days

$Q = 0{,}65 \times 10^6\ m^3$ — $t_1 = 0$; $t_2 = 81$ days

Gauged flow ~ $1{,}7 \times 10^6\ m^3$

The above results indicate that the base-flow contribution to river discharge amounts to 27% and 38% respectively of the gauged flow at station A2M25A for the duration of each respective recession. The average contribution amounts to 32,5%.

ANALYSIS FOR THE PERIOD OCTOBER, 1977 TO AUGUST, 1980

The stabilizing influence of the reservoirs on stream flow at station A2M25A is evident in Figure C-2, daily discharge being maintained at some 1,5 cumecs for the period July to October, 1979. The base-flow recession curve constructed for Figure C-2 is therefore not regarded to represent true base-flow recession. Rather, it represents some equivalent component (of the stream hydrograph) that includes the effect of both true base-flow discharge and reservoir-influenced flow.

The quasi base-flow recession curve (Fig. C-2) was analysed for two periods, as follows:

PERIOD 1

The stabilizing influence of the reservoirs is included in this period.

$Q_{tp} = 41{,}83 \times 10^6\ m^3$ $\qquad$ $K_1 = 1{,}7\ m^3/s$
$K_2 = 655$ days

$Q = 33{,}48 \times 10^6\ m^3$ $\qquad$ $t_1 = 0$
$t_2 = 459$ days

Gauged flow ~ $165 \times 10^6\ m^3$

PERIOD 2

This period excludes the stabilizing influence of the reservoirs.

$Q_{tp} = 41{,}83 \times 10^6\ m^3$ $\qquad$ $K_1 = 1{,}7\ m^3/s$
$K_2 = 655$ days

$Q = 27{,}91 \times 10^6 \ m^3$

$t_1 = 0$
$t_2 = 313$ days

Gauged flow ~ $64 \times 10^6 \ m^3$

The contribution of "base flow" to surface discharge amounts to 20% (period 1) and 44% (period 2) respectively. The average contribution amounts to 32% of the gauged discharge.

CHAPTER 3

HYDROLOGY OF THE STREAM-AQUIFER SYSTEM

3.1 GEOHYDROLOGIC SETTING

The Crocodile River Valley alluvial aquifer typifies a water-course aquifer traversed by a hydraulically connected stream. The river has an average slope of 0,5 metres per km through the study area, and partially penetrates the adjoining alluvial aquifer. Features such as cut-off meanders, natural levels and flood plains indicate that the river has reached maturity.

The alluvial deposits constitute the primary aquifer in the study area. These deposits vary considerably in lateral extent and thickness. The relatively dense and clay-rich sandy loam soil of the alluvial flood plain accounts for the often semi-confined nature of the alluvial aquifer. The average thickness of the overburden varies between 6 and 9 metres, below which are found the aquiferous sands, gravels and coarser riverine deposits. The depth to bed rock seldom exceeds 16 metres. A limited zone of weathered bed rock, generally less than 2 metres thick, underlies the alluvial deposits.

3.2 OCCURRENCE OF GROUND WATER

3.2.1 ALLUVIAL AQUIFER

3.2.1.1 GEOMETRY OF THE ALLUVIAL AQUIFER

The lateral extent of the alluvial aquifer has been determined from photogeological interpretation, field investigation of bed-rock outcrop and information gained from exploration drilling programmes.

The alluvial deposits reach their maximum lateral extent in the extreme north of the study area (Fig. 3.2), narrowing discontinuously southwards as bed rock outcrops nearer the river. The alluvium ranges in width from less than 500 metres to more than 2000 metres, and encompasses an area of approximately 74 km^2.

3.2.1.2 CHARACTERIZATION OF THE ALLUVIAL AQUIFER

A generalized geohydrological profile of the alluvial deposits as determined from exploration boreholes is presented in Figure 3.1. A detailed description of each exploration borehole drilled during this study is presented in Table 3.1. The air rotary drilling method was used. Initial problems experienced with this method resulted from the inability to drive casing through the pebble horizons encountered in boreholes G32646 and G32647. These boreholes were later successfully completed using the cable tool method of drilling.

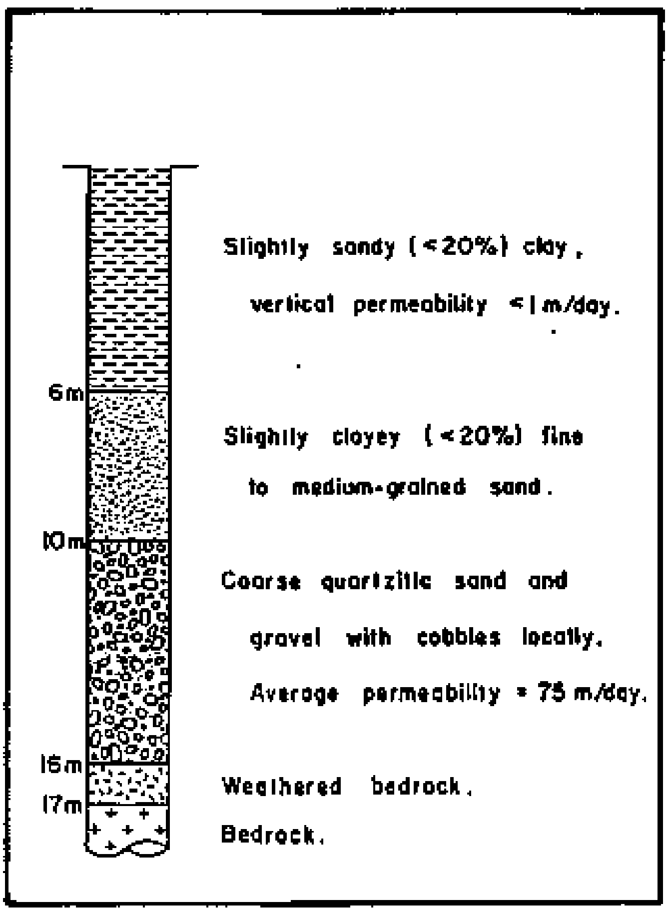


Figure 3.1. Generalized profile of the alluvium.

TABLE 3.1. LOGS OF BOREHOLES DRILLED BY THE DEPARTMENT OF WATER AFFAIRS IN 1981.

EXPLORATION BOREHOLE: G32646 — ELEVATION: 924,65 m.a.m.s.l.
DATE COMPLETED: 12-08-80 — TOTAL DEPTH: 24 m
CASING DETAILS: 152 mm ø; 0-18 m plain
STRUCK AND REST WATER LEVELS: struck = 15 m; static = 9,5 m

0-3 m	Very compact grey clay (appears as "heavy" turf soil at surface)
3-9 m	Slightly sandyish brown clay
9-11 m	Sandy brown clay with calcrete
11-14 m	Reddish-brown sandy clay
14-15 m	Reddish-brown clayey sand containing less than 10% quartzitic gravel
15-16 m	Medium to coarse gravel (grain ø 1 to 4 mm)
16-18 m	Abundant fine sand containing 20-25% gravel including angular pebbles up to 25 mm ø
18-20 m	Fine sand
20-21 m	Weathered granite
21-24 m	Fresh granite

EXPLORATION BOREHOLE: G32647 — ELEVATION: 923,21 m.a.m.s.l.
DATE COMPLETED: 25-08-80 — TOTAL DEPTH: 32 m
CASING DETAILS: 165 mm ø; 0-12 m plain; 12-18 m slotted
STRUCK AND REST WATER LEVELS: struck = 15 m; static = 8,6 m

0-3 m	Very compact grey clay (appears as "heavy" turf soil at surface)
3-7 m	Slightly sandyish brown clay
7-15 m	Brown clayey fine sand
15-16 m	Fine to coarse sand and gravel. Rounded pebbles up to 30 mm ø
16-19 m	Slightly clayey very fine sand
19-21 m	Weathered granite
21-32 m	Fresh granite, quartz and feldspar-rich with associated biotite and hornblende

EXPLORATION BOREHOLE: G32648 — ELEVATION: 919,18 m.a.m.s.l.
DATE COMPLETED: 29-07-80 — TOTAL DEPTH: 22 m
CASING DETAILS: 165 mm ø; 0-11 m plain; 11-17 m slotted; 17-20 m plain
STRUCK AND REST WATER LEVELS: struck = 10 m; static = 10 m

0-4 m	Reddish-brown slightly sandyish clay
4-10 m	Very fine-grained quartzitic sand, colour as above
10-12 m	Fine-grained quartzitic sand containing small pebbles up to 5 mm ø
12-15 m	Pebbles up to 30 mm ø. Finer fraction washed out
15-18 m	Sandy quartzitic gravel
18-19 m	Fine quartzitic gravel and sand
19-21 m	Weathered granite
21-22 m	Fresh granite

EXPLORATION BOREHOLE: G32649 — ELEVATION: 918,97 m.a.m.s.l.
DATE COMPLETED: 31-07-80 — TOTAL DEPTH: 18 m
CASING DETAILS: 165 mm ø; 0-14 m plain
STRUCK AND REST WATER LEVELS: struck = 10 m; static = 9,5 m

0-2 m	Grey-brown compact grey clay
2-7 m	Reddish-brown slightly sandyish clay
7-9 m	Fine-grained quartzitic sand
9-12 m	Very coarse gravel containing rounded pebbles up to 60 mm ø
12-13 m	Medium to coarse gravel
13-14 m	Decomposed granite
14-17 m	Weathered granite
17-18 m	Fresh granite

EXPLORATION BOREHOLE: G32650 — ELEVATION: Not levelled
DATE COMPLETED: 21-08-80 — TOTAL DEPTH: 54 m
CASING DETAILS: 165 mm ø; 0-32 m plain; 32-38 m slotted
STRUCK AND REST WATER LEVELS: struck = 34 m; static = 29 m

0-3 m	Red slightly clayey soil
3-11 m	Fine to medium quartzitic gravel and subordinate sand
11-15 m	Fine-grained quartzitic sand
15-24 m	Same as 3-11 m above
24-30 m	Same as 11-15 m above
30-34 m	Same as 3-11 m above
34-37 m	Very coarse quartzitic gravel including rounded pebbles up to 30 mm ø and boulders (150 mm ø)
37-54 m	Mixed granite and gabbro fraction. Particles rounded to angular. Fault breccia.
54 m	Fresh dark-grey gabbro

EXPLORATION BOREHOLE: G32651 ELEVATION: 923,75 m.a.m.s.l.
DATE COMPLETED: 26-08-80 **TOTAL DEPTH:** 48 m
CASING DETAILS: 165 mm ø; 0-20 m plain
STRUCK AND REST WATER LEVELS: struck = 11 m; static = 6 m

0-3 m	Reddish-brown compact clay
3-13 m	Calcitic gravel. Calcite particles larger and more predominant between 10 and 13 m
13-17 m	Slightly weathered shale
17-48 m	Shale

EXPLORATION BOREHOLE: G32652 ELEVATION: 917,11 m.a.m.s.l.
DATE COMPLETED: 29-08-80 **TOTAL DEPTH:** 14,5 m
CASING DETAILS: 165 mm ø; 0-7,5 m plain; 7,5-13,5 m slotted
STRUCK AND REST WATER LEVELS: struck = 10,5 m; static = 7 m

0-10 m	Grey-green compact clay
10-12 m	Fine-grained quartzitic gravel
12-14 m	Coarse quartzitic gravel, pebbles up to 20 mm ø
14-15 m	Dark granite rich in quartz and hornblende

EXPLORATION BOREHOLE: G32653 ELEVATION: 932,05 m.a.m.s.l.
DATE COMPLETED: 03-09-80 **TOTAL DEPTH:** 31 m
CASING DETAILS: 165 mm ø; 0-6 m plain
STRUCK AND REST WATER LEVELS: struck = 10,5 m; static = 8,5 m

0-2 m	Rust-brown clayey soil
2-10 m	Clayey brown soil with calcrete nodules between 9-10 m
10-15 m	Decomposed calcrete gravel
15-18 m	Decomposed calcrete and weathered dolomite
18-31 m	Fresh dolomite

EXPLORATION BOREHOLE: G32654 ELEVATION: 931,10 m.a.m.s.l.
DATE COMPLETED: 04-09-80 **TOTAL DEPTH:** 25 m
CASING DETAILS: 165 mm ø; 0-12 m plain
STRUCK AND REST WATER LEVELS: struck = 8 m; static = 8 m

0-1 m	Rust-brown soil
1-8 m	Reddish-brown fine-grained sand
8-11 m	Medium to coarse granitic gravel
11-12 m	Coarse granitic gravel, pebbles up to 20 mm ø
12-13 m	Same as 8-11 m above
13-15 m	Fresh pink granite rich in quartz and feldspar

EXPLORATION BOREHOLE: G32655 ELEVATION: 928,51 m.a.m.s.l.
DATE COMPLETED: 09-09-80 **TOTAL DEPTH:** 16,5 m
CASING DETAILS: 165 mm ø; 0-4,5 m plain; 4,5-16,5 slotted
STRUCK AND REST WATER LEVELS: struck = 10,5 m; static = 9,5 m

0-2 m	Light-brown clayey soil
2-6 m	Sandyish clay
6-14 m	Coarse calcrete gravel and sand in clayey matrix
14-16,5 m	Very coarse gravel, pebbles up to 40 mm ø

EXPLORATION BOREHOLE: G32656 ELEVATION:929,74 m.a.m.s.l.
DATE COMPLETED: 10-09-80 **TOTAL DEPTH:** 25 m
CASING DETAILS: 165 mm ø; 0-12,5 m plain; 12,5-18,5 slotted
STRUCK AND REST WATER LEVELS: struck = 14 m; static = 10,5 m

0-2 m	Brown clayey soil
2-7 m	Red-brown sandyish clay
7-14 m	Coarse calcrete gravel and sand in a clayey matrix
14-15 m	Coarse quartzitic gravel
15-17 m	Fine-grained quartzitic gravel
17-18 m	Coarse quartzitic gravel and pebbles
18-19 m	Fine-grained quartzitic gravel
19-22 m	Same as 17-18 m above
22-25 m	Fine-grained quartzitic gravel

EXPLORATION BOREHOLE: G32657 ELEVATION: 936,88 m.a.m.s.l.
DATE COMPLETED: 17-09-80 **TOTAL DEPTH:** 22 m
CASING DETAILS: 165 mm ø; 0-16,5 m plain
STRUCK AND REST WATER LEVELS: struck = 9 m; static = 9 m

0-9 m	Brown clayey soil
9-13 m	Poorly rounded to angular fragments of fresh dolomite in a fine-grained gravel matrix
13-22 m	Fresh dolomite

The alluvium attains an average maximum thickness of 16 metres. The basal portion of the alluvial deposits consists of cobbles, gravel and coarse sand on average 6 metres thick. This forms the main water-bearing horizon of the alluvial aquifer. It grades upwards into an often slightly clayey, fine to medium-grained sand fraction. A combination of fine sand, silt and clay in varying constituent percentages, averaging 6 metres thick, forms the overburden. This overburden severely limits the vertical infiltration of water on the alluvial flood plain.

Granulometric analyses performed on samples obtained from BRGM exploration boreholes indicate aquifer permeabilities ranging from 8 m/day to some 580 m/day (BRGM, 1977, p. 21). These values are based on the empirical relation

$$K = A \; . \; (d_{10})^2 \qquad (3.1)$$

where d_{10} is the grain-size diameter, as read from a grain-size gradation curve, at which 10% by weight of the soil particles are finer and 90% are coarser. For K in m/s and d_{10} in mm, BRGM used a value for the coefficient A varying between 0,05 and 0,6 in their calculations. This value is based on calculations from tests performed on sands in the U.S.A. According to Freeze and Cherry (1979), the coefficient A is equal to 0,01 (for K in m/s and d_{10} in mm). Use of this value in Equation (3.1) reduces the maximum permeability calculated by BRGM by this method to 116 m/day.

Substitution of the value of the saturated thickness of the alluvial aquifer in the equation

$$T = Kd \qquad (3.2)$$

where T = transmissivity (m^2/day)
K = permeability (m/day)
d = saturated thickness of the aquifer (m)

allows for the computation of the permeability from aquifer-test results. BRGM (1977) in this way arrived at values varying between 12 m/day and 466 m/day. A re-calculation of the BRGM data, however, yields a maximum permeability calculated by this method of 173 m/day. Similar calculations based on more recent aquifer tests by Hobbs (1982) place an upper limit of some 120 m/day on the permeability of the alluvial aquifer, with an average in the order of 75 m/day.

The control exercised by geology on the geometry of the alluvial aquifer allows for the delineation of four sub-areas (Fig. 3.2).

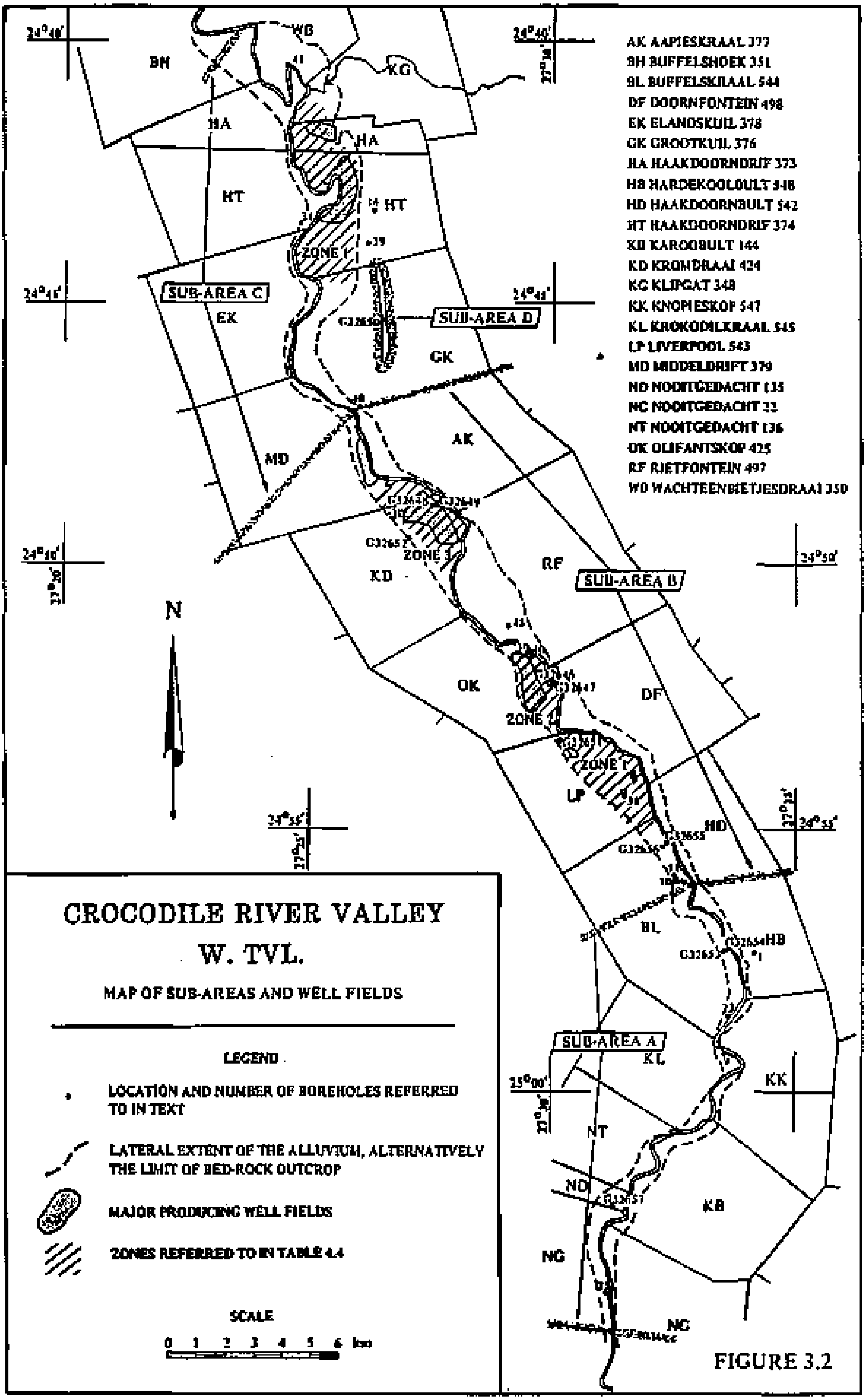

CROCODILE RIVER VALLEY
W. TVL.
MAP OF SUB-AREAS AND WELL FIELDS
LEGEND
LOCATION AND NUMBER OF BOREHOLES REFERRED TO IN TEXT
LATERAL EXTENT OF THE ALLUVIUM, ALTERNATIVELY THE LIMIT OF BED-ROCK OUTCROP
MAJOR PRODUCING WELL FIELDS
ZONES REFERRED TO IN TABLE 4.4
SCALE
0 1 2 3 4 5 6 km
AK AAPIESKRAAL 377
BH BUFFELSHOEK 351
BL BUFFELSKRAAL 544
DF DOORNFONTEIN 498
EK ELANDSKUIL 378
GK GROOTKUIL 376
HA HAAKDOORNDRIF 373
HB HARDEKOOLBULT 548
HD HAAKDOORNBULT 542
HT HAAKDOORNDRIF 374
KB KAROOBULT 144
KD KRONDRAAI 424
KG KLIPGAT 348
KK KNOPIESKOP 547
KL KROKODILKRAAL 545
LP LIVERPOOL 543
MD MIDDELDRIFT 379
ND NOOITGEDACHT 135
NG NOOITGEDACHT 33
NT NOOITGEDACHT 136
OK OLIFANTSKOP 425
RF RIETFONTEIN 497
WB WACHTEENBIETJESDRAAI 350
SUB-AREA A
SUB-AREA B
SUB-AREA C
SUB-AREA D
ZONE 1
ZONE 3
N

FIGURE 3.2

SUB-AREA A

This zone extends from Nooitgedacht 22 in the south, to the Hardekoolbult 548/Haakdoornbult 542 boundary. The alluvium in this zone has an average width of approximately 500 metres along both banks. It is reasonably well-defined by extensive outcrops of dolomite and quartzite.

The area is further characterized by the very shallow depth to bed rock along portions of the river banks. Examples hereof are BRGM auger drillings KL9 (9 metres), BL23 (4 metres) and HD1 (1,5 metres). Further, an outcrop of dolomite is visible in a gully some 100 metres from the river on the farm Karoobult 144. However, depths to bed rock in boreholes NG23 (16 metres) on the river bank, G32653 (16 metres), G32654 (13 metres) and G32657 (13 metres) located some 200 to 400 metres from the river approach the maximum observed depth as determined from exploratory drilling.

High-yielding boreholes in this zone are scarce, only 17 out of 76 boreholes (22%) yielding more than 12 l/s. These boreholes generally tap the dolomitic aquifer. Isolated yields in the order of 18 l/s are realized.

Exploration boreholes G32653 (dolomite) and G32654 (granite) straddle the fault, traversing the northern portion of this sub-area, but yielded little water. The estimated blow yield of G32653 was 0,4 l/s. Borehole G32654 was practically dry. These boreholes are 80 m apart.

SUB-AREA B

This zone extends from the Hardekoolbult 548/Haakdoornbult 542 boundary to the northern boundary of Aapieskraal 377. In this area the aquifer is especially well-developed, albeit discontinuous, along the left bank. Large cut-off meanders occur on the farms Liverpool 543 and Olifantskop 425. The alluvial aquifer is weakly developed along the right bank except on the farm Rietfontein 497.

The area is further characterized by numerous (127) high-yielding boreholes (> 18 l/s circa 1980) tapping the alluvium. Boreholes BL9 (21 l/s), BL10 (19 l/s) and BL11 (15 l/s) on the farm Buffelskraal 544 (Fig. 3.2) are thought to tap ground water from the major fault traversing this farm (Fig. 2.2).

The aquifer generally is characterized by a thinner overburden than elsewhere. Examples are exploration boreholes G32649 (3 metres), OK40 (5 metres), RF45 (4 metres), G32646 (3 metres) and G32651 (3 metres). Borehole G32652, located some 1700 metres from the river on the farm Kromdraai 424, is a notable exception. A 10-metre thick overburden of very clayey material overlies a 2-metre thick water-bearing horizon consisting of very coarse gravels. The position of this borehole indicates the lateral extent of the alluvial aquifer at this locality.

SUB-AREA C

This zone extends from the northern boundary of Aapieskraal 377 to the farm Wachteenbietjesdraai 350 in the extreme north.The southern portion of this sub-area (on the left bank the farms Middeldrift 379 and Elandskuil 378, on the right bank Aapieskraal 377 and Grootkuil 376) is characterized by a relatively narrow zone of alluvium (less than 500 metres along the left bank and 800 metres along the right bank). Outcrops of gabbro/norite cover extensive areas. They are especially visible close to the river on the northern and southern portions of the farms Middeldrift 379 and Elandskuil 378 respectively.

The alluvial aquifer broadens considerably on the right bank north of Grootkuil 376. The most productive well fields in the study area are located on the farm Haakdoorndrift 374. Some 82 of the 117 boreholes in this sub-area that yielded more than 20 l/s when tested (circa 1980), are located on this farm. Mine exploration boreholes in the area indicate significant weathering of the gabbroic and granitic bed rock. In places the bed rock is up to 30 m deep.

The greater part of the left bank further than 300 metres from the river is underlain by very shallow bed rock (mainly gabbro and norite), generally less than 9 metres below the surface. The overburden consists mainly of decomposed bed rock and associated clay material. Nearer the river, depths to bed rock increase up to 20 metres.

SUB-AREA D

This zone extends along the strike of the fault mainly on the farm Grootkuil 376. Riverine deposits in this zone, as revealed in exploration borehole G32650, indicate the presence of a fossil river channel, most probably that of the Crocodile River.

Exploration borehole G32650 revealed a 4-metre thick aquiferous horizon consisting of coarse quartzitic gravels, pebbles and boulders at a depth of 34 metres. The overburden consists of finer quartzitic gravels intercalated with more sandy horizons. A 14-metre thick zone consisting of fault debris and containing a small percentage of chert nodules underlies the water-bearing horizon. Fresh norite was struck at 52 metres, indicating the fault to lie a small distance to the east of this borehole.

The distribution of boreholes tapping ground water in this zone indicate the zone to be less than 100 metres wide. Attempts by farmers to find significant ground-water supplies either side of this zone have been unsuccessful.

3.2.2 BED-ROCK AQUIFER

The various geological formations (Section 2.2) that surround and underlie the alluvial aquifer constitute the secondary (or bed-rock) aquifers in the study area. These rock types generally store and transmit much smaller quantities of water than the alluvium of the primary aquifer.

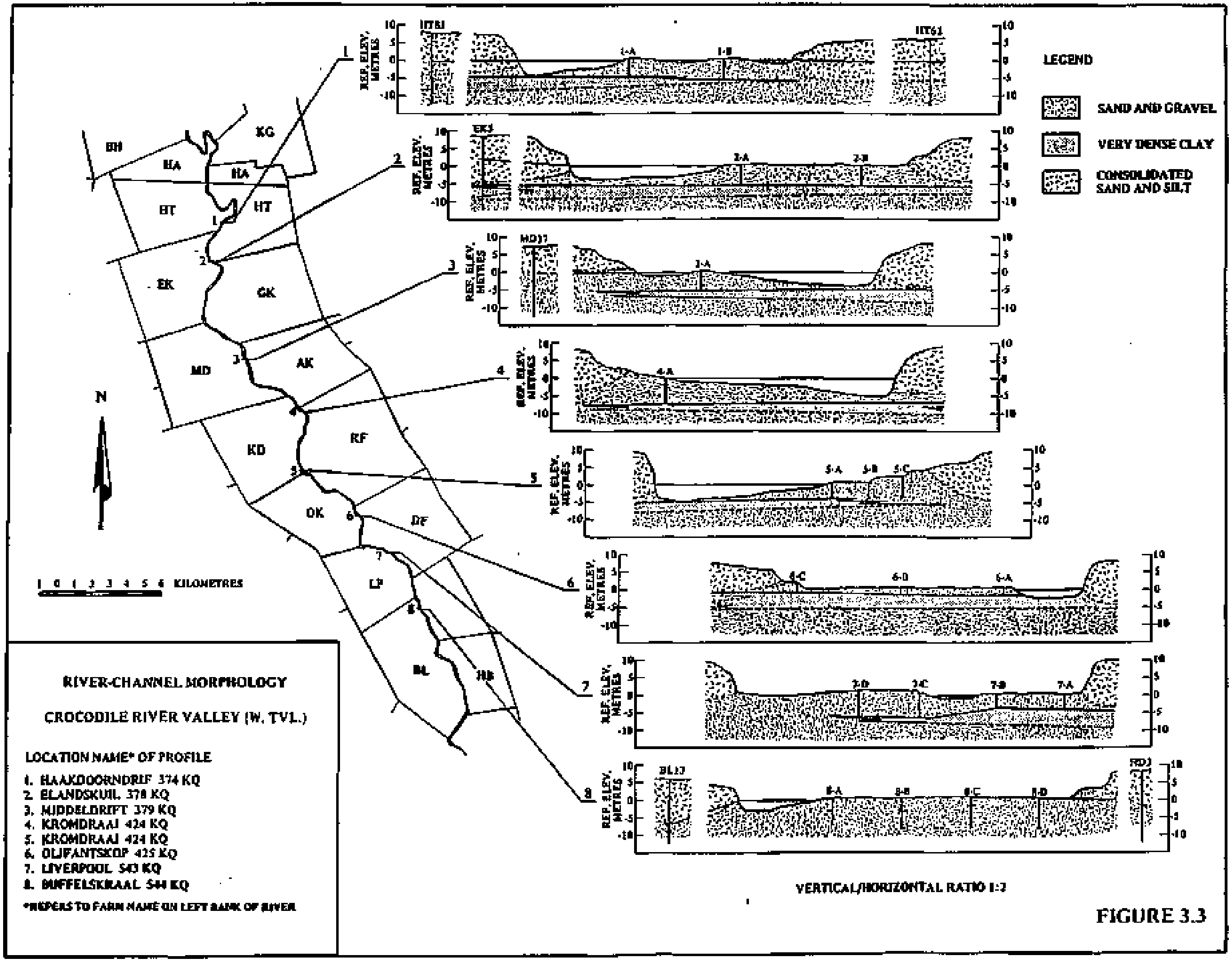
The hydrocensis performed by BRGM (1977) and Hobbs (1982) confirmed the relative sparseness of boreholes located outside the alluvial aquifer. Furthermore, few boreholes are known to tap bed-rock aquifers with yields exceeding 3 l/s. Exceptions are some high-yielding boreholes (greater than 15 l/s) that tap the dolomitic bed rock in the southern portion of the study area. Previous work on these dolomites (Bosazza, 1953 and Keyser, 1955) indicates that it is essentially uncavemed, although isolated solution cavities may occur.

3.3 RIVER-CHANNEL MORPHOLOGY

Eight sites in the river bed were selected for investigation. Each location was dictated by accessibility and work-space availability. Profiles were drilled across the river bed at each site using a Cobra drill. The results of this investigation are schematically presented in Figure 3.3 and detail information is contained in Table 3.2.

TABLE 3.2. RESULTS OF THE COBRA-DRILLING PROGRAMME

Profile Number	Coordinate (lat.) and location	Drilling Number	Depth in metres	Lithology
1	24°43'25"	A	0 - 5,2	Coarse, sandy, quartzitic gravel
			5,2	Light-brown, very slightly sandy clay
	Haakdoorndrift 374 KQ	B	0 - 6,3	Coarse, sandy quartzitic gravel
			6,3	Coarse gravel in a very clayey matrix
2	24°44'35"	A	0 - 6	Coarse sand and quartzitic gravel
			6	Very dense and compact, grey-coloured clay
	Elandskuil 378 KQ	B	0 - 6	Coarse sand and quartzitic gravel
			6	Very dense and compact, grey-coloured clay
3	24°47'35"	A	0 - 5	Coarse quartzitic sand and gravel
			5	Brown-coloured dense and very compact clay
	Middeldrift 379 KQ			
4	24°49'03"	A	0 - 7,3	Coarse quartzitic gravel
			7,3	Very dense and compact clay
	Kromdraai 424 KQ			
5	24°50'55"	A	0 - 4,5	Coarse gravel and small rounded pebbles
			4,5	Dense and compact clay
	Kromdraai	B	0 - 5	Coarse gravel and small rounded pebbles in a slightly clayey matrix
		C	0 - 6	Coarse gravel and small rounded pebbles in a very slightly clayey matrix
6	24°52'10"	A	0 - 1,9	Very fine, sandy gravel
			1,9	Dense slightly sandyish clay
	Olifantskop 425 KQ	B	0 - 1,9	Very fine, sandy gravel
			1,9	Very dense and compact clay
		C	0 - 2,3	Very fine, sandy gravel
			2,3	Compact, sandyish clay
7	24°53'22"	A	0 - 4,6	Fine quartzitic gravel
			4,6	Dense, compact grey-coloured clay
	Liverpool 543 KQ	B	0 - 4,2	Fine-grained quartzitic gravel
			4,2	Dense, compact grey-coloured clay
		C	0 - 7,5	Coarse quartzitic gravel
			7,5 - 7,7	Coarse gravel in a clay matrix
			7,7	Dense, compact grey-coloured clay
8	24°55'00"	A	0 - 7,6	Coarse quartzitic gravel, slightly clayey at 7,6 metres
	Buffelskraal 544 KQ	B	0 - 8,6	Coarse quartzitic gravel; very coarse with pebbles at 8,6 metres
		C	0 - 8,5	Coarse quartzitic gravel; very coarse with pebbles at 8,5 metres



LEGEND
SAND AND GRAVEL
VERY DENSE CLAY
CONSOLIDATED SAND AND SILT
REF. ELEV. METRES
VERTICAL/HORIZONTAL RATIO 1:2
0 1 2 3 4 5 6 KILOMETRES
N
RIVER-CHANNEL MORPHOLOGY
CROCODILE RIVER VALLEY (W. TVL.)
LOCATION NAME* OF PROFILE
1. HAAKDOORNDRIF 374 KQ
2. ELANDSKUIL 378 KQ
3. MIDDELDRIFT 379 KQ
4. KROMDRAAI 424 KQ
5. KROMDRAAI 424 KQ
6. OLIFANTSKOP 425 KQ
7. LIVERPOOL 543 KQ
8. BUFFELSKRAAL 544 KQ
*REFERS TO FARM NAME ON LEFT BANK OF RIVER

FIGURE 3.3

The depth of penetration achieved was limited to the depth of a very dense and compact clay horizon occurring at varying depths below the surface of the river bed. The 50 mm diameter sample barrel could not penetrate this horizon. Relatively undisturbed samples were taken at depth intervals of 1 metre at each sounding. However, many samples were lost as a result of flushing of the sample barrel by formation water upon withdrawal.

The main feature revealed by this study was the presence of an impermeable clay layer at depths varying from 2 to 8 metres below the bottom of the river bed at 7 of the 8 sites investigated. This horizon is overlain by unconsolidated and water-saturated coarse quartzitic sands and gravels. The lower elevation of the base of the alluvial aquifer than the clay horizon indicates the latter to be underlain by more sands and gravels. This is substantiated by the fact that well points sunk in the river bed by farmers during the drought of the mid-1960's penetrated unconsolidated sands and gravels located below the clay horizon. The thickness of the clay ranges from 0,5 to 2,5 metres at profile 3 on the farm Middeldrift 379 (J.D. van den Berg, personal communication, 1980). Further, none of the exploration boreholes revealed the presence of impermeable clay lenses within the main aquiferous horizon of the alluvial aquifer adjacent to the river. This indicates that the clay occurs as an almost continuous horizon in and along the river bed, but pinches out laterally within a short distance of the river.

The river banks are composed of a well-consolidated clay-rich loamy soil and are generally densely vegetated with phreatophytes. These factors severely limit infiltration through the river banks above the river bed. Bank-to-bank channel widths average less than 20 metres. The channel gradient averages 0,5 metre per river kilometre. From the above it is clear that the river only partly penetrates the alluvial aquifer.

CHAPTER 4

HYDRODYNAMIC STUDY OF THE STREAM-AQUIFER SYSTEM

4.1 INTRODUCTION

The water-level monitoring programme in the study area was started by BRGM in 1976 using 17 observation boreholes. This included three automatic water-level recording stations. The network was extended by a further seven boreholes following the investigation by Hobbs in 1980.

Water-level monitoring has been conducted on a monthly basis in the above-mentioned 24 boreholes. In addition, upwards of 120 boreholes located throughout the study area have been monitored annually since 1980 (except 1981). This has been conducted *circa* April of each year, when ground-water abstraction for irrigation reaches a minimum.

4.2 HYDROLOGIC RESPONSE

Since the early 1970's, the aquifer system has been responding to a period of stabilized flow in the Crocodile River and increased use of ground water for irrigation.

4.2.1 LONG-TERM MONTHLY RESPONSE

The long-term ground-water level response in selected observation boreholes is shown in Figure 4.1. The observed response to surface discharge indicates that significant recharge of the alluvial aquifer results from consecutive monthly discharges in excess of the 7 x 10^6 m^3 per month generally sustained by reservoir releases. Such conditions existed prior to April, 1981. Ground-water recharge is evident by the rise in ground-water levels in boreholes LP31, OK39 and WB41 (Fig. 3.2) following the peak discharges in March, 1977 (>350 x 10^6 m^3),

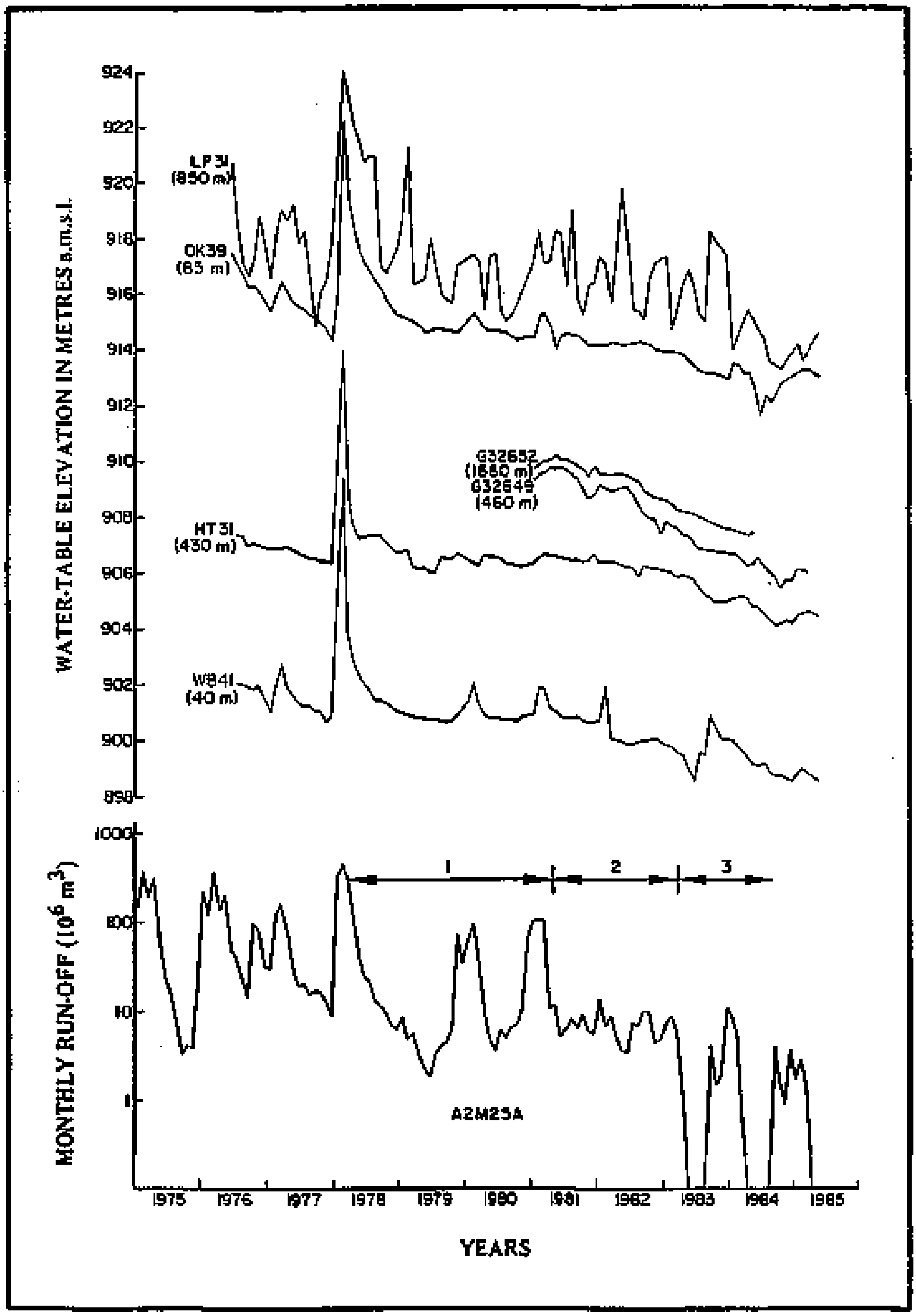


Figure 4.1. Long-term ground-water level response in selected observation boreholes. Values in brackets indicate distance from the river.

February, 1980 (>200 x 10^6 m^3) and February, 1981 (>360 x 10^6 m^3). The major flood of February, 1978 (>480 x 10^6 m^3) submerged many open boreholes on the alluvial flood plain. This "direct" recharge event completely replenished the alluvial aquifers.The discharge hydrograph in Figure 4.1 further shows three distinct discharge regimes.

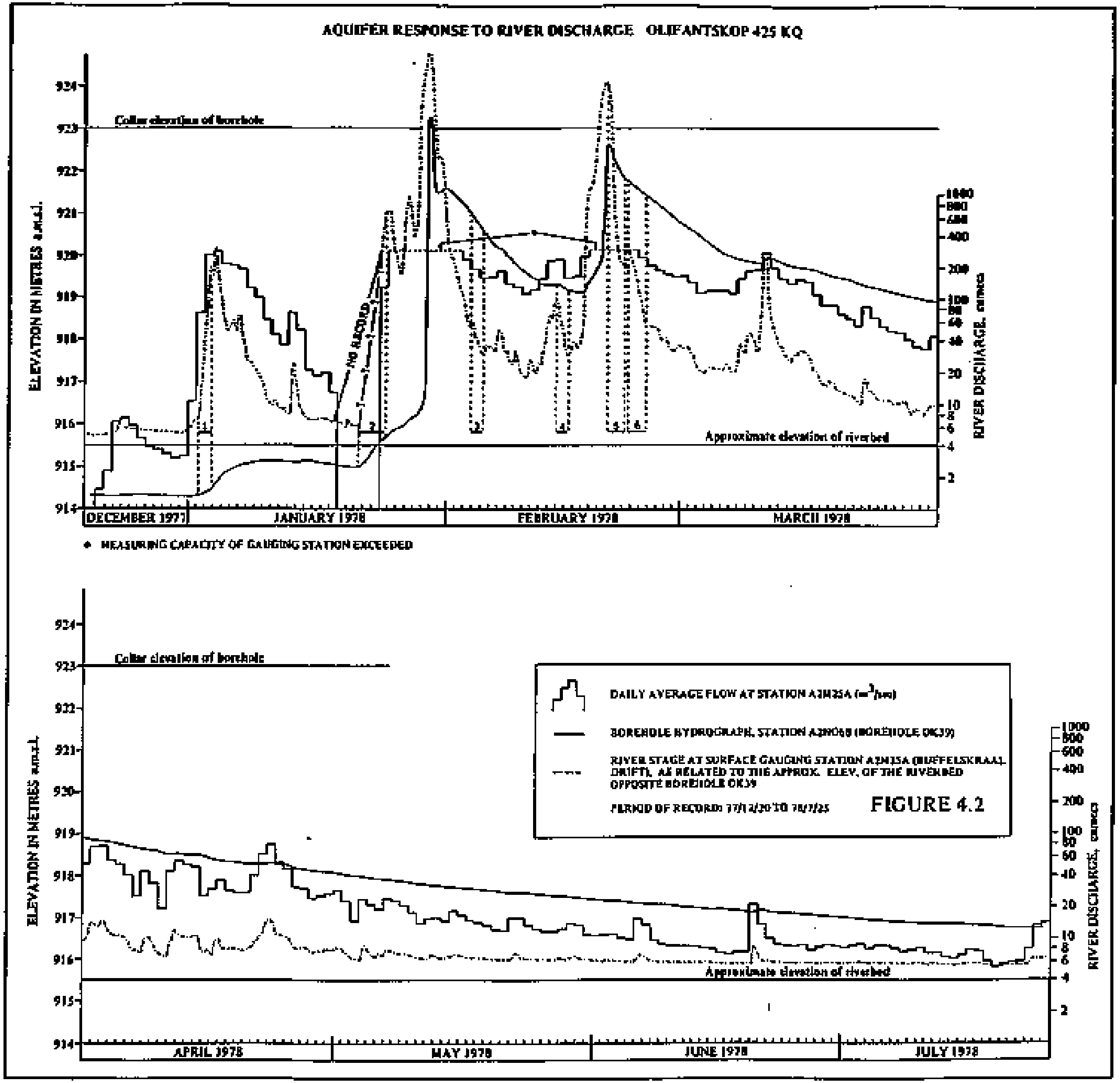
Regime 1 reflects the hydrograph generated by a combination of reservoir releases and run-off from precipitation. Regime 2 characterizes mainly reservoir-sustained flow. Regime 3 reflects seasonal reservoir releases superimposed on essentially no-flow conditions.

The influence which each of the above regimes had on ground-water levels is visible in the borehole hydrographs (Fig. 4.1). The minimal decline in ground-water levels prior to April, 1981 is attributed to recharge of the alluvial aquifer generated by the two peak-discharge events. A steady decline in ground-water levels is witnessed for the duration of the second discharge regime, this despite a sustained average surface discharge of some 7 x 10^6 m^3 per month. A sharper decline in ground-water levels follows the onset of no-flow conditions (regime 3). The irregular fluctuations of the water level in borehole LP31 are the result of abstraction from nearby active irrigation wells.

4.2.2 AQUIFER RESPONSE TO FLOODING

The response of the primary aquifer to the flood of January/February, 1978, as monitored by the automatic water-level recorder installed on borehole OK39 (station A2N068) on the farm Olifantskop 425, is graphically illustrated in Figure 4.2. The recorder is located approximately 85 metres from the river and some 8 km downstream from surface gauging station A2M25A.

In order to draw a more direct comparison between the river stage at station A2M25A and the water level in borehole OK39, the river stage as monitored at station A2M25A has been expressed as a height above the approximate elevation of the river bed opposite the borehole. It is accepted that some discrepancy will exist as a result of the difference in cross-sectional area of the river channel at these sites. Nevertheless, a tight relationship between ground-water levels and river stage is observed.


AQUIFER RESPONSE TO RIVER DISCHARGE   OLIFANTSKOP 425 KQ
Collar elevation of borehole
ELEVATION IN METRES a.m.s.l.
RIVER DISCHARGE, cumecs
NO RECORD
Approximate elevation of riverbed
DECEMBER 1977
JANUARY 1978
FEBRUARY 1978
MARCH 1978
* MEASURING CAPACITY OF GAUGING STATION EXCEEDED
DAILY AVERAGE FLOW AT STATION A3H25A (m³/sec)
BOREHOLE HYDROGRAPH, STATION A3N058 (BOREHOLE OK39)
RIVER STAGE AT SURFACE GAUGING STATION A3H25A (BUFFELSKRAAL DRIFT), AS RELATED TO THE APPROX. ELEV. OF THE RIVERBED OPPOSITE BOREHOLE OK39
PERIOD OF RECORD: 77/12/20 TO 78/7/25
APRIL 1978
MAY 1978
JUNE 1978
JULY 1978
FIGURE 4.2

Calculations based on the flow characteristics at station A2M25A yielded rough estimates of the flow velocity for discharges of various magnitude (Table 4.1). Daily average discharges in excess of 200 cumecs realize a minimum flow velocity of 1,7 m/s. Peak discharges of this order are therefore expected to arrive some 80 minutes later at a point 8 km downstream from station A2M25A. This time lag is regarded as negligible on the time scale of Figure 4.2, and will be disregarded as having any influence on the time lag evident in the response of the aquifer to peak discharges and related river stages.

TABLE 4.1. ESTIMATED AVERAGE FLOW VELOCITY OF DISCHARGES OF DIFFERING MAGNITUDE AT STATION A2M25A AS DEDUCED FROM FLOW-GAUGING RECORDS

Discharge (Q) in m^3/s	*Average flow velocity in m/s*
0,25	0,45
2,61	0,80
3,82	1,16
4,05	1,23
102,00	1,32
136,00	1,38
169,00	1,69
207,00	1,69

The response of the aquifer to each of the three peak-discharge events reflected in Figure 4.2 is discussed below.

PERIOD 3 TO 4 JANUARY:

The discharge on these two days exceeded 250 and 272 cumecs respectively, which realized a rise of approximately 4 metres in river stage. The ground-water level prior to this period was some 1,5 metres below river stage.

The ground-water level in borehole OK39 started to rise some 8 hours after the onset of the peak discharge. The continuing response is gradual, manifesting a rise of some 0,8 metres over a period of about 8 days. Seven days separate the river-stage and ground-water level peaks. The BRGM aquifer test on OK39 indicates an aquifer permeability of some 12 m/day at this site. Dividing this value into the distance of the borehole from the river (85 metres) yields a travel time of 7 days for the propagation of a flood wave through the aquifer over this distance. The computed and observed travel times agree well.

PERIOD 25 JANUARY TO 3 FEBRUARY:

The average flow in this period exceeded the gauged 276 cumecs, and resulted in extensive flooding of areas adjacent to the river. The peak discharge occurred on the 29th January, at which time the borehole was submerged and flood water recharged the aquifer directly through the borehole. The preceding period of 8 days witnessed a 1,4 metre rise in ground-water level.

A study of the recorder chart for the period of direct inflow reveals that the borehole was submerged for some 20 hours, with the peak of the flood standing approximately 0,5 metres above the collar of the borehole. This constitutes a rise of over 6 metres in ground-water level. The small peak evident on the descending limb of the hydrograph following this flood peak correlates with the contributive discharge of the Pienaars River after having been delayed by the Klipvoor Dam.

PERIOD 18 TO 23 FEBRUARY:

A daily average flow in excess of 276 cumecs is once again witnessed with the peak occurring on the 20th February. The rapid rise of 2,1 metres in ground-water level took place over a period of 2,75 days, with approximately 5 hours separating the river-stage and ground-water level peaks. No flooding of the borehole occurred. The shape of the recession curve during the period of 17 days following this peak shows a marked similarity to that following the previous peak. The slight influence (on the recession curve) resulting from the high discharge on the 11th March, when the river stage barely reached the elevation of water in the borehole, possibly reflects pressure effects transmitted to the now fully saturated aquifer at this locality.

4.2.2.1 AQUIFER DIFFUSIVITY

Additional information concerning the aquifer parameters may be obtained from an analysis of the propagation of a flood wave through the alluvial aquifer following an abrupt change in river stage (Oakes, 1980). An analytic solution to this problem is provided in Huisman (1972) and Walton (1970), and is based on the theory that the propagation of a train of sinusoidal waves through the aquifer, in response to correlative changes in river stage, is exhibited as sinusoidal fluctuations of the water level in a borehole. The greater the distance of the borehole from the river, the smaller the amplitude of the transmitted wave and the greater the time lag.

The equation relating a sudden change in river stage to the change in water level in a borehole can be written non-dimensionally as

$$s = s_d \, W(u_h) \qquad (4.1)$$

where

$$u_h = x(S/4Tt)^{1/2} \qquad (4.2)$$

s = change in water level in the borehole (metres)
s_d = abrupt change in river stage (metres)
x = distance of the borehole from the river (metres)
t = time after the abrupt change in river stage (days)
T = transmissivity of the aquifer (m^2/day)
S = storage coefficient (dimensionless)
$W(u_h)$ = is read as the "well function for non-leaky artesian aquifers with a drain having an abrupt change in stage" (Walton, 1970). This can be determined from Equation (4.1). The ratio S/T can now be calculated from the equation

$$S/T = 4t(u_h)^2/x^2 \qquad (4.3)$$

The ratio S/T has been computed for each of the time periods depicted in Figure 4.2. The results are tabulated in Table 4.2 below:

TABLE 4.2. COMPUTED VALUES FOR THE RATIO S/T

Period	t (days)	s (m)	s_d (m)	$W(u_h)$	u_h	S/T
1	1.6	0.20	3.60	0.0556	1.36	1.6×10^{-3}
2	3.1	0.98	5.04	0.1944	0.92	1.5×10^{-3}
3	1.5	0.42	0.94	0.4468	0.84	2.0×10^{-4}
4	1.6	0.14	1.36	0.1029	1.15	1.2×10^{-3}
5	2.0	0.80	4.32	0.1852	0.94	1.0×10^{-3}
6	2.2	0.32	1.76	0.1818	0.95	1.1×10^{-3}

The ratio S/T provides a useful tool for determining either the transmissivity or the storativity of an aquifer, if one of these values are known. The results listed in Table 4.2 yield an average value for S/T of 1,1 x 10^{-3} for the aquifer at this locality. The BRGM aquifer test on borehole OK39 yielded a transmissivity value of 130 m^2/day. Substitution of this value into the formulation S/T = 1,1 x 10^{-3} yields a value for S of 0,14 (14%). This is also the specific yield (S_y) of the aquifer as determined from a re-analysis of the BRGM aquifer test (Hobbs, 1982).

The applicability of the concept of aquifer diffusivity to better estimate the hydraulic parameters of the alluvial aquifer is corroborated by the above exercise. However, the method requires at least a continuous record of both ground-water level and river-stage changes in the immediate vicinity of the area to which it is to be applied. This factor presently limits the practical implementation of the method for the Crocodile River Valley.

4.3 AQUIFER TESTS

4.3.1 GENERAL

The transmissivity of the alluvial aquifer as determined from 8 constant yield aquifer tests performed by BRGM (1977) ranged from 130 m^2/day to 3100 m^2/day. Storativity ranged from 5 x 10^{-3} (0.5%) to 1,3 x 10^{-1} (13%). However, none of the aquifer tests investigated the stream-aquifer relationship.

Three constant yield aquifer tests were performed during the field investigation phase of this study. The location of the aquifer-test sites was primarily dictated by the need for additional geohydrological information concerning the nature of the aquifer in these localities. For instance, the aquifer test on borehole G32647 was aimed primarily at evaluating the stream-aquifer relationship. A detailed discussion of this test is presented in Subsection 4.3.2. The other boreholes tested were G32648 and G32655. All three of these boreholes fully penetrate the primary aquifer. A single fully penetrating observation borehole was made use of in each test.

Despite the fact that the relatively low yields at which the boreholes were tested realized only small drawdowns in the observation boreholes (Table 4.3), the

TABLE 4.3. TABULATED AQUIFER TEST RESULTS

PRODUCTION BOREHOLE NO.	OBSERVATION BOREHOLE NO.	REST WATER LEVEL (m)	PUMPING RATE (l/s)	TOTAL DRAWDOWN (m)	DURATION OF TEST (hours)	DATE TESTED	HYDRAULIC T (m2/day)	PARAMETERS S	METHOD OF ANALYSIS
G32647		9,82	3,3	5,52	67,5	October 1980	370	4×10^{-3}	COOPER-JACOB
	G32646	9,61		0,30			333	$4{,}8 \times 10^{-3}$	HANTUSH (inflection point)
							300	$(S_y) 5{,}5 \times 10^{-2}$	NEUMAN
							312	$(S) 4{,}1 \times 10^{-3}$	
							312	$(S_y) 2 \times 10^{-2}$ $(S_A) 4{,}6 \times 10^{-3}$	BOULTON
							361	4×10^{-3} (image method)	HANTUSH
G32648		9,60	3,0	2,73	31	October 1980	593	$6{,}2 \times 10^{-3}$	HANTUSH
	G32649	9,80		0,07			939	5×10^{-2}	COOPER-JACOB
							621	$6{,}8 \times 10^{-2}$	WALTON
G32655		8,88	5,8	2,97	54	October 1980	1148	0,01	COOPER-JACOB
	G32656	9,53		0,18			998	2×10^{-2}	THEIS
							613	-------	NEUMAN (recovery)

resulting time-drawdown data proved interpretable. Attempts at conducting step-drawdown tests were unsuccessful, mainly due to the fact that the water level in the pumped boreholes could not be monitored accurately for lack of conduit tubing in which to measure (none was installed). As a result, no well-efficiencies for the pumped boreholes were determined.

Both the horizontal and vertical permeability of the primary aquifer have been determined at two aquifer-test sites. The Neuman (1975) method of analysis, which allows for the calculation of these parameters, was applied to the test on G32647, and yielded values for the horizontal (K_r) and vertical (K_z) permeability of 52 m/day and 0,052 m/day respectively. Similarly, a re-analysis of the BRGM test on LP31 following the same method yielded a value for K_r of 76 m/day and for K_z of 0,35 m/day (Hobbs, 1982).

4.3.2 AQUIFER TEST ON G32647

The bi-log time-drawdown curves obtained for observation borehole G32646 indicated the presence of possible delayed yield phenomena, and were accordingly analysed following the methods of Neuman (Fig. 4.3) and Boulton (Fig. 4.4). The results (Table 4.3) are in close agreement.

The late drawdown data on the semi-log time-drawdown curves seem to indicate the approach of steady-state flow conditions. The results (Table 4.3) obtained from the analysis of these curves by the methods of Cooper-Jacob (Fig. 4.5) and Hantush's inflection point method (Fig. 4.6) corroborate those of Neuman and Boulton.

The inflection point method of Hantush affords a check on the correctness of the analysis (Kruseman and De Ridder, 1976). The method requires, amongst other things, that the steady-state drawdown should be approximately known. Application of the method to Figure 4.6 for time (t) = 20 minutes yields a theoretical drawdown value of 0,12 metres. This agrees exactly with that observed on the graph and indicates that the steady-state drawdown was accurately extrapolated.

Figure 4.7 explores the further possibility that the observed apparent delayed-yield phenomenon might be the effect of recharge from the river. According to Kruseman and De Ridder (1976, p. 120), the Hantush image method takes into account the effect of one recharge boundary "when the effective line of recharge does not correspond with the bank or the streamline of the river ...". This may be the result

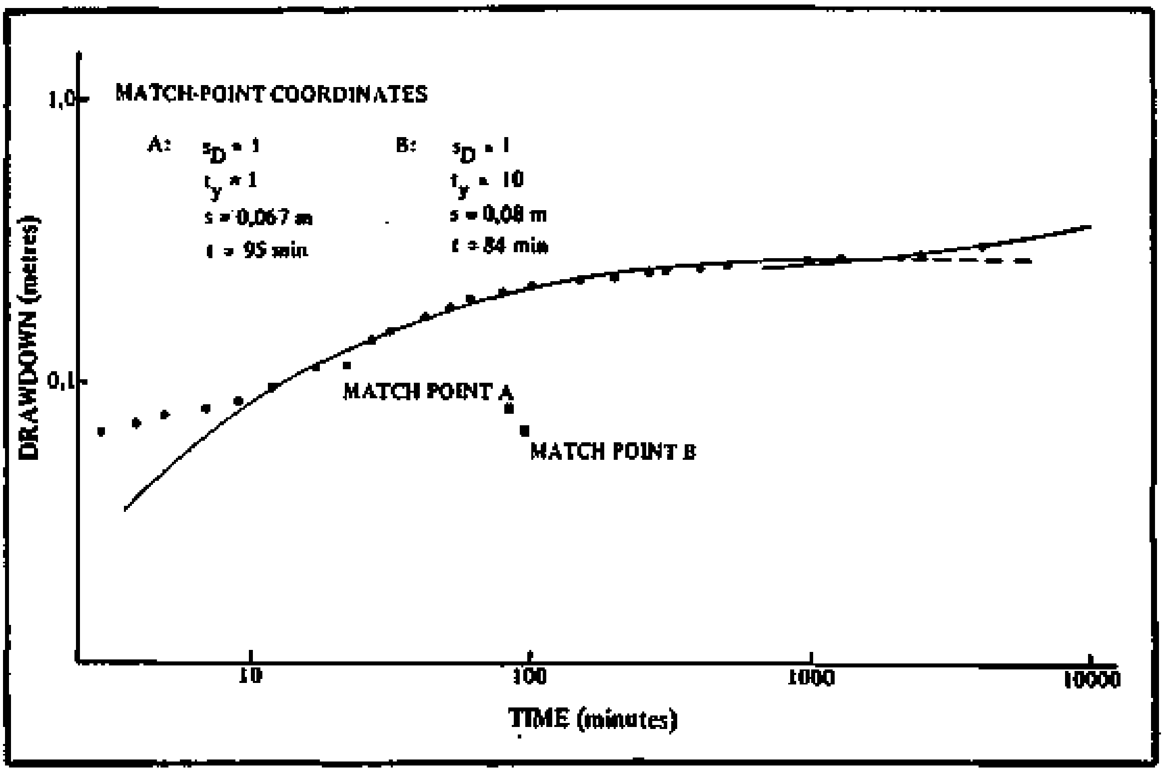


Figure 4.3. Bi-log time-drawdown Neuman analysis for observation borehole G32646.

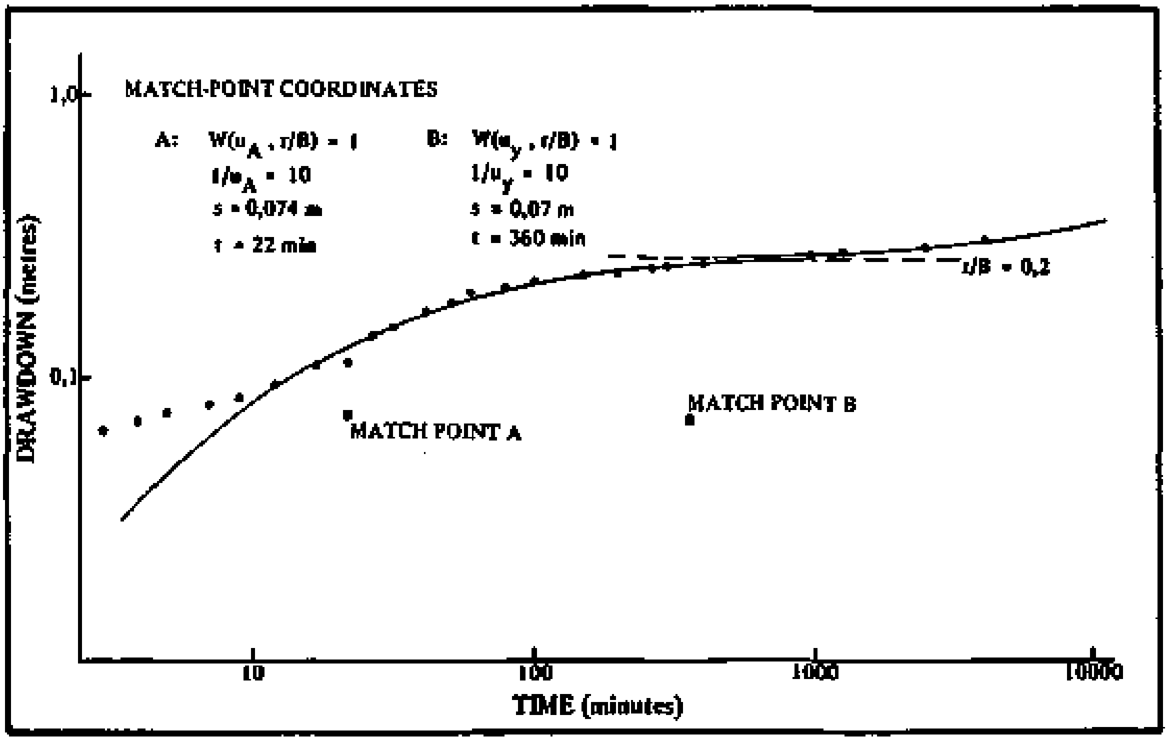


Figure 4.4. Bi-log time-drawdown Boulton analysis for observation borehole G32646.

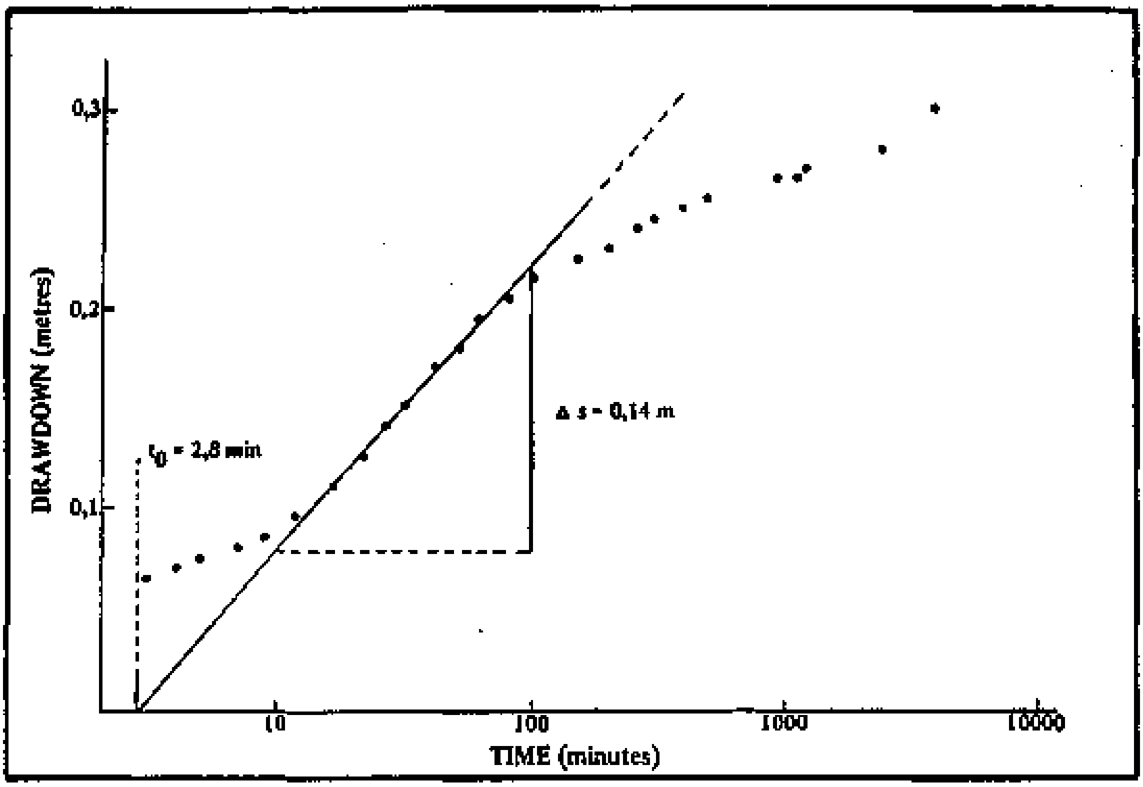


Figure 4.5. Semi-log time-drawdown Jacob analysis for observation borehole G32646.

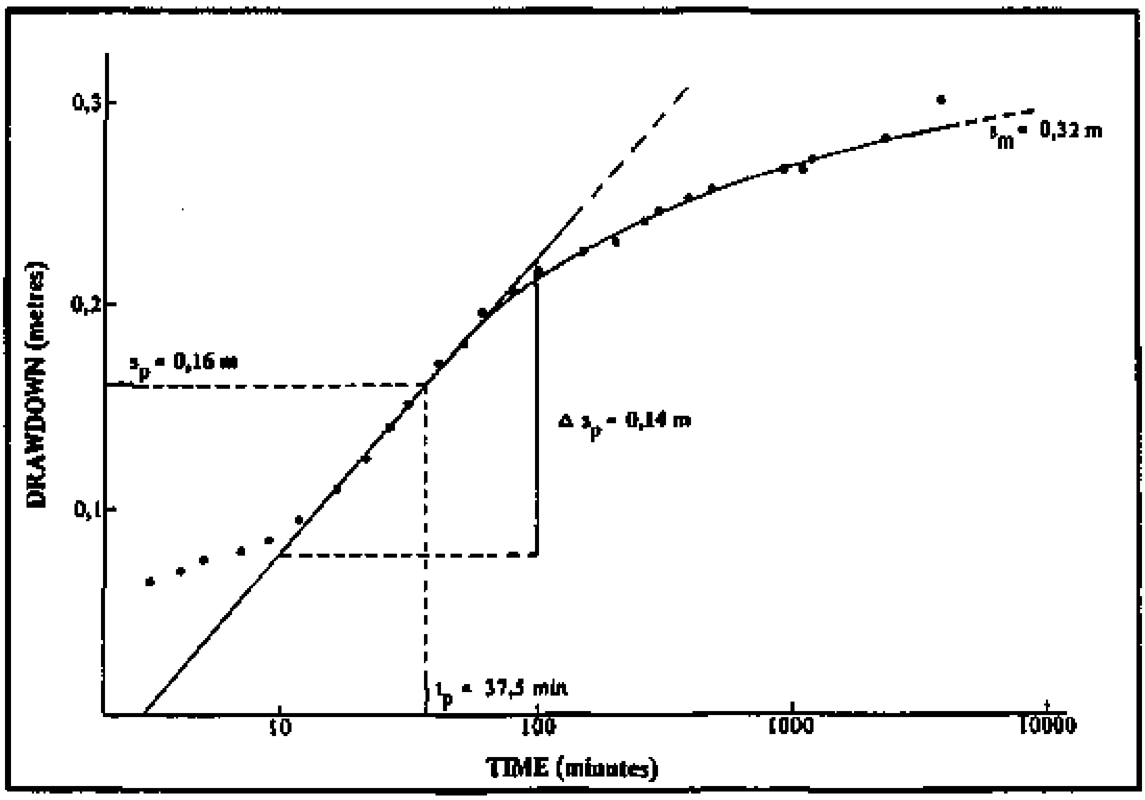


Figure 4.6. Semi-log time-drawdown Hantush inflection-point analysis for observation borehole G32646.

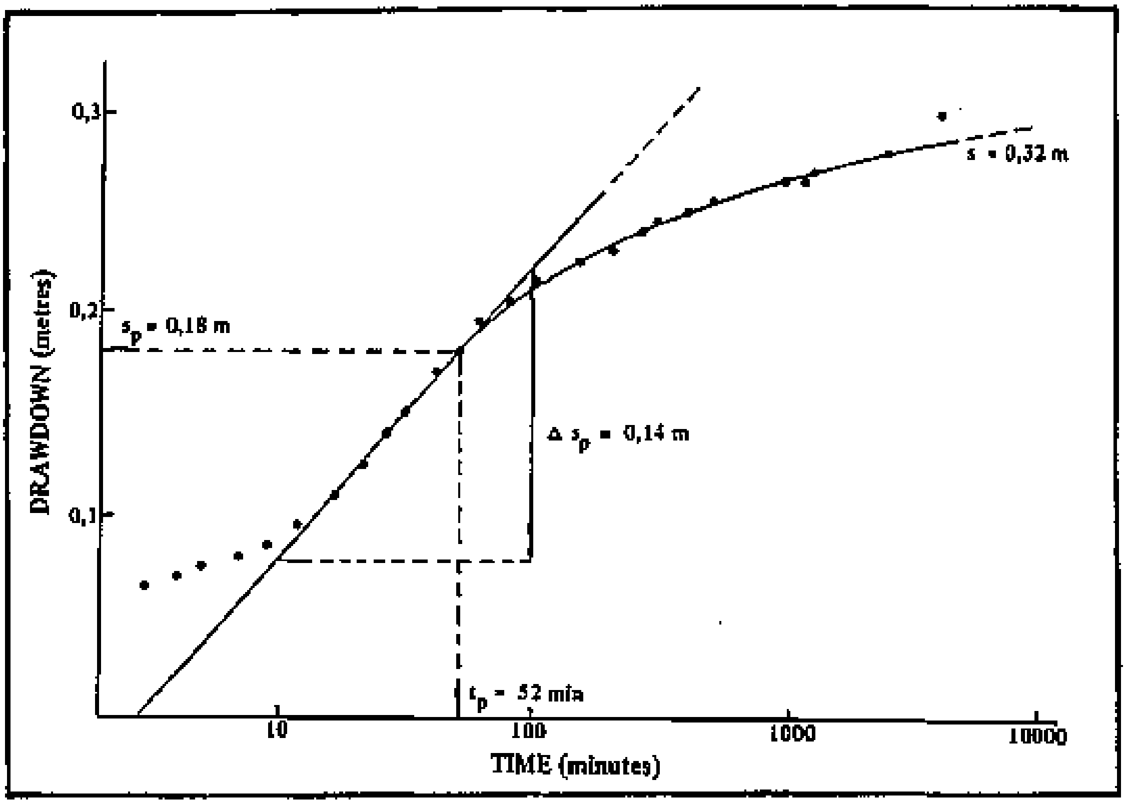


Figure 4.7. Semi-log time-drawdown Hantush image-method analysis for observation borehole G32646.

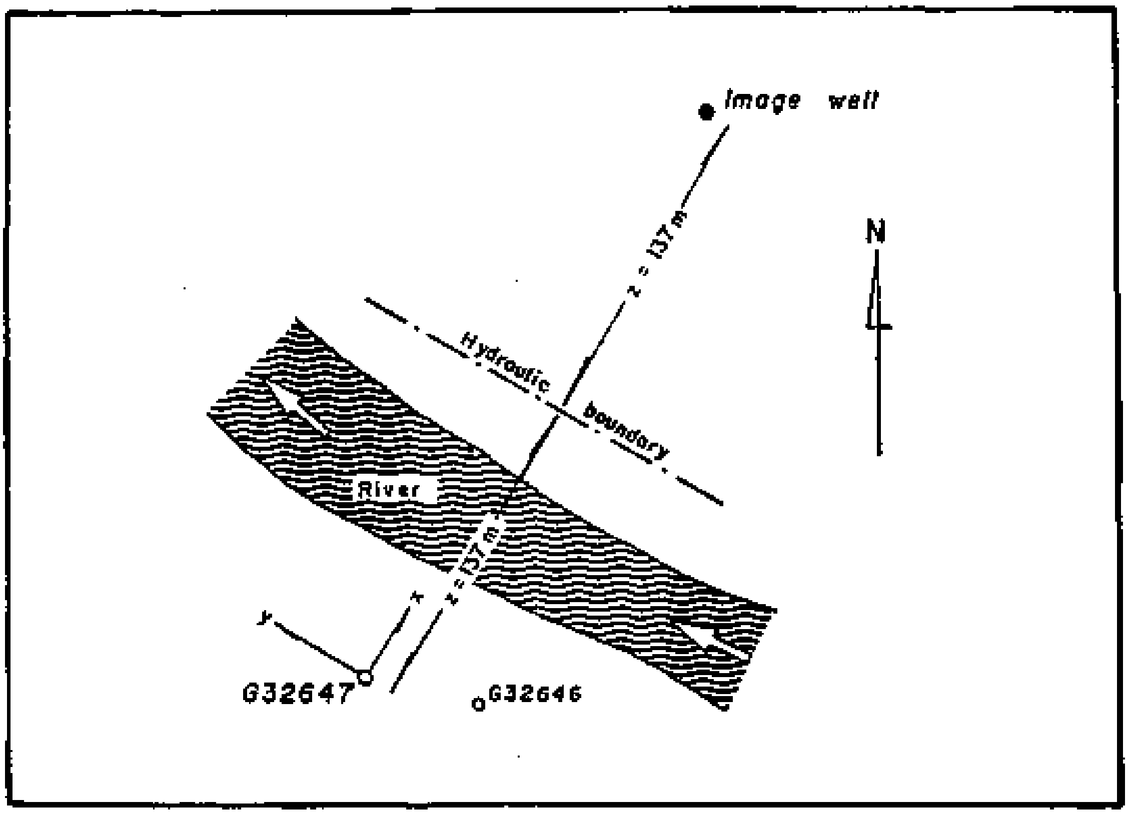


Figure 4.8. Schematic illustration of the application of the Hantush image method to the aquifer test performed on borehole G32647.

of partial penetration of the recharging boundary, or an entrance resistance at the boundary contact. From Section 3.3 it is evident that both these factors exist in this case. The analysis indicated that the hydraulic boundary (effective line of recharge) is located 137 metres from borehole G32647, as shown in Figure 4.8.

The results of this aquifer test illustrate the difficulty in distinguishing which of the effects of delayed gravity drainage or recharge from the river are manifested on the time-drawdown curves. Both possibilities fit the available data and information excellently, both are equally applicable and yield results which are in close agreement. However, it is concluded that:

(i) The river acts as a recharge boundary and the influence thereof outweighs the effect of delayed gravity drainage.

(ii) The aquifer undergoes a transition from semi-unconfined to unconfined conditions with pumping at this locality.

The latter conclusion is seen to hold true for the greater portion of the alluvial aquifer.

4.4 GROUND-WATER LEVELS

Figures 4.9 to 4.12 represent ground-water level contour maps of the study area. These maps show a marked similarity to one another, with the ground-water level contours exhibiting much the same configuration for each time period.

The ground-water level contours are observed to resolve into four distinct configurations which can be correlated to the sub-areas as defined earlier in this report. The maps all indicate a ground-water gradient from east to west in sub-area B. These conditions are in accordance with the geology of this portion of the study area, the alluvial aquifer being weakly developed along the right bank in the presence of very shallow granitic bed rock, and extensively developed along the left bank.

Each map also indicates a distinct ground-water gradient towards the east across the river in sub-area C.

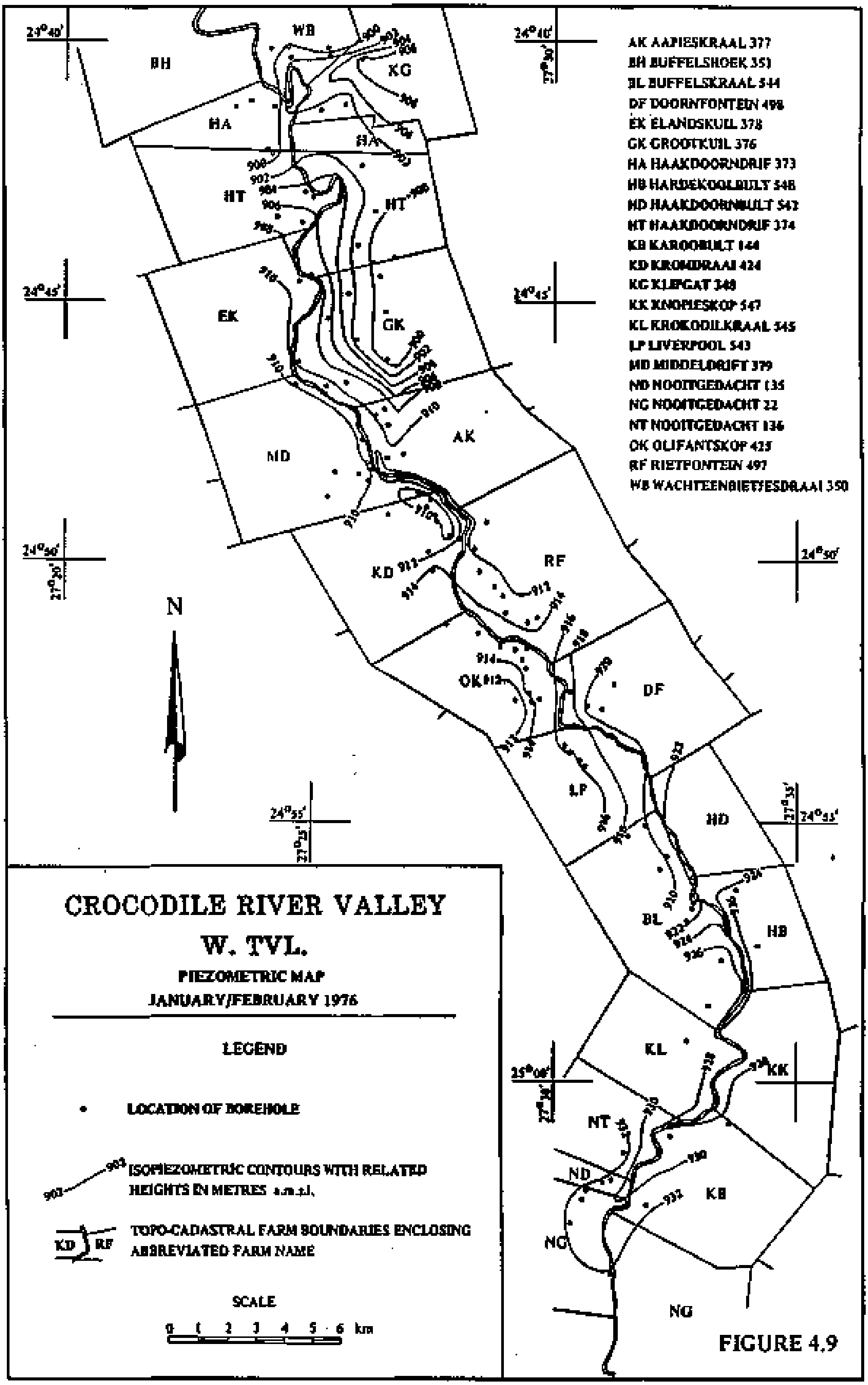
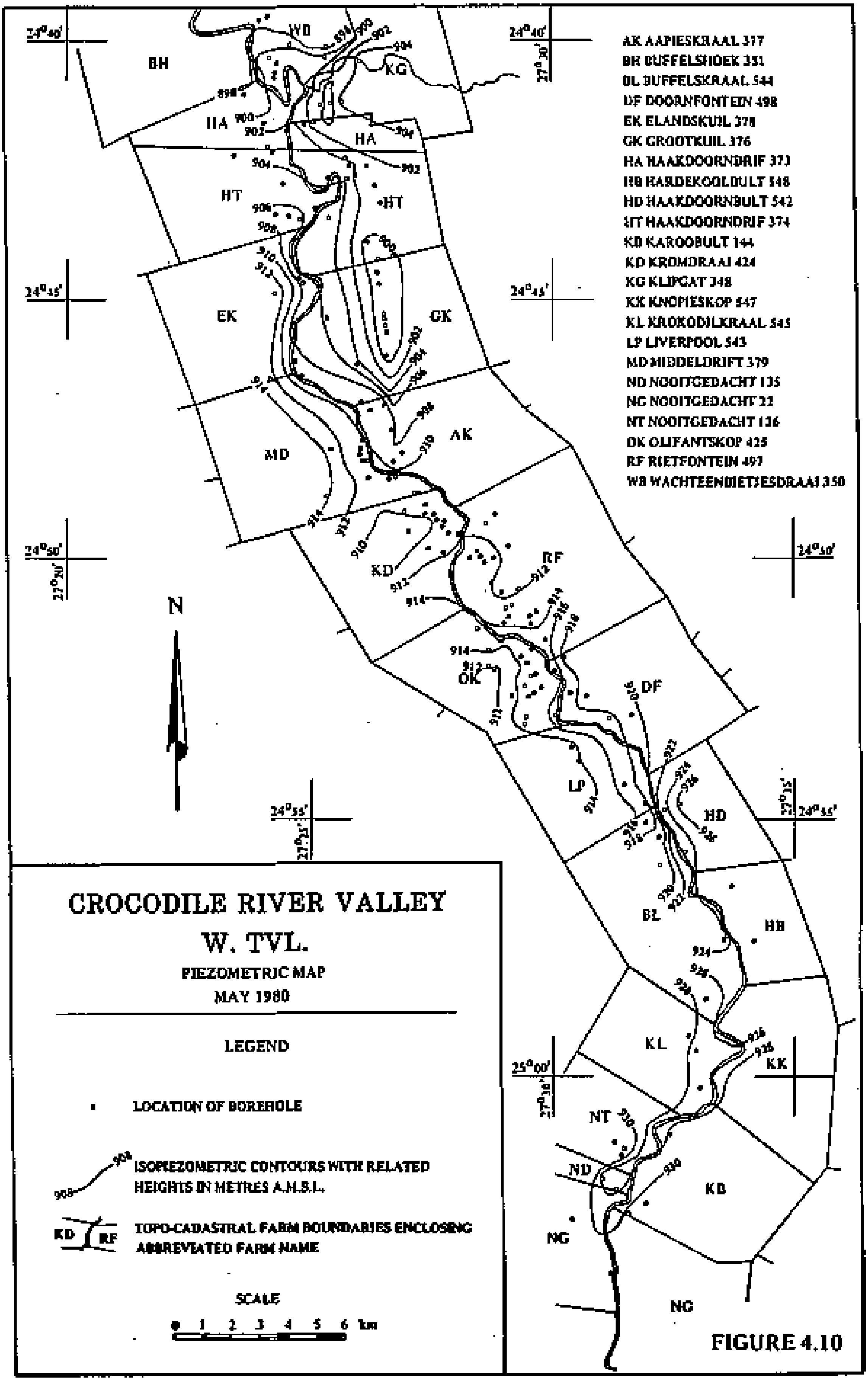

CROCODILE RIVER VALLEY
W. TVL.
PIEZOMETRIC MAP
JANUARY/FEBRUARY 1976
LEGEND
LOCATION OF BOREHOLE
ISOPIEZOMETRIC CONTOURS WITH RELATED HEIGHTS IN METRES a.m.s.l.
TOPO-CADASTRAL FARM BOUNDARIES ENCLOSING ABBREVIATED FARM NAME
SCALE
0 1 2 3 4 5 6 km
AK AAPIESKRAAL 377
BH BUFFELSHOEK 351
BL BUFFELSKRAAL 544
DF DOORNFONTEIN 498
EK ELANDSKUIL 378
GK GROOTKUIL 376
HA HAAKDOORNDRIF 373
HB HARDEKOOLBULT 548
HD HAAKDOORNBULT 542
HT HAAKDOORNDRIF 374
KB KAROOBULT 144
KD KROMDRAAI 424
KG KLIPGAT 348
KK KNOPIESKOP 547
KL KROKODILKRAAL 545
LP LIVERPOOL 543
MD MIDDELDRIFT 379
ND NOOITGEDACHT 135
NG NOOITGEDACHT 22
NT NOOITGEDACHT 136
OK OLIFANTSKOP 425
RF RIETFONTEIN 497
WB WACHTEENBIETJESDRAAI 350
N
24°40'
24°45'
24°50'
24°55'
25°00'
27°20'
27°25'
27°30'
27°35'

FIGURE 4.9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GK GROOTKUIL 376
HA HAAKDOORNDRIF 373
HB HARDEKOOLBULT 548
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HT HAAKDOORNDRIF 374
KB KAROOBULT 144
KD KROMDRAAI 424
KG KLIPGAT 348
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LP LIVERPOOL 543
MD MIDDELDRIFT 379
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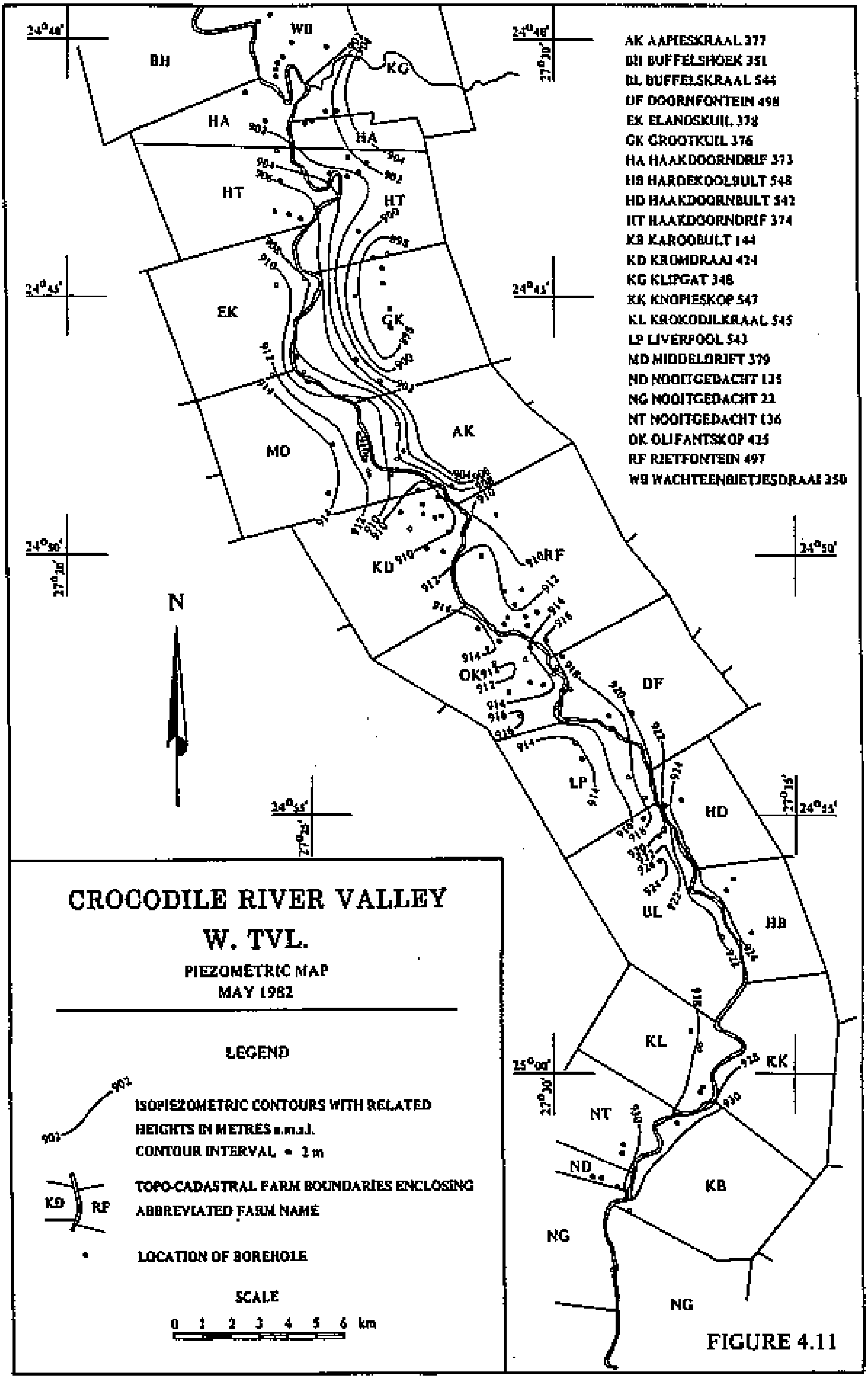
NG NOOITGEDACHT 22
NT NOOITGEDACHT 136
OK OLIFANTSKOP 425
RF RIETFONTEIN 497
WB WACHTEENBIETJESDRAAI 350
N
CROCODILE RIVER VALLEY
W. TVL.
PIEZOMETRIC MAP
MAY 1980
LEGEND
LOCATION OF BOREHOLE
ISOPIEZOMETRIC CONTOURS WITH RELATED HEIGHTS IN METRES A.M.S.L.
TOPO-CADASTRAL FARM BOUNDARIES ENCLOSING ABBREVIATED FARM NAME
SCALE
0 1 2 3 4 5 6 km

FIGURE 4.10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HD HAAKDOORNBULT 542
HT HAAKDOORNDRIF 374
KB KAROOBULT 144
KD KROMDRAAI 424
KG KLIPGAT 348
KK KNOPIESKOP 547
KL KROKODILKRAAL 545
LP LIVERPOOL 543
MD MIDDELDRIFT 379
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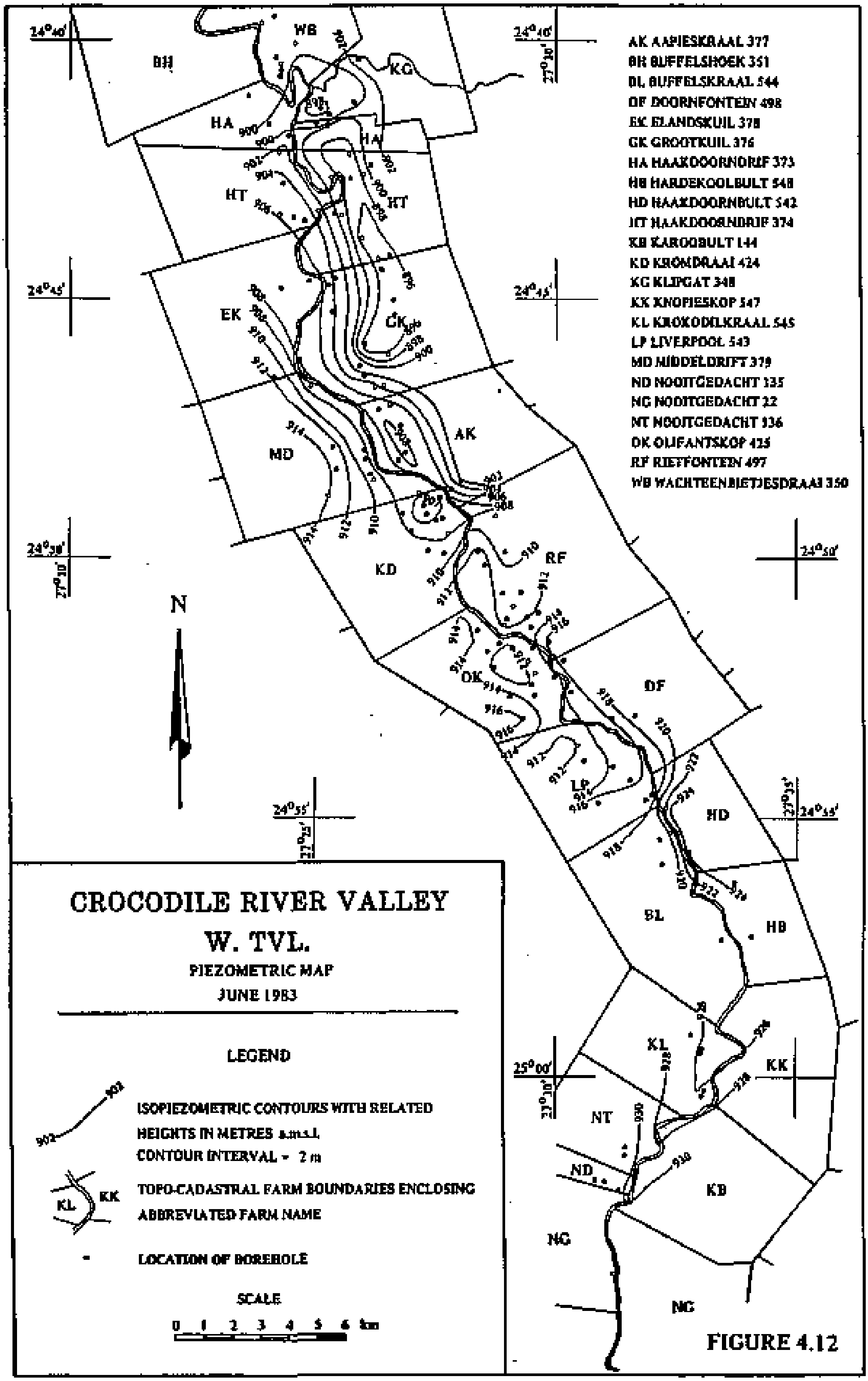
NG NOOITGEDACHT 22
NT NOOITGEDACHT 136
OK OLIFANTSKOP 425
RF RIETFONTEIN 497
WB WACHTEENBIETJESDRAAI 350
N
CROCODILE RIVER VALLEY
W. TVL.
PIEZOMETRIC MAP
MAY 1982
LEGEND
ISOPIEZOMETRIC CONTOURS WITH RELATED HEIGHTS IN METRES a.m.s.l.
CONTOUR INTERVAL = 2 m
TOPO-CADASTRAL FARM BOUNDARIES ENCLOSING ABBREVIATED FARM NAME
LOCATION OF BOREHOLE
SCALE
0 1 2 3 4 5 6 km

FIGURE 4.11


CROCODILE RIVER VALLEY
W. TVL.
PIEZOMETRIC MAP
JUNE 1983
LEGEND
ISOPIEZOMETRIC CONTOURS WITH RELATED HEIGHTS IN METRES a.m.s.l.
CONTOUR INTERVAL = 2 m
TOPO-CADASTRAL FARM BOUNDARIES ENCLOSING ABBREVIATED FARM NAME
LOCATION OF BOREHOLE
SCALE
0 1 2 3 4 5 6 km
AK AAPIESKRAAL 377
BH BUFFELSHOEK 351
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KD KROMDRAAI 424
KG KLIPGAT 348
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LP LIVERPOOL 543
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ND NOOITGEDACHT 335
NG NOOITGEDACHT 22
NT NOOITGEDACHT 336
OK OLIFANTSKOP 425
RF RIETFONTEIN 497
WB WACHTEENBIETJESDRAAI 350
N

FIGURE 4.12

A trough-like configuration of the ground-water contours characterizes sub-area D. This is the result of large-scale abstraction from the well field that taps the fossil river channel associated with the fault in this locality.

The progressive development of cones of dewatering in the alluvial aquifer at various localities in the study area is evident in Figures 4.11 and 4.12. Examples are those on the farms Liverpool 543, Olifantskop 425, Kromdraai 424 and Haakdoorndrift 374. As evidenced from Figure 3.2, each of these localities supports an active well field of varying proportions.

4.5 GROUND-WATER BUDGET

4.5.1 GROUND-WATER STORAGE

The potential of ground water to support large-scale irrigation in the study area is limited to the storage capacity of the alluvial aquifer. Simple volumetric calculations based on average values for saturated aquifer thickness, storativity (as determined from aquifer tests) and areal extent of the alluvial aquifer provided an estimate of the storage capacity of this aquifer (Table 4.4). The characterization of the alluvial aquifer into sub-areas facilitated this estimation. The zones referred to in respect of sub-areas B and C are indicated in Figure 3.2.

TABLE 4.4. ESTIMATED STORAGE CAPACITY OF THE ALLUVIAL AQUIFER

AREA	AREAL EXTENT (km^2)	SATURATED AQUIFER THICKNESS (m)	STORATIVITY	STORAGE CAPACITY (10^6 m^3)
Sub-area A	15,20	7	4,4x10-3	0,5
Sub-area B:				
Zone 1	6,05	9	$1,1 \times 10^{-2}$	0,6
Zone 2	3,32	9	$1,0 \times 10^{-1}$	3,0
Zone 3	3,70	9	$6,5 \times 10^{-2}$	2,2
Remainder	16,53	6	$4,4 \times 10^{-2}$	4,4

Sub-area C:				
Zone 1	9,00	20	$5,2 \times 10^{-2}$	9,4
Remainder	20,50	10	$5,2 \times 10^{-2}$	10,7
Sub-area D	3,19	10	$4,0 \times 10^{-2}$	1,3
TOTAL				**32,1**

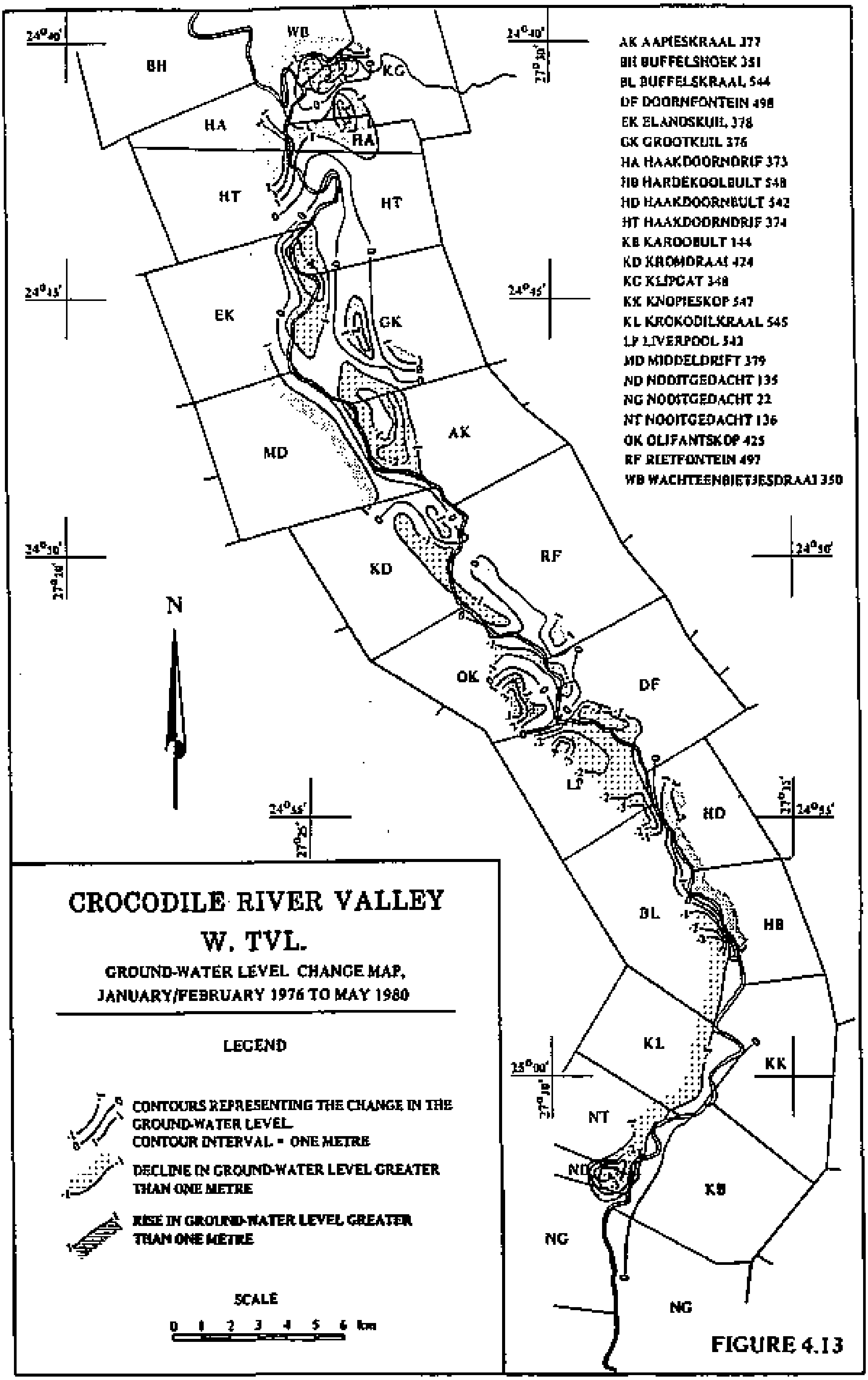
Neglecting the estimated storage capacity of sub-area D, it is apparent that the storage capacity of the alluvial aquifer adjoining the river amounts to some 31 x 10^6 m^3. This estimate is deemed reliable within the limitations imposed by the use of averaged hydraulic parameters over the large areal extent of the alluvial aquifer.

4.5.2 CHANGE IN STORAGE

Ground-water level change maps have been compiled for the periods January/February, 1976 to May, 1980 (Fig. 4.13), May, 1980 to May, 1982 (Fig. 4.14) and May, 1982 to June, 1983 (Fig. 4.15). These maps clearly reveal zones of decline and rise of the ground-water level over the corresponding time periods.

Both Figures 4.13 and 4.14 indicate that the zone of least change in ground-water level (the zero contour) closely approximates the course of the river channel. This is in keeping with the observation that continuous stream flow in excess of 7 x 10^6 m^3 (on average) per month maintains the ground-water level in the aquifer immediately adjoining the river at the elevation of water in the river channel. This implies that significant recharge takes place under the above-mentioned flow conditions. The zones of significant ground-water decline (>2 metres) are seen to closely resemble the position of active well fields.

Figure 4.15 illustrates the extensive decline in ground-water levels in the study area following the continued large-scale abstraction of ground water in the absence of significant stream flow. The average decline along the river channel ranges between 1 and 2 metres. However, declines in excess of 2 metres are realized in certain localities, especially where extensive ground-water abstraction closely adjoins the river.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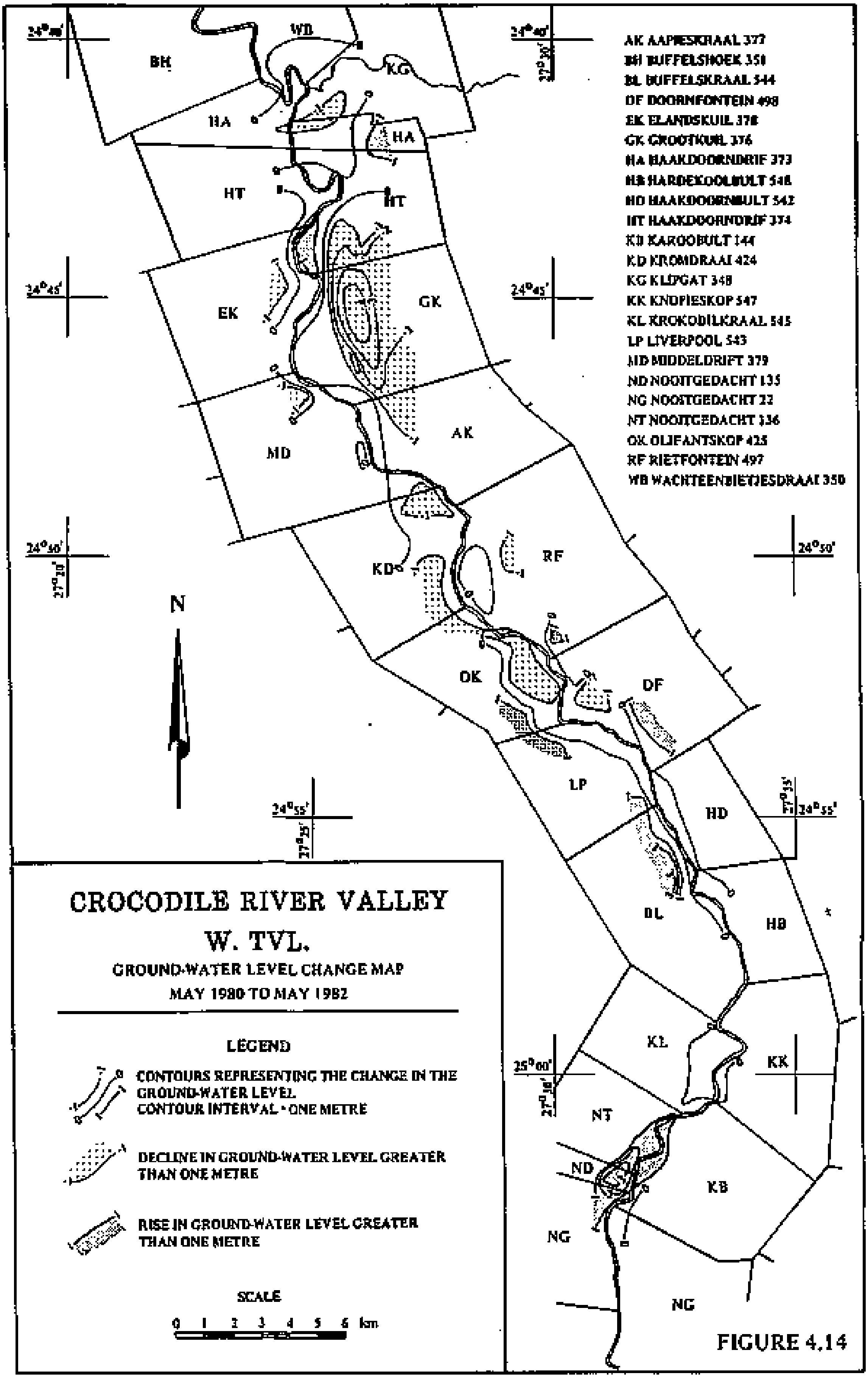
HB HARDEKOOLBULT 548
HD HAAKDOORNBULT 542
HT HAAKDOORNDRIF 374
KB KAROOBULT 144
KD KROMDRAAI 474
KG KLIPGAT 348
KK KNOPIESKOP 547
KL KROKODILKRAAL 545
LP LIVERPOOL 543
MD MIDDELDRIFT 379
ND NOOITGEDACHT 135
NG NOOITGEDACHT 22
NT NOOITGEDACHT 136
OK OLIFANTSKOP 425
RF RIETFONTEIN 497
WB WACHTEENBIETJESDRAAI 350
N
CROCODILE RIVER VALLEY
W. TVL.
GROUND-WATER LEVEL CHANGE MAP,
JANUARY/FEBRUARY 1976 TO MAY 1980
LEGEND
CONTOURS REPRESENTING THE CHANGE IN THE GROUND-WATER LEVEL
CONTOUR INTERVAL = ONE METRE
DECLINE IN GROUND-WATER LEVEL GREATER THAN ONE METRE
RISE IN GROUND-WATER LEVEL GREATER THAN ONE METRE
SCALE
0 1 2 3 4 5 6 km

FIGURE 4.13



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HB HARDEKOOLBULT 548
HD HAAKDOORNBULT 542
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KB KAROOBULT 144
KD KROMDRAAI 424
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KK KNOPIESKOP 547
KL KROKODILKRAAL 545
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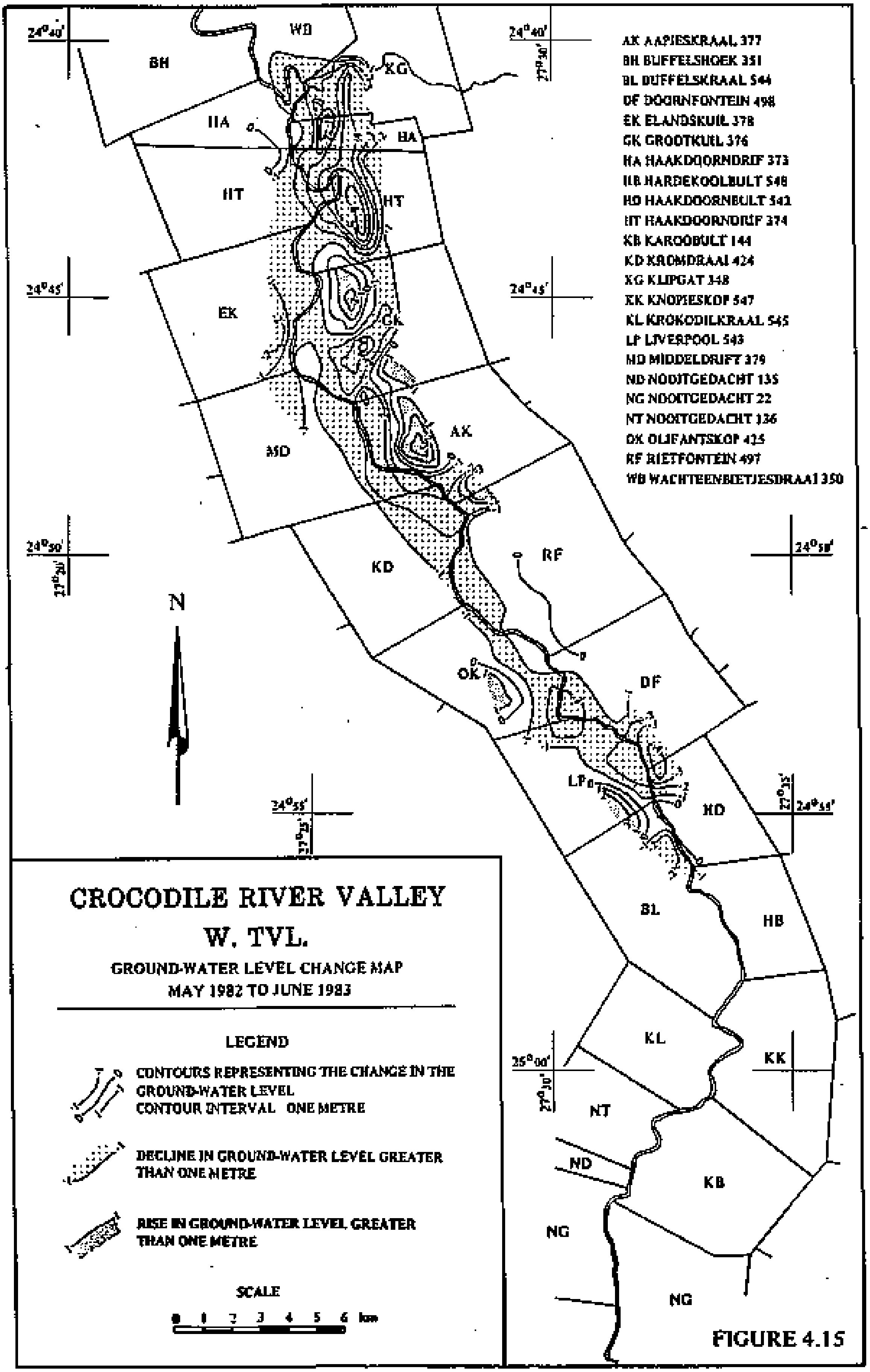
MD MIDDELDRIFT 379
ND NOOITGEDACHT 135
NG NOOITGEDACHT 22
NT NOOITGEDACHT 136
OK OLIFANTSKOP 425
RF RIETFONTEIN 497
WB WACHTEENBIETJESDRAAI 350
N
CROCODILE RIVER VALLEY
W. TVL.
GROUND-WATER LEVEL CHANGE MAP
MAY 1980 TO MAY 1982
LEGEND
CONTOURS REPRESENTING THE CHANGE IN THE GROUND-WATER LEVEL
CONTOUR INTERVAL - ONE METRE
DECLINE IN GROUND-WATER LEVEL GREATER THAN ONE METRE
RISE IN GROUND-WATER LEVEL GREATER THAN ONE METRE
SCALE
0 1 2 3 4 5 6 km

FIGURE 4.14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RF RIETFONTEIN 497
WB WACHTEENBIETJESDRAAI 350
N
CROCODILE RIVER VALLEY
W. TVL.
GROUND-WATER LEVEL CHANGE MAP
MAY 1982 TO JUNE 1983
LEGEND
CONTOURS REPRESENTING THE CHANGE IN THE GROUND-WATER LEVEL
CONTOUR INTERVAL ONE METRE
DECLINE IN GROUND-WATER LEVEL GREATER THAN ONE METRE
RISE IN GROUND-WATER LEVEL GREATER THAN ONE METRE
SCALE
0 1 2 3 4 5 6 km

FIGURE 4.15

The zones of rise in ground-water level evident in Figure 4.15 generally coincide with those areas where pumping has ceased, causing a recovery of the ground-water level.

Accepting that the ground-water reservoir was full in May, 1980 and again in May, 1981 following the peak-discharge events, then Figure 4.14 can be regarded as representing the ground-water level change map for the period May, 1981 to May, 1982.

Simple volumetric calculations based on the contoured ground-water level changes for each period and assuming an average storativity of 5% for the alluvial aquifer, indicate a decrease in the volume of stored ground water as follows:

(i) $2{,}1 \times 10^6$ m^3 for the period May, 1981 to May, 1982.
(ii) $6{,}4 \times 10^6$ m^3 for the period May, 1982 to June, 1983.

If it is further accepted that the estimated full capacity of the ground-water reservoir approximates 31×10^6 m^3, then this reservoir contained $28{,}9 \times 10^6$ m^3 *circa* May, 1982 and $22{,}5 \times 10^6$ m^3 *circa* June, 1983.

4.5.3 RECHARGE

An estimate of the magnitude of recharge to the alluvial aquifer can be gained from the following simple formulation:

STARTING CAPACITY - ABSTRACTION + RECHARGE = PRESENT CAPACITY (4.4)

If it is accepted that the full allocation (ABSTRACTION in (4.4) above) of $29{,}7 \times 10^6$ m^3 per year for irrigation from ground water is utilized, then recharge for the period May, 1981 to May, 1982 amounted to $27{,}6 \times 10^6$ m^3. This represents 90% of the full capacity of the ground-water reservoir. Similarly, recharge for the period May, 1982 to June, 1983 is calculated at $23{,}3 \times 10^6$ m^3, or 75% of the aquifer full capacity.

4.5.4 SURFACE OUTFLOW

The simple formulation that

SURFACE INFLOW - ABSTRACTION (SCHEDULING) - LOSSES TO THE AQUIFER (RECHARGE) = SURFACE OUTFLOW (4.5)

affords an estimate of the volume of surface outflow from the study area to be made.

Total surface run-off at station A2M25A for the period May, 1982 to June, 1983 amounted to 74 x 10^6 m^3, with scheduled irrigation requiring 33,2 x 10^6 m^3 per year. Following formulation (4.5) above, 17,5 x 10^6 m^3 left the study area as surface outflow in the period May, 1982 to June, 1983. No gauging station exists to monitor surface outflow at the lower extremity of the study area. However, a volume of 10,3 x 10^6 m^3 originating from reservoir releases was calculated to have left the study area as surface outflow in the above-mentioned period (personal communication, Resident Water Control Officer, 1984). This volume does not include flow originating as local rainfall run-off, which factor is inherent in the 17,5 x 10^6 m^3 computed above.

Accepting the generalizations inherent in the foregoing computations and formulations, then the independently derived values for surface outflow from the study area for the period May, 1982 to June, 1983 are in sufficient agreement to corroborate the order of recharge calculated for the same period.

4.6 HYDROCHEMISTRY

4.6.1 GENERAL

A total of 122 ground-water and 5 river-water samples were collected throughout the study area in May, 1980. The samples were analysed for their major ion chemistry at the Hydrological Research Institute of the Department of Water Affairs. The main object of the hydrochemical study was to better delineate the extent of the alluvial aquifer and the zone of the stream-aquifer interaction. The chemistry of ground water from the various bed-rock aquifers was also investigated to ascertain the alluvial aquifer to bed-rock aquifer relationship. A third consideration was the suitability of ground water for irrigation use.

The results of the analyses have been plotted on a Piper (1944) tri-linear diagram in Figure 4.16. This diagram indicates the extremely variable chemical composition of the ground water. The majority of the samples indicate a mixed cation composition with bicarbonate as the dominant anion, and are classified as fresh and of recent origin (Johnson, 1975). This observation is substantiated by the fact that 65% of the samples have a total dissolved solids (TDS) concentration of less than 1000 mg/l. Some 18% of the samples have a TDS concentration greater than 1500 mg/l, the majority of these representing ground water from boreholes tapping the various bed-rock aquifers.

Water of similar chemical composition occupies similar portions of the Piper diagram. This allows the analysed ground-water samples to be characterized according to the plotting position of the samples of the alluvial and various bed-rock aquifers as indicated (Fig. 4.17).

The predominantly sodium-bicarbonate composition of the ground water from the granite bed-rock aquifer refelcts the chemistry of the acid plutonic unit of the Bushveld Complex, comprising the Bushveld Granite. Similarly, the chemistry of the mafic intrusives (mainly gabbro and norite) could be responsible for the predominantly calcium/magnesium-bicarbonate composition of ground water from the bed-rock aquifers. The alluvial ground-water field on the Piper diagram is centred around the average composition of the river water. Mixing between the various types of ground water also exist (Fig 4.17).

The correlative Schoeller graph (Fig. 4.18) illustrates the significant difference in composition between the ground waters of the various bed-rock aquifers, and the similar chemical composition of alluvial ground water and surface water. The latter reflects the influence of recharge from the river to the alluvial aquifer.

4.6.2 CHANGES IN CHEMICAL QUALITY

A total of 43 boreholes were re-sampled in April, 1984, and the analyses compared to the previous results. This exercise yielded mixed results, with a number of the samples revealing a deterioration in quality, others an improvement and many remaining essentially unchanged.

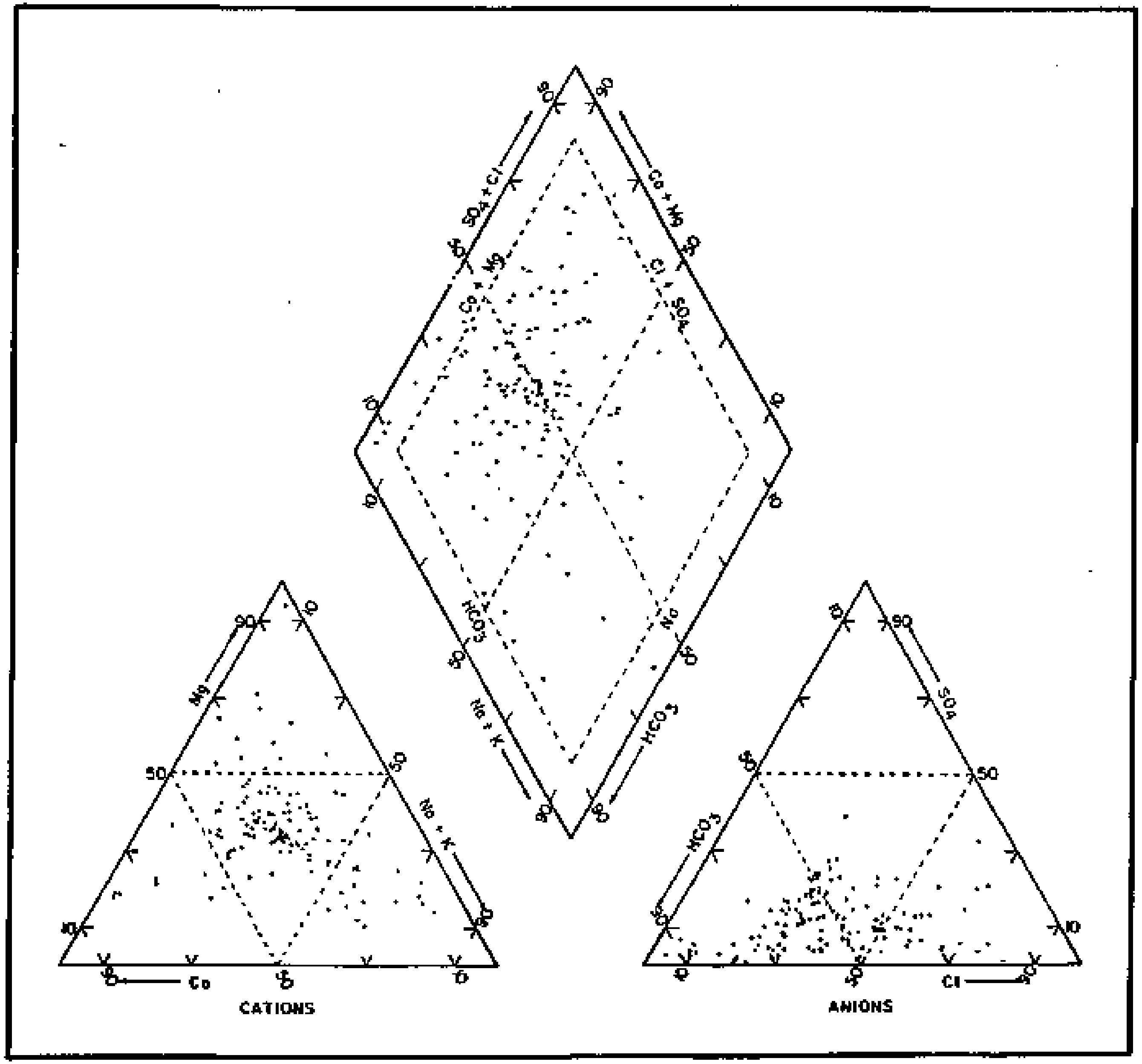

Figure 4.16. Tri-linear plot of ground-water chemistry of the study area.

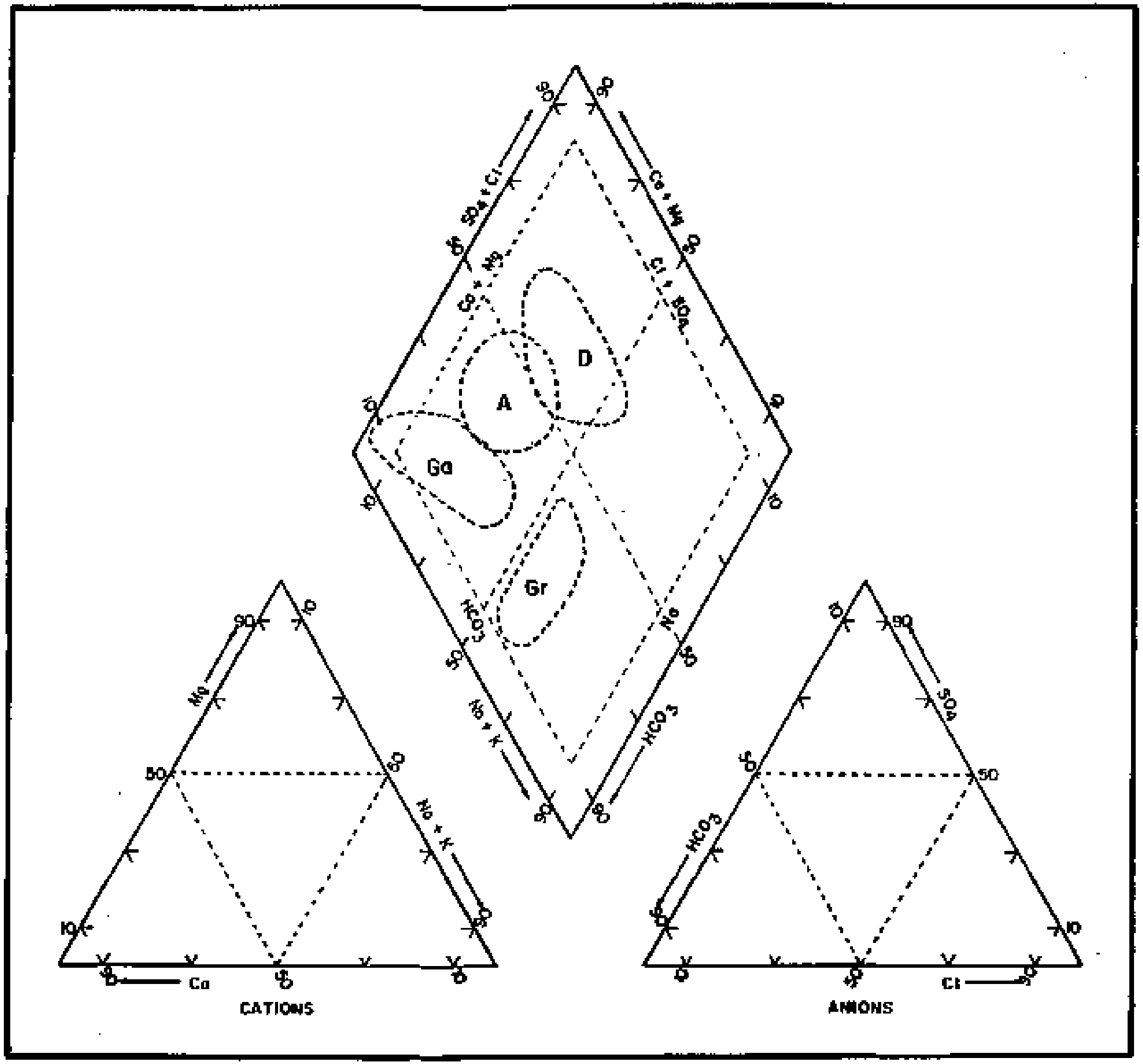

Figure 4.17. Characterization of ground waters from the primary and various bed-rock aquifers in the study area (A = alluvium, D = dolomite, Ga = gabbro, Gr = granite).

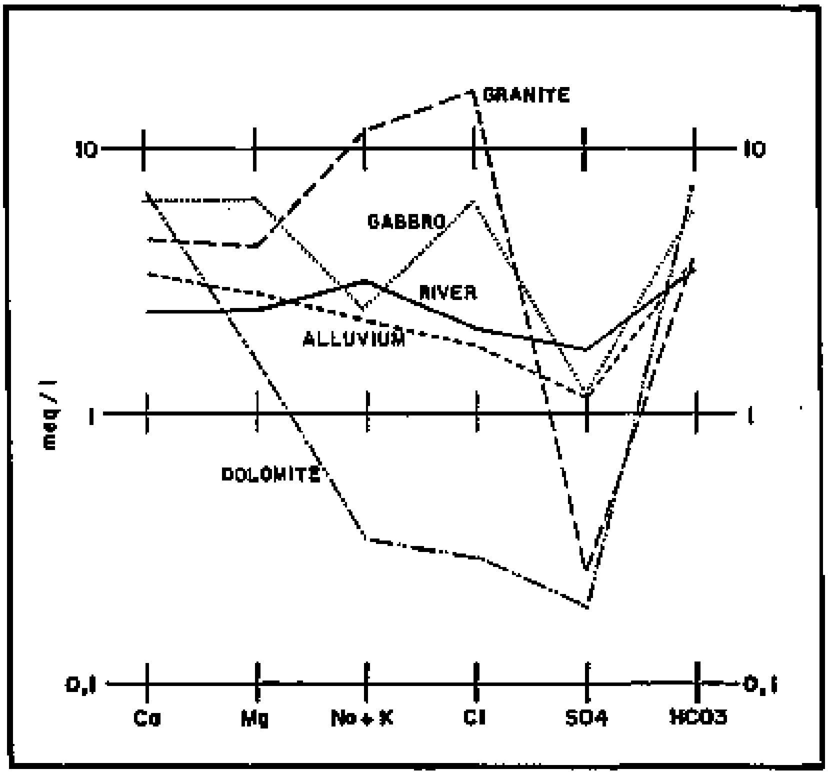

Figure 4.18. Correlative Schoeller diagram of selected ground-water chemistries and surface water.

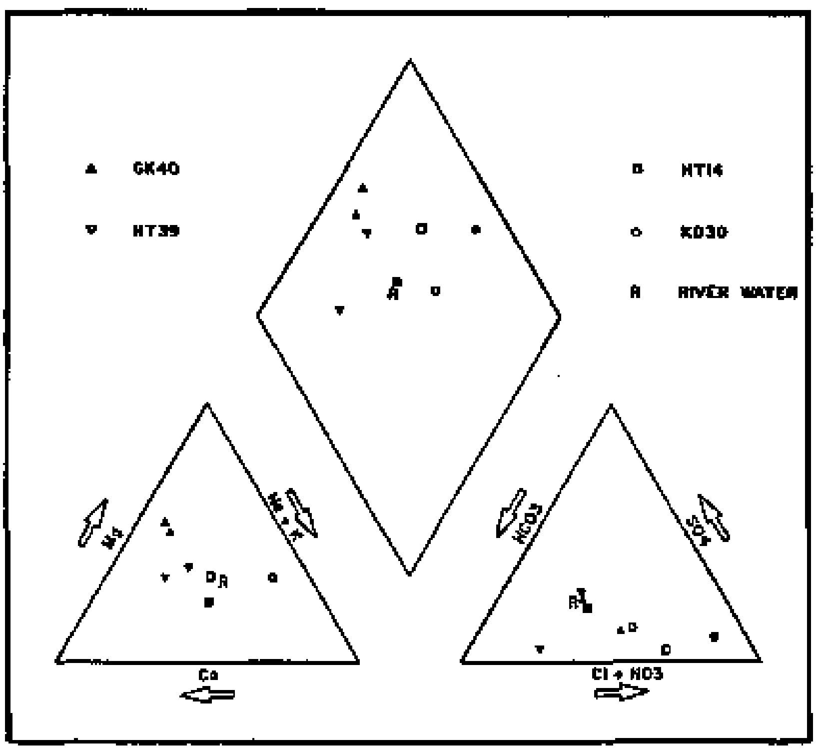

Figure 4.19. Changes in ground-water quality between May, 1980 and April 1984 in selected boreholes.

Some of the more significant changes are illustrated in Figure 4.19. Table 4.5 represents a summarized analysis of each sample depicted in Figure 4.19 for each period.

TABLE 4.5. CHEMICAL ANALYSES OF GROUND-WATER SAMPLES FROM BOREHOLES MONITORED IN MAY, 1980 AND APRIL, 1984.

(Values in mg/l . May, 1980 value depicted above April, 1984 value)

Sampled	pH	Cond	TDS	Ca	Mg	Na+K	HCO_3	Cl	SO_4
KD30	7,9	320	2197	134	109	439	684	640	143
	7,5	842	5368	225	347	1117	630	2520	389
HT14	7,8	157	1005	134	50	144	265	343	32
	7,5	97	725	78	28	88	277	107	93
GK40	7,7	110	746	91	77	27	320	204	72
	7,4	84	634	70	57	27	246	84	97
HT39	7,4	36	476	57	33	48	257	49	14
	7,6	133	940	134	54	58	349	183	39
River	7,3	71	524	48	30	74	211	72	82

(NB River -water sample representative of the average river-water composition in May, 1980)

The significant deterioration in the quality of ground water from borehole KD30 is attributed to the influence of large-scale abstraction by the well field in this locality. This factor, in conjunction with the insignificant recharge from the river in the period following March, 1983, has allowed the poorer quality ground water of the granitic bed-rock aquifer adjoining this well field (Fig. 3.2) to be drawn into the alluvial aquifer. The quality of ground water from borehole HT14 shows an improvement, the composition in April, 1984 approaching that of river water in 1980. This is attributed to the encroachment of better quality alluvial ground water into the vicinity of this borehole. Although borehole HT14 penetrates only the gabbroic bed-rock aquifer, the alluvial aquifer in close proximity thereto is well-developed. Furthermore, abstraction of ground water for irrigation has caused a steeper gradient of the water table in the direction of this borehole.

4.6.3 QUALITY OF GROUND WATER FOR IRRIGATION

The following factors generally determine the suitability of water for irrigation:

(i) chemical composition of the water,
(ii) soil type, and
(iii) type of crop to be irrigated.

The U.S. Salinity Laboratory Staff (1954) developed a classification system for determining the suitability of ground water for irrigation based on:

(i) the salinity hazard,
(ii) the sodium hazard, and
(iii) the residual sodium carbonate.

Only the first two factors mentioned above will be discussed.

4.6.3.1 SALINITY HAZARD

The salinity hazard is determined by the specific conductance of the water, generally expressed in mS/m at 25°C. The U.S. Salinity Laboratory Staff (1954) divided the salinity hazard of irrigation water into four classes, ranging from low salinity (C1) through medium (C2) and high (C3) to very high salinity water (C4), based on conductivity (Fig. 4.20). Thus, the suitability of ground water for irrigation generally decreases as the conductivity thereof increases.

The majority of ground-water samples from the study area fall into the high salinity (C3) class (Fig. 4.20). However, irrigation water in the study area is classed as a medium- to high-salinity water (classes C2 and C3 respectively). Following the U.S. Salinity Laboratory Staff (1954), these waters can be used if a moderate amount of leaching and, at least, adequate drainage takes place.

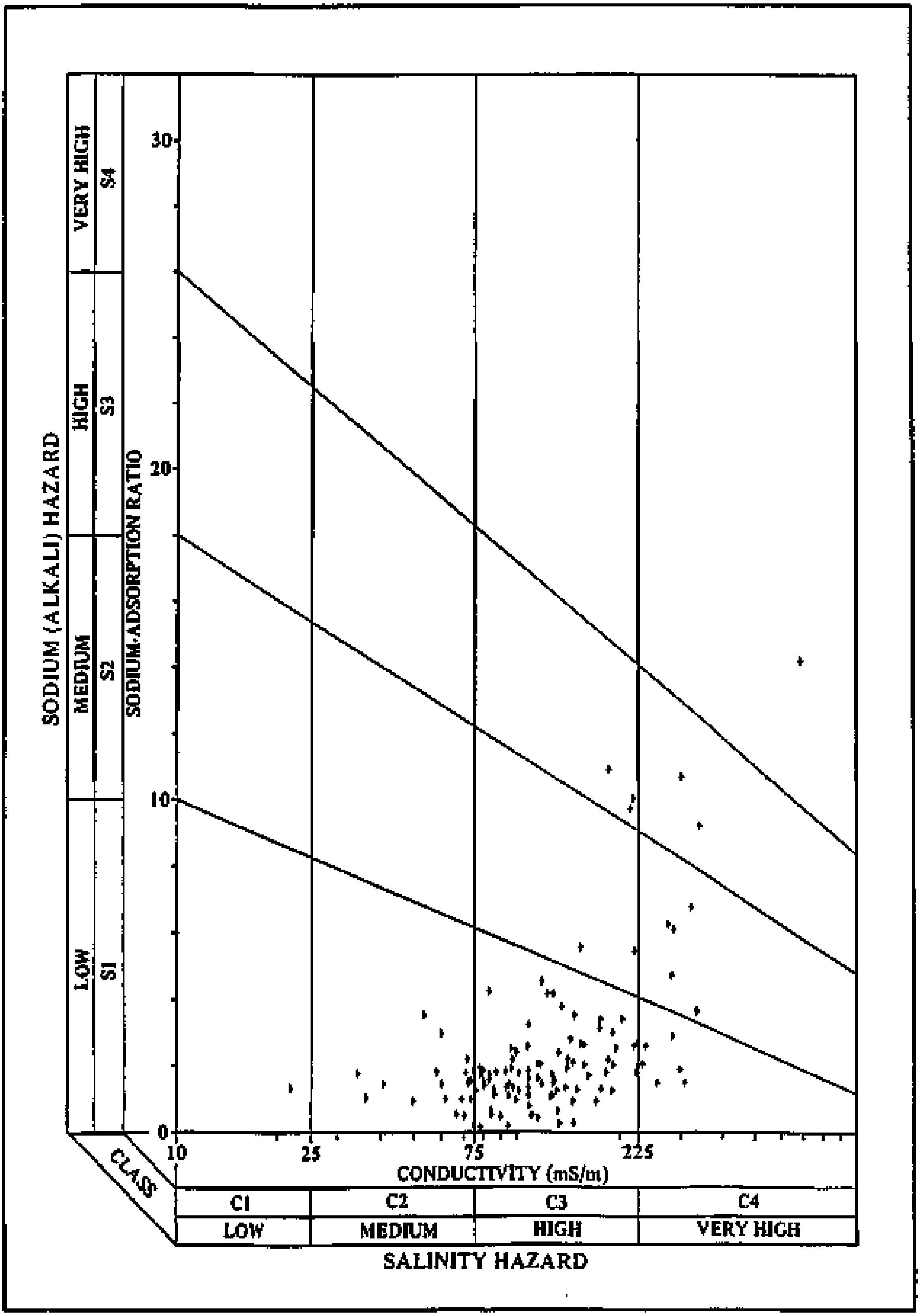

Figure 4.20. Classification of ground water for irrigational use based on electrical conductivity and the sodium-adsorption ratio.

4.6.3.2 SODIUM HAZARD

The sodium hazard is a function of the sodium-adsorption ratio (SAR) of water. This is defined by the equation

$$SAR = Na/((Ca + Mg)/2)^{1/2} \quad (4.6)$$

in which concentrations are expressed in milli-equivalents per litre. The effect of exchangeable sodium on the physical properties of a soil forms the basis of the U.S. Salinity Laboratory Staff (1954) classification of irrigation water with respect to the sodium hazard. The sodium hazard increases as the proportion of sodium among the cations increases.

From the generally mixed cation composition of ground water in the study area, it is to be expected that the sodium hazard for these waters is low. This observation is confirmed in Figure 4.20, since by far the greater number of samples plot in the S1 sodium hazard field.

CHAPTER 5

MODELLING OF THE STREAM-AQUIFER SYSTEM

5.1. BACKGROUND INFORMATION

Modelling of ground-water flow by digital computer was first successfully done during the late sixties. Prickett and Lonnquist, as well as Pinder, produced their first models in 1968. These were based on mathematical principles originally described by Peaceman and Rachford (1955).

By 1971 the model by Prickett and Lonnquist (1971) was generally available, since it was published in the well-documented Bulletin 55 by the Illinois State Water Survey. For many years, this model has been used by modellers to simulate ground-water level responses and is still in use today.

Many refinements in ground-water modelling have been introduced through the years. These mainly relate to the mathematical techniques for solving the ground-water flow equation. Up till 1973, all models used finite difference methods for approximating Equation 5.1. This was normally done in the horizontal plain (x-y), since three-dimensional models were too large and unmanageable. Freeze (1969) preferred models in the vertical plain (x-z) which, for specific problems such as infiltration, yield better results.

$$\nabla . Km \nabla h = S_y \partial h / \partial t + W(x,y,t) \qquad (5.1)$$

where

h	hydraulic head
m	saturated thickness of the aquifer
K	hydraulic conductivity
S_y	specific yield
W	vertical distance from the aquifer per unit area

In 1974, Pinder (1974) was the first to publish his finite element approximation to the ground-water flow equation. The main advantage of this model, above the well-established finite difference models, was that the geometry of the ground-water system could be approximated with a much higher degree of accuracy. However, finite element models probably take 3-5 times longer to set up. Also, it is mathematically much more complicated than the finite difference approach and, for that reason, many of the modellers prefer finite differences.

Further developments came in 1975 with the ability to include the movement of water quality and therefore pollutants in the models. Leaders in this field were Konikow *et. al.*, (1974) (finite difference) and Pinder (finite element). Other developments in this respect include the method of characteristics, the random walk model and mixing cell models.

In 1976, stochastic principles were briefly introduced into the ground-water models. It was soon realized that the accuracy of the models was not significantly improved by this refinement. Very few researchers presently include stochastic principles in their models. They are not intended to improve accuracy but to give specific probability ranges for the estimates.

Other refinements which do not necessarily relate to the simulation of the Crocodile River System are the Optimal Ø-technique (Botha *et. al.*, 1981), the removal of point singularities (Bakkes and Botha, 1981) and the use of global elements (Botha and Bakkes, 1984) rather than finite elements. These developments could be implemented in future modelling of the Crocodile System, but do not presently warrant inclusion in the model.

Although ground-water flow has been modelled extensively during the past 15 years, very few of these simulations included conjunctive use of surface and subsurface water (Dunlap *et. al.*, 1985). One of the reasons for this is perhaps that an additional set of parameters is introduced and that two complex equations, rather than one, as in the case of ground-water flow, have to be solved. Ground-water flow can be simulated using a two- or three-dimensional parabolic differential equation, but movement of water in a stream is described by the hyperbolic equations in (5.2).

$$z(\partial v/\partial l) + v(\partial z/\partial l) + \partial z/\partial t = q_l/b + q_v/b$$

and

$$v(\partial v/\partial l) + g(\partial z/\partial l) + v(q_l + q_v)/bz + \partial v/\partial t = g(S_0 - S_f) \qquad (5.2)$$

where

- b channel width
- g gravitational acceleration
- l space coordinate
- q_v flow into the channel per unit length through its wetted perimeter
- q_l lateral inflow per unit length over the channel banks and from tributaries
- S_f friction slope
- S_0 slope of the channel bottom
- t time
- v velocity of flow
- z depth of flow

A complicating factor in the calculation of the stream flow is that a hyperbolic equation is generally more successfully solved by finite difference methods. This puts a serious restriction on the whole simulation exercise, since the Crocodile River System is relatively narrow and sinuous. Its geometry can only with difficulty be simulated with finite difference techniques. The stream-flow equation can, of course, be solved by finite difference techniques, thus obtaining water-levels in the river. These values can then be used as an input into a finite element model to simulate the ground-water response.

Modelling of river flow was done by Pinder (1971) using finite difference methods. The parameters, as mentioned in Equation 5.2, were considered in his model. These are also the parameters needed for the simulation of flow in the Crocodile River. A finite difference model for the Crocodile River Area was first constructed to test the sensitivity of each of the parameters. In simulations of this kind, it is normally required that values for the parameters be known for a specific period of time and under a variety of conditions, to calibrate the model. In the case of the Crocodile River, very few of these parameters have been evaluated in the past. Stream-flow data in the downstream areas, the permeability of the river bed and its thickness, abstraction rates from the river and roughness characteristics of the river channel are not known. Under these circumstances Equations 5.2 cannot be used for modelling purposes.

After several trial runs, it was decided to abandon this approach to simulate river flow. Although Equation 5.2 can be used in future models, not enough is known to use this equation in this present study.

A different approach to the problem of simulating the effect which the river has on the subsurface water resources would be to assume that the flood hydrograph is known. The flood hydrograph, as measured in terms of space and time, can then be used as an input into the ground-water flow model, and the effect of recharge to the ground-water regime can be studied.

One of the prerequisites of the modelling exercise was to keep the model as simple as possible. Bearing this in mind, and seeing that the constraint of the hyperbolic stream-flow equation has temporarily been removed, it was decided to experiment with both the finite difference and finite element approaches. In general terms, the main practical differences between the two approaches are as follows:

FINITE DIFFERENCES

- A rectangular network over the area in question is required.
- The accuracy to which geometric irregularities, such as the river, geological features, borehole positions and other observation points can be considered, is low.
- To improve its accuracy, the network can be refined. However, the size of the computer and the number of data values to be entered make networks exceeding 600 nodes impractical.
- Setting up a finite difference model is vastly simpler than in the case of a finite element model.

FINITE ELEMENTS

- The network normally consists of triangles or rectangles of any shape and/or size.
- Complicated geometric features can be simulated with great accuracy.
- Networks exceeding 600 elements become impractically large.
- Constructing a finite element network, digitizing and numbering the node positions, numbering the elements and entering this information together with the hydraulic constants into the computer, takes 3-5 times longer than in the case of finite differences.

5.2 TRIAL SIMULATIONS

In any modelling exercise, the accuracy and complexity of the model should match the data. It is senseless to develop models that are mathematically highly accurate if the data is suspect. In the initial stages of the present modelling exercise, it was intended to keep the model as simple as possible. For this reason, a finite difference approach was preferred.

5.2.1 FINITE DIFFERENCE SIMULATIONS

Two attempts at simulating the stream-aquifer system using the finite difference technique were made. Figures 5.1 and 5.2 illustrate the distribution of pumping and observation boreholes in the study area. Figures 5.3 and 5.4 demonstrate the two networks which have been used. The mesh spacing of 250 metres used in Figure 5.3 provided sufficiently detailed coverage of the zone of stream-aquifer interaction. However, the dimensions of the mesh (>4000 nodes) proved impractical in terms of computational cost and effort, considering that an average of 10 parameter values have to be entered at each of the nodes.

Computational effort can be economized by increasing either the size of the time step or the mesh spacing (Rushton and Tomlinson, 1977). However, stability and convergence criteria generally limit a significant increase in the size of the time increment. The mesh spacing of the second finite difference network (Fig. 5.4) was therefore increased to 1000 metres, reducing the number of nodes to 360. Trial simulations indicated that the accuracy of the model was completely inadequate in areas of steep gradients, because of the large mesh spacing. Furthermore, that the zone of stream-aquifer interaction and the course of the river could not be simulated in sufficient detail with such a large mesh spacing. At this stage, it was decided to abandon finite difference approximations altogether and resort to the finite element method.

5.2.2 FINITE ELEMENT SIMULATIONS

The finite element approach allows the use of either rectangular (Figures 5.5 and 5.6) or triangular (Fig. 5.7) elements. This, in turn, allows for greater flexibility in

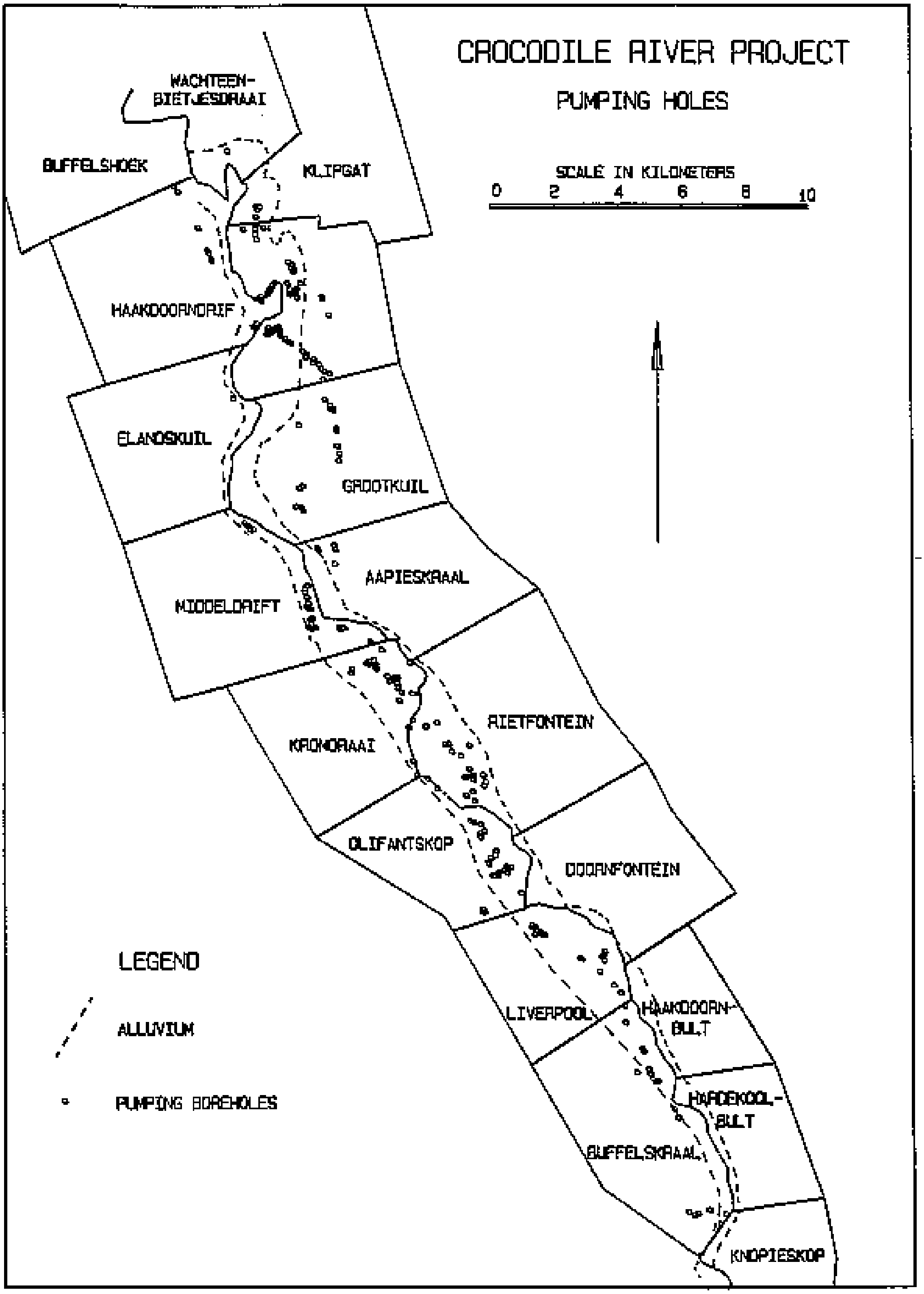

Figure 5.1. Location of pumping boreholes.

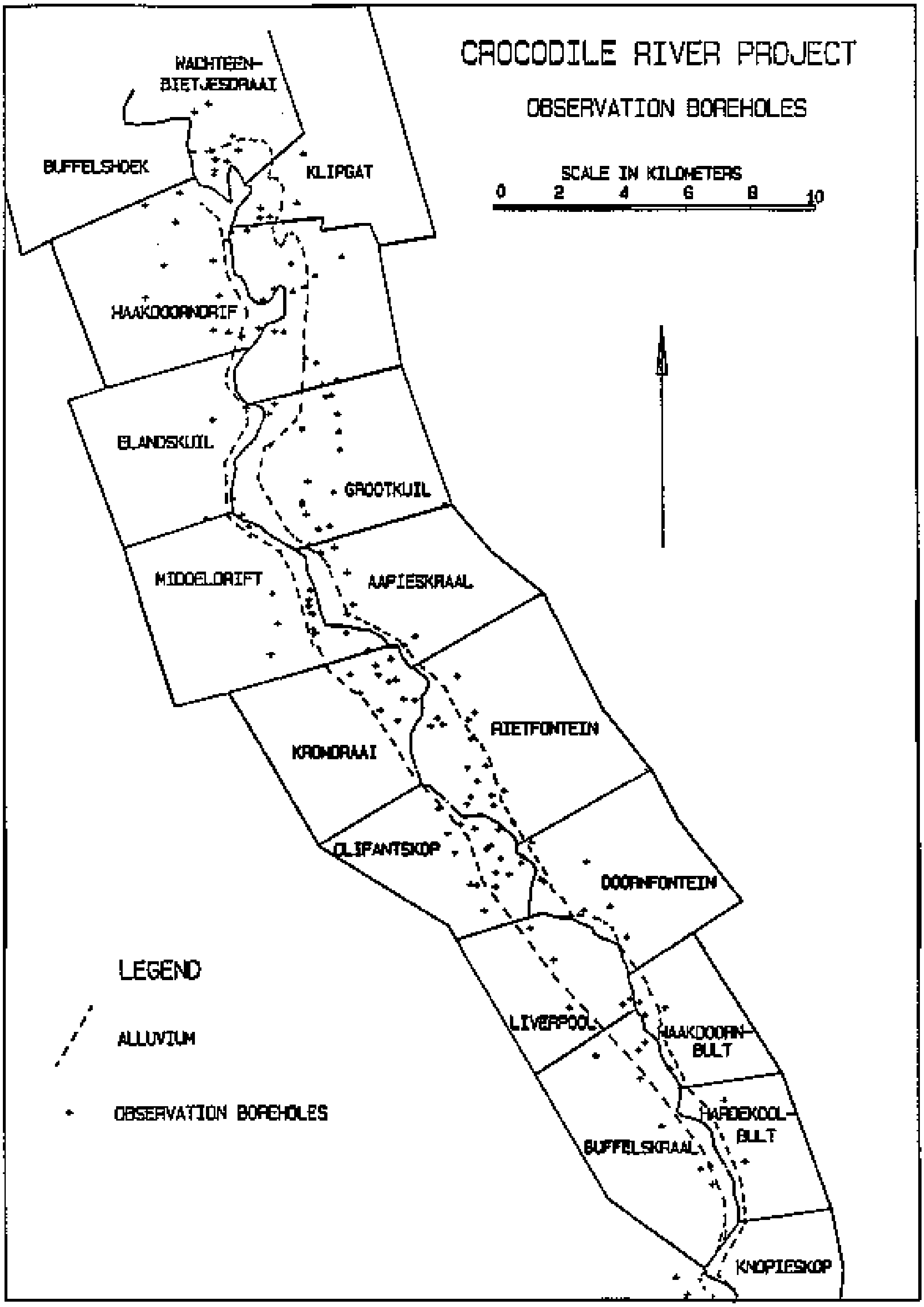

Figure 5.2. Location of observation boreholes.

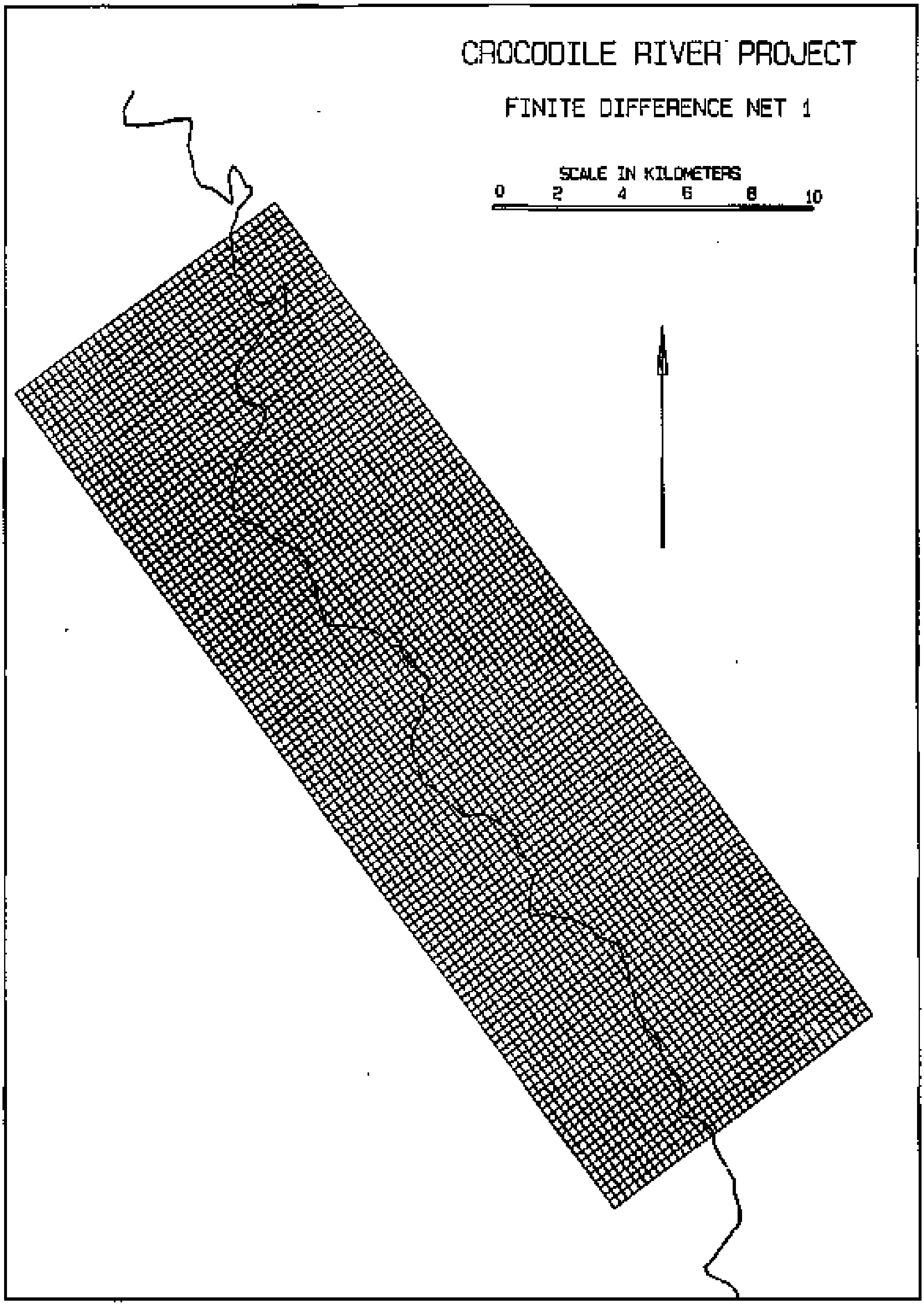

Figure 5.3. Finite difference network for simulation 1.

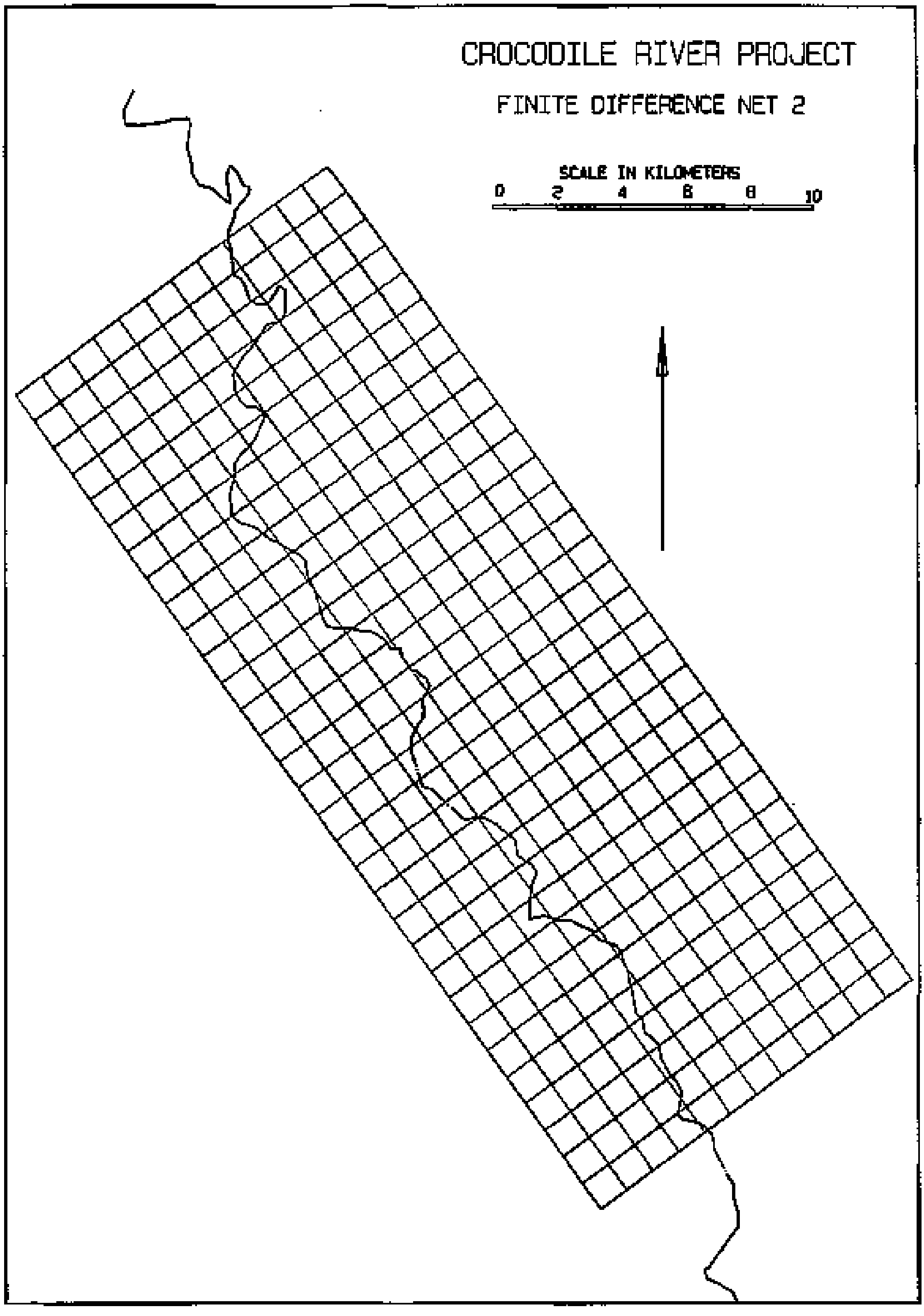

Figure 5.4. Finite difference network for simulation 2.

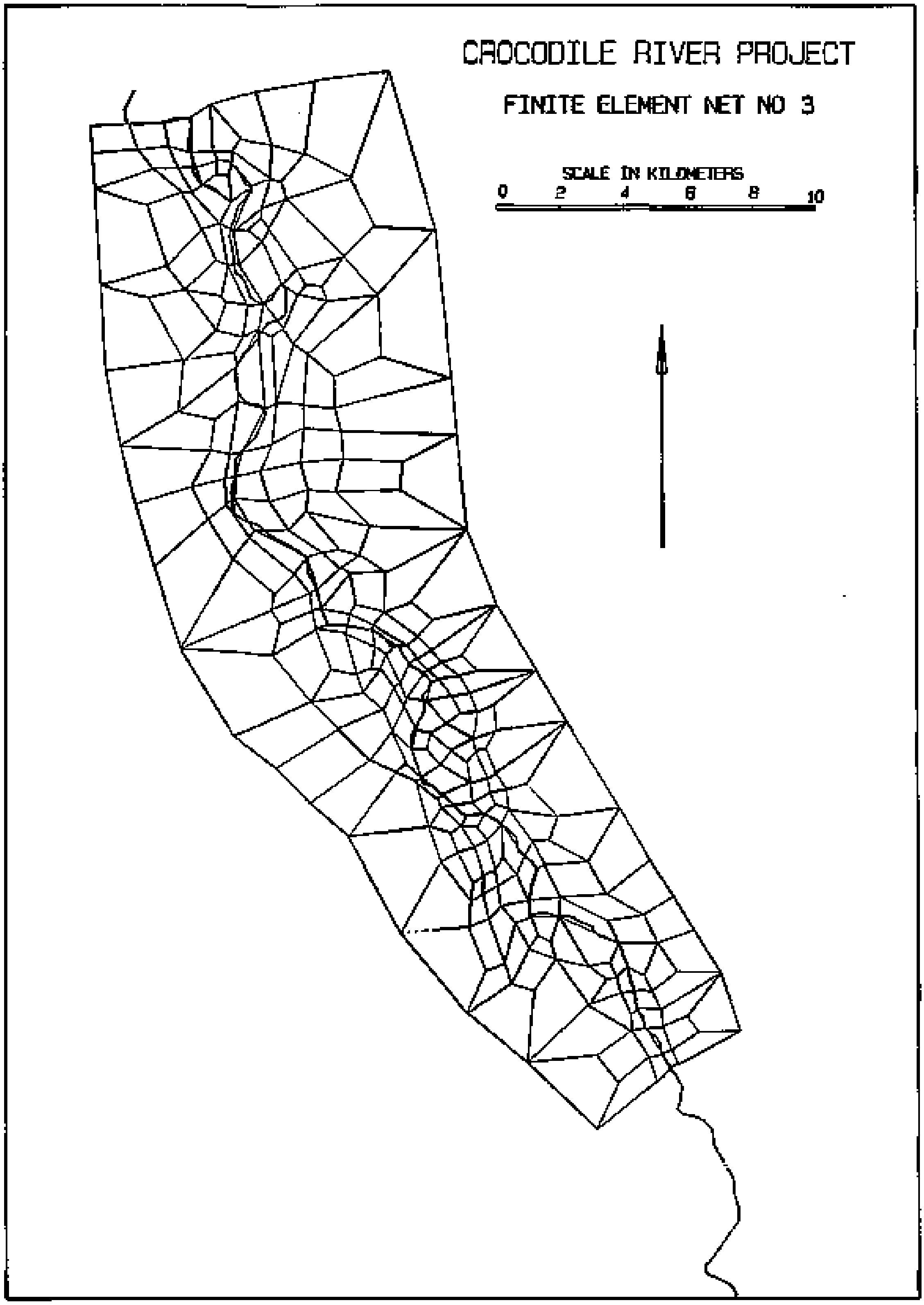

Figure 5.5. Finite element network for simulation 3.

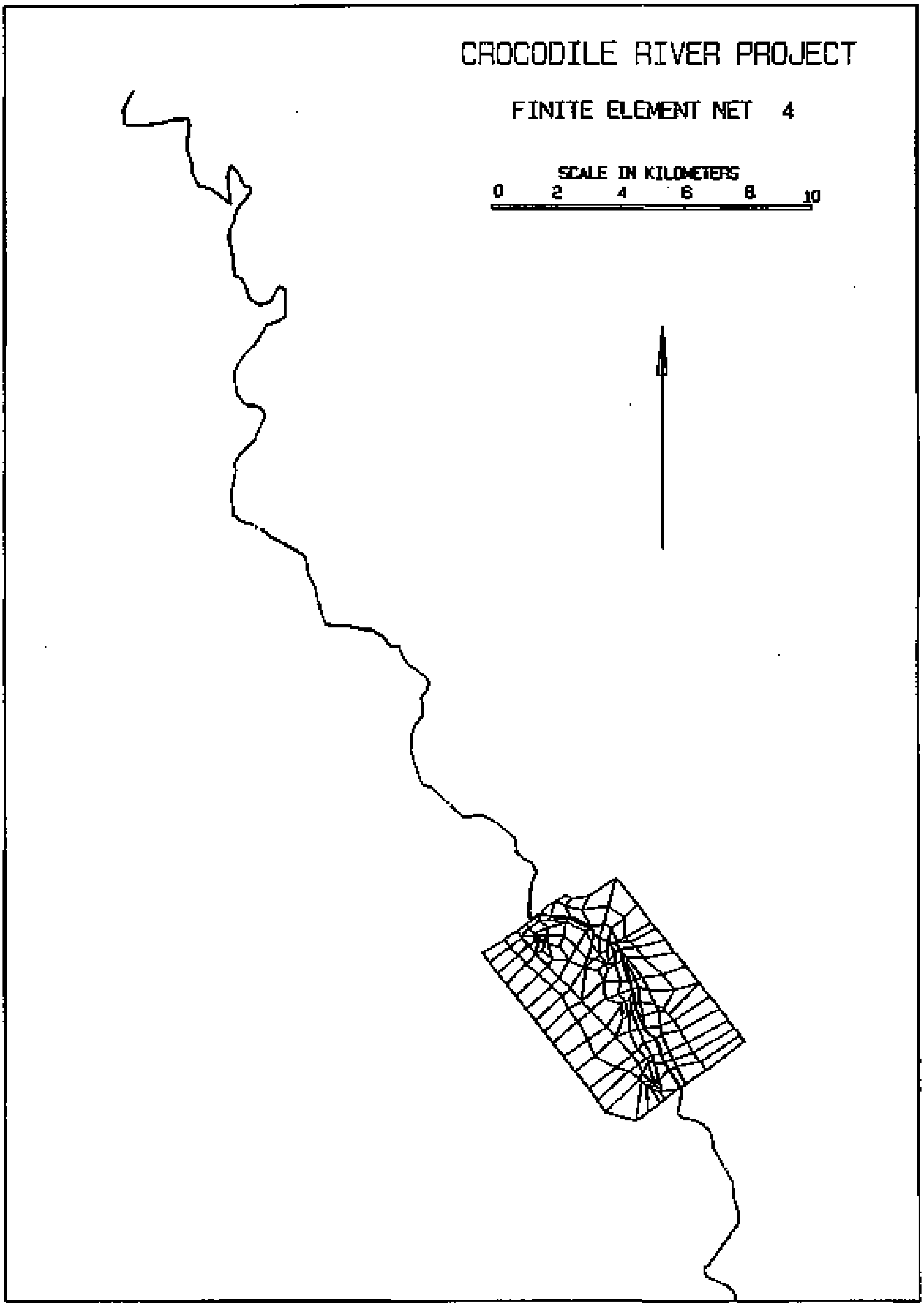

Figure 5.6. Finite element network for simulation 4.

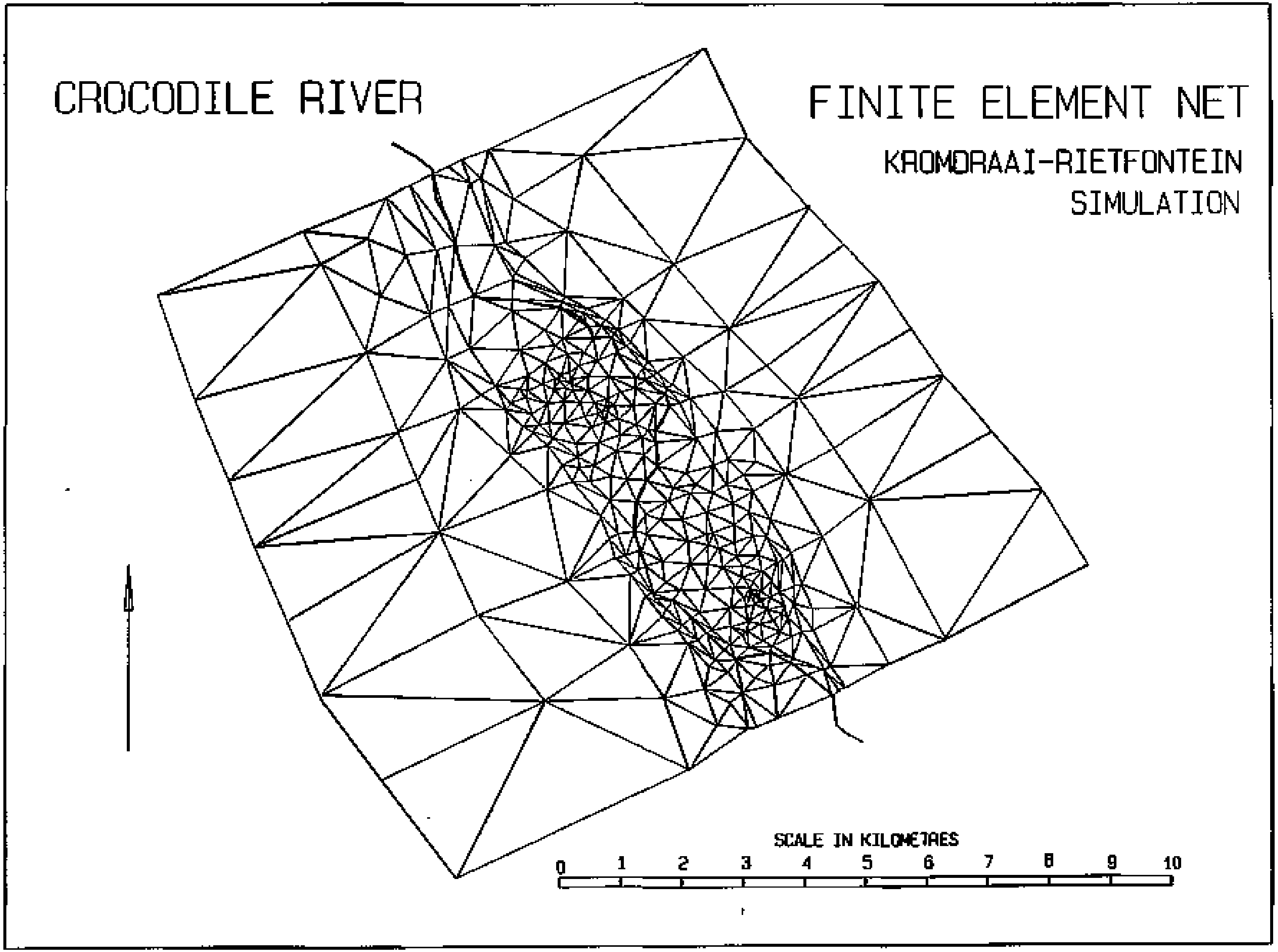

Figure 5.7. Finite element network for simulation 5.

grid design. Although rectangular elements have a slightly higher mathematical accuracy, this is normally insignificant in comparison to the degree of accuracy to which parameter values are known. Triangles have the following specific advantages:

- Fewer nodes are obtained by grouping triangles.
- The size of matrices required solving the equations is therefore significantly reduced (smaller half-band width).
- The solution time is significantly reduced.

In terms of creating a grid, a time saving of up to 50% can be achieved over that for rectangular elements. A triangular network of 500 elements typically requires only 80K words at single precision computer space with a half-band width of 50. The solution time required for each time step is in the order of 6 seconds.

Even though triangular elements are comparatively easy to use, it was decided to experiment with rectangular elements at first, since the ISOQUAD program by Pinder (1974) was available, and had been implemented on the Univac Computer at the University of the Orange Free State for other simulations.

Two networks were constructed using rectangular finite elements. In the first simulation the network presented in Figure 5.5 was used. As in the case of the second finite difference simulation, the large dimensions of the mesh elements caused the model to inaccurately portray the water-level response and head distribution in the relatively narrow alluvial aquifer. This model required about 100K words computer space, and was on the limit of being impractical in terms of its size. Refinement of the mesh would only exacerbate this problem. Following this, it was decided to concentrate further simulations on smaller portions of the stream-aquifer system. Figure 5.6 presents the network for the next simulation. Although a significant improvement in the sensitivity of the output was obtained during this simulation, it was soon realized that further refinement of the network would have to be made before realistic answers could be obtained. Seeing that triangular elements have a distinct advantage over rectangular elements, it was decided to utilize the former in future simulations.

The four major zones of ground-water abstraction in the study area each represent ideal targets for simulation. The eventual choice of model area fell upon the central portion of the study area encompassing the well fields on the farms Kromdraai 424 and Rietfontein 497. The refined finite element network constructed for this simulation is shown in Figure 5.7. The elements for this grid span, as completely as practical, the limits of the stream-aquifer system to be modelled. That portion of the simulated area encompassing the alluvial aquifer is spanned by a more detailed grid than the bounding bed-rock aquifer. This follows a basic principle of the finite element approximation, namely that the number and size of triangular elements required depends on the complexity of the simulation and the accuracy demanded. In addition, 32 of the finite element aquifer nodes also serve to define the course of the river channel and orient the routing of stream flow in the modelled area. These nodes are located such that the general course of the channel is approximated by straight-line segments.

5.2.3 PARAMETER IDENTIFICATION

A computer programme was developed to solve the two-dimensional ground-water flow equation (Equation 5.1) for steady or unsteady conditions in a horizontal plane. Recharge from the river is handled by inputting the stream hydrograph at each node along the river. Parameters used in this simulation, and applicable to each of the nodes, are:

Aquifer parameters

> Permeability, saturated thickness, storativity, abstraction, constant head conditions, historic water-level responses and water-levels at the start of the simulation period.

River Parameters

> River width, elevation of floor of river, thickness of river bottom, permeability of river bottom, run-off hydrograph.

Each of these parameters contribute significantly to the response of the system. Many of these are interrelated, and the accuracy to which each of them is known is discussed below:

Formation permeability and storage

> In the total area comprizing the Crocodile River System, only twelve pumping tests have been performed to date. These were done in boreholes drilled into the alluvium. The local permeability and the amount of water contained in the alluvium have been calculated from these tests.

Apart from the alluvium, many other rock types are also present. Neither the permeability nor the storage characteristics of these rocks are known.

Thickness of the aquifers

The thickness of the aquifers is probably the best known parameter. More than 400 boreholes have been drilled into the alluvium along the river. Most of these penetrate the complete thickness of the alluvial aquifer.

Thicknesses which are not known are, for instance, the depth to which the bed rock which bounds and underlies the alluvium is permeable.

Abstraction

In any model, the rate at which water is abstracted from the aquifer has to be known for calibration of the model. None of the more than 200 pumping boreholes in the area have water meters fitted. Abstraction rates and frequencies are therefore not known.

The abstraction rates used in the model had therefore to be inferred from the inventoried borehole yields and scheduling on each of the farms. The situation is presently being rectified with the installation of water meters. Future runs of the model will therefore have significantly higher accuracies.

Historic ground-water levels

Levels of the water table in the alluvium have been measured at several occasions in the past. Contours of the levels have been drawn and the response of the water level during rainy, as well as dry periods, is known to some extent.

Due to a dearth of "bed-rock" boreholes, few water levels could be monitored in the bed rock underlying and surrounding the alluvium. Water levels had to be inferred for these areas. In the alluvium itself, anomalies are also present where boreholes close to each other are observed to have water-level differences of 5-10 metres. Furthermore, pumpage from some of the boreholes could not be stopped for water-level measurements, and although some of the measurements were made in winter, discrepancies in water levels could be the result of abstraction.

River width and floor elevation

Although these two parameters seem easy to measure, it should be realized that the width of the river is different for each level of flow. Also, the bottom of the river is not flat and elevations have to be averaged for modelling purposes.

Thickness of river bottom and permeability

The thickness of the river bottom and the vertical permeability are the two parameters which determine, to a very large extent, the rate of water movement into or out of the alluvium.

No tests have been done to date to measure either of these parameters.

Run-off hydrograph

As indicated above, the parameters which govern stream flow have not been determined for this section of the Crocodile River. It was therefore decided that the run-off hydrograph instead of the more sophisticated stream-flow equation be used for present simulation purposes. In the future, as more information is obtained through weirs for instance, the stream-flow equation, instead of the run-off hydrograph, can be used.

5.2.4 SUMMARY

In all, little is known about the parameters required for modelling of the Crocodile River System. Some researchers may regard this as a disadvantage and that modelling should not be attempted. This is disputed. A model is a tool. It is commonly used by the hydrologist or geohydrologist during the development stage of a water-supply system to provide short-term answers. The Crocodile River Scheme is presently in this stage. A model should be started with the minimum of data and refined as additional information becomes available.

The so-called final management model is obviously what everyone seems to strive for. It was, however, never the purpose of this modelling exercise to construct a final management model. The concept of a final management model is perhaps one of the greatest misconceptions in hydrology. There is no such thing as a final management model. Each and every model can be used for management purposes. It is only the degree of confidence of the predictions which can be questioned.

Equally important to understand is that a specific model can yield answers at different levels of confidence, depending on the type of question put to it. Models are therefore extremely useful tools in the hands of the experienced geohydrologist/modeller.

5.3 RESULTS OF SIMULATIONS

Two typical situations have been simulated to prove the versatility of the model. One of these situations relate to the present circumstances where the river has not flowed for a considerable length of time. The other represents a wet period when the river flows almost constantly.

5.3.1 SIMULATION OF DROUGHT CONDITIONS

Drought conditions, such as that presently occurring in the study area, can easily be handled by the present model. Parameters for the ground-water equation are entered into the model by means of a data file. The computer then prompts the operator to input information about the river by asking relevant questions. Floods during the drought period are accommodated by specifying the number of floods in a simulation period, their duration and the flood hydrograph for each flood. The input of the information can be in hours, days, weeks or months.

Since all computer simulations of this kind are time dependent, the programme is structured in such a way that a continuous update of the water-levels in the aquifers is provided during the whole of the simulation period. If, for instance, the simulation of the ground-water level response is required for 300 days ahead in time, the programme will also calculate and print the water-level response at intermediate times, such as after 1, 3, 7, 15, 31, 63, 127 and 255 as well as at 300 days. A constant scan of the reaction of the system is thus obtained. Also, during floods in the river, the response of the system is calculated at the same time intervals as that used for the input of the flood hydrograph. If, for instance, two floods have to be simulated, the one being a five- and the other a ten-day flood at 100 days and at 150 days after simulation has started, ground-water level responses will be calculated for each day during the duration of the floods.

Results of a trial simulation are presented in Figures 5.8 to 5.18. Parameter values used in the simulations are presented in Appendix A, together with the detailed results. The position of observation and pumping boreholes in the modelled area is indicated in Figure 5.8. The sections A1 - E1 and A2 - E2 indicate the position of the two profiles depicted in Figures 5.9 and 5.10 respectively. These profiles illustrate the time-dependent water-level response in the alluvial aquifer at different distances from the river. The water-level response is greater and more rapid at positions A1 and A2 than at progressively further distances from the river. The contours in the figures represent the response of the ground-water level from the initial levels at the start of the simulation. It was found that presentations of the relative ground-water level response, rather than its elevation in terms of metres above mean sea level, are more meaningful because the rise or decline of the ground-water levels as a result of external influences is more clearly illustrated. However, the computer output can easily be changed to provide elevation contours if desired.

The value of the model and the sensitivity of the system is fully appreciated by comparing the contour diagrams. Some points of interest are:

- A slight drop in the water levels in areas of ground-water abstraction is witnessed up to the first flood at day 100. The magnitude of this drop is in accordance with that observed during the dry months.

- After 100 days, and for the next five days, a theoretical flood of 1 metre is applied over the length of the river in the simulated area. The simulation frequency automatically changes to daily intervals. Contours were drawn for the 100- day and 105-day situations (Figures 5.11 and 5.12 respectively). The significant rise in the ground-water levels beneath the river can be seen.

- After this flood and up to 150 days, there is no water in the river, with the result that the ground-water levels even out. Noticeable are the two ground-water mounds which establish themselves on the opposite side of the river to where abstraction occurs. These mounds can be attributed to the combined effect of the recharge pulse and that of the dewatering cone after the flood has ceased.

- The second flood, lasting 10 days, has a similar but more pronounced effect than the first.

- The final decay of the water passing through the alluvium can be observed after 160 days, up until the end of the simulation at 287 days.

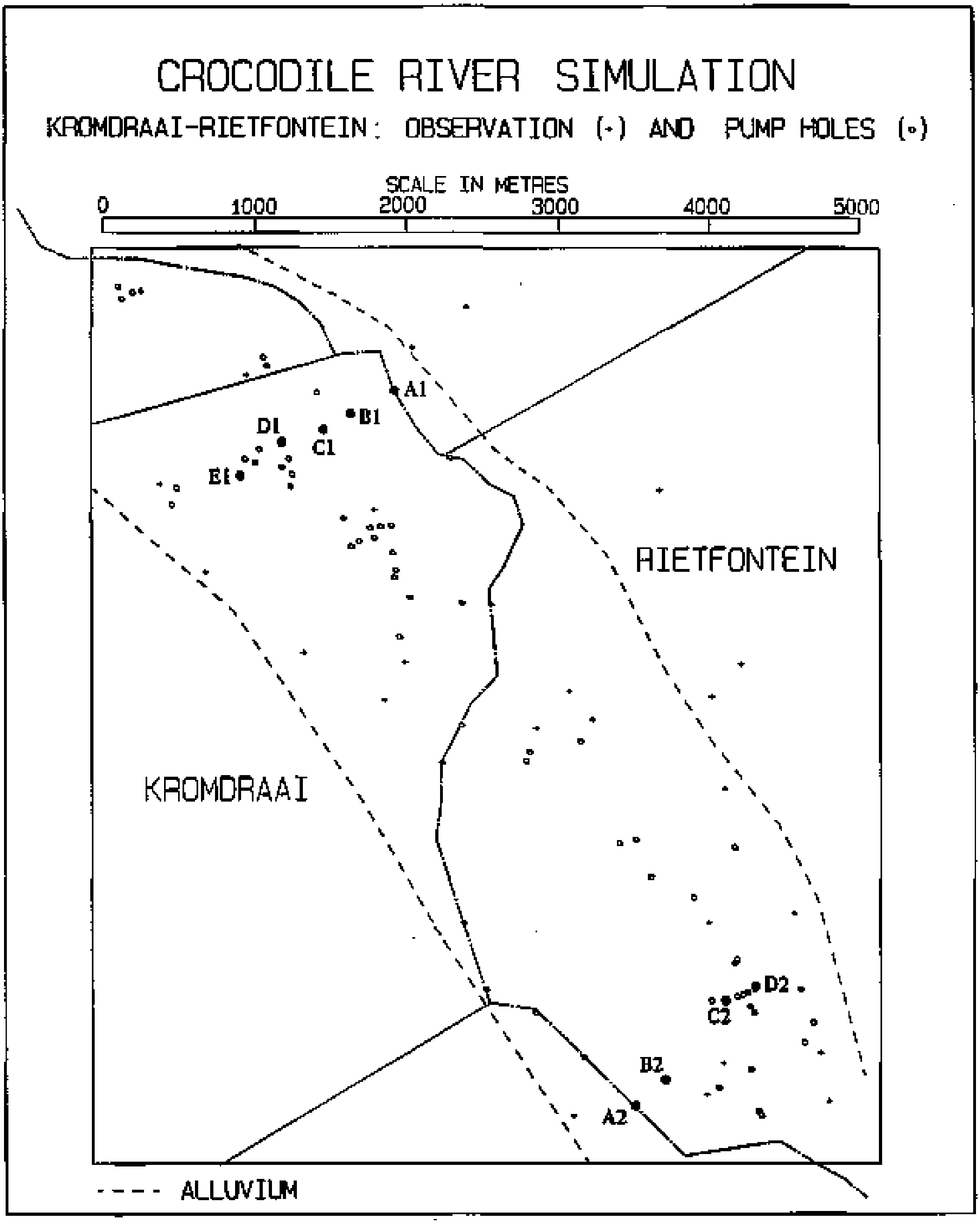

Figure 5.8. Location of the pumping boreholes, observation boreholes and sections 1 (A1 - E1) and 2 (A2 - D2) in the simulated area.

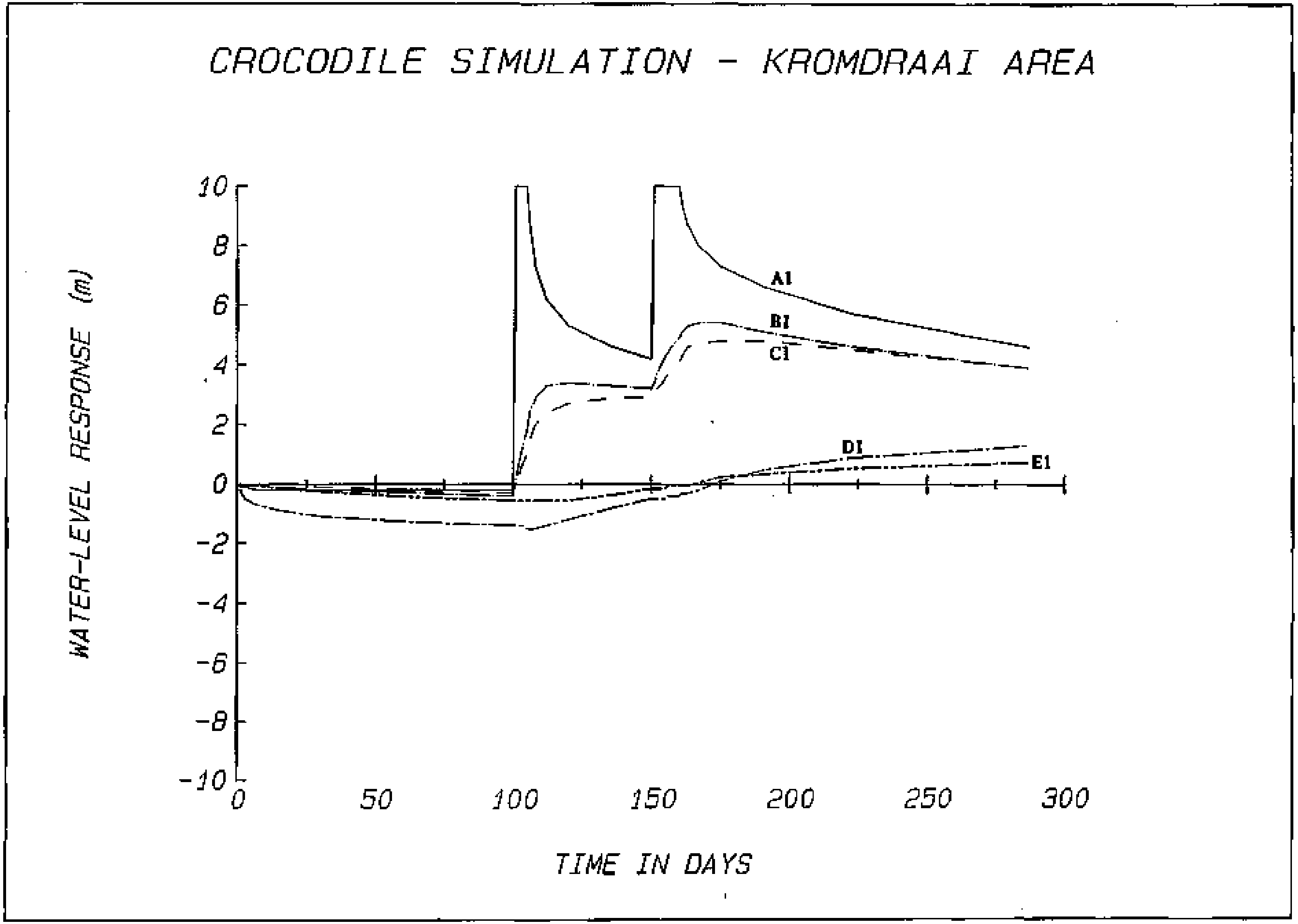

Figure 5.9. Simulated ground-water level response along section 1.

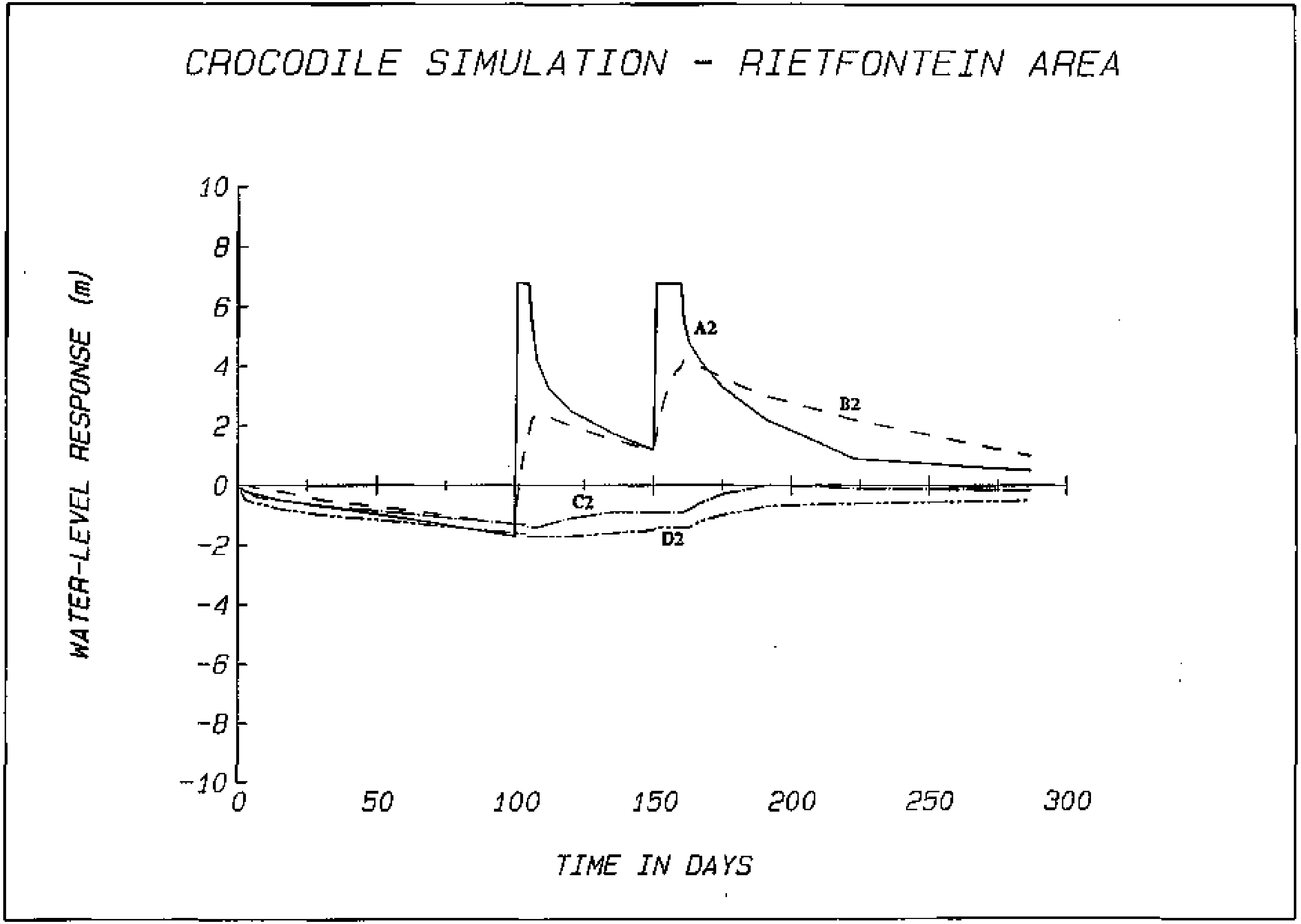

Figure 5.10. Simulated ground-water level response along section 2.

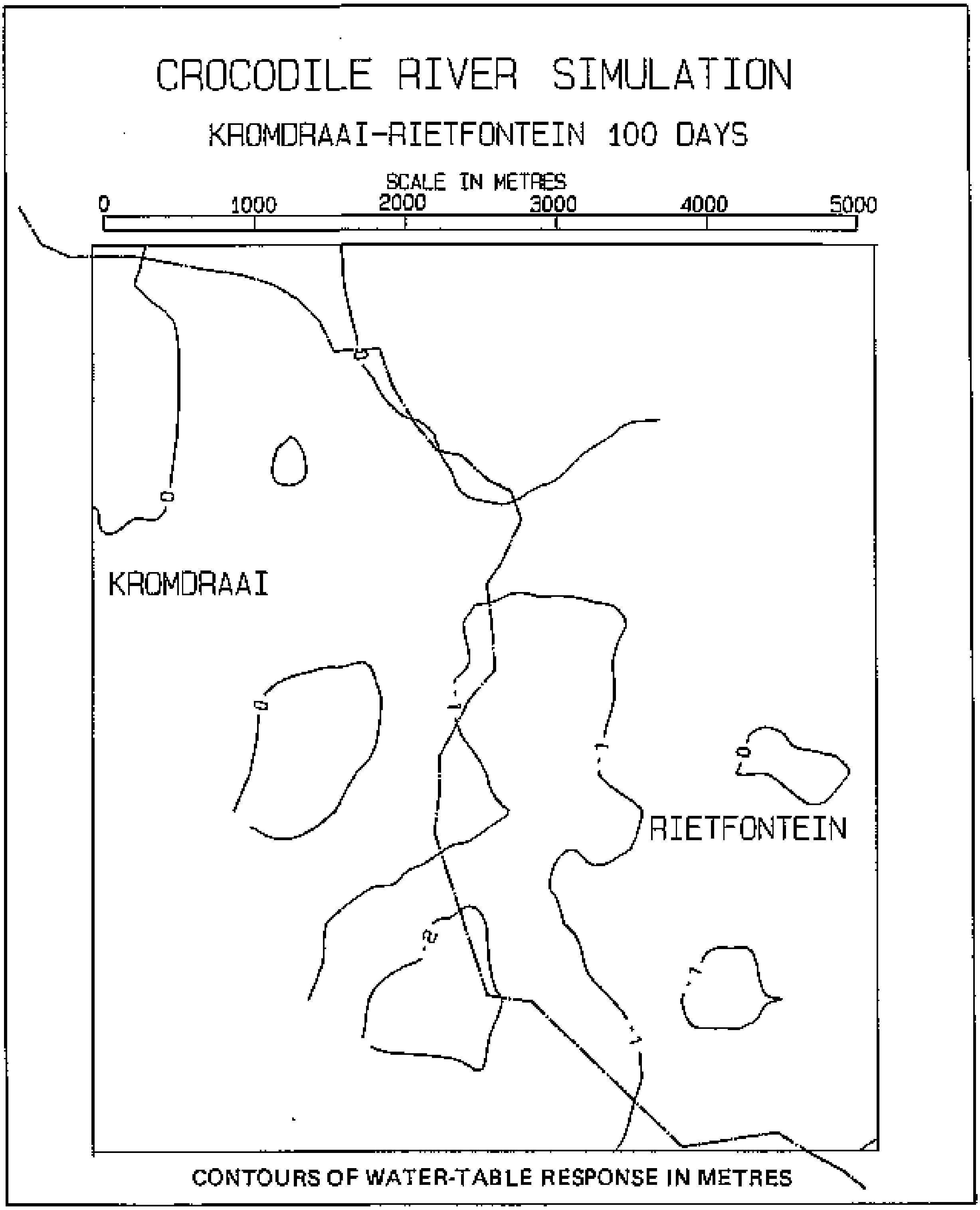

Figure 5.11. **Ground-water level contours in the simulated area at 100 days.**

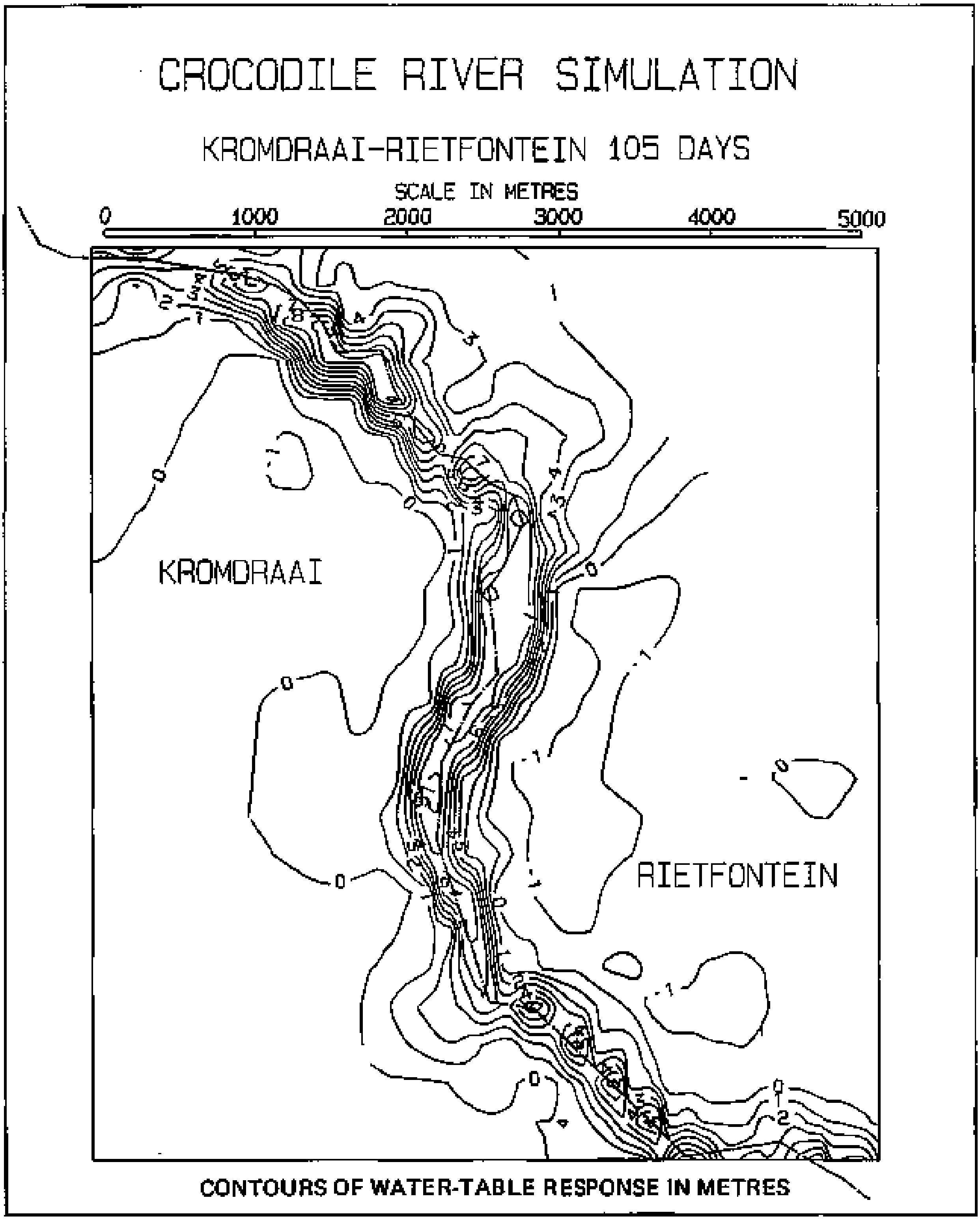

Figure 5.12. Contoured ground-water level response in the simulated area at 105 days.

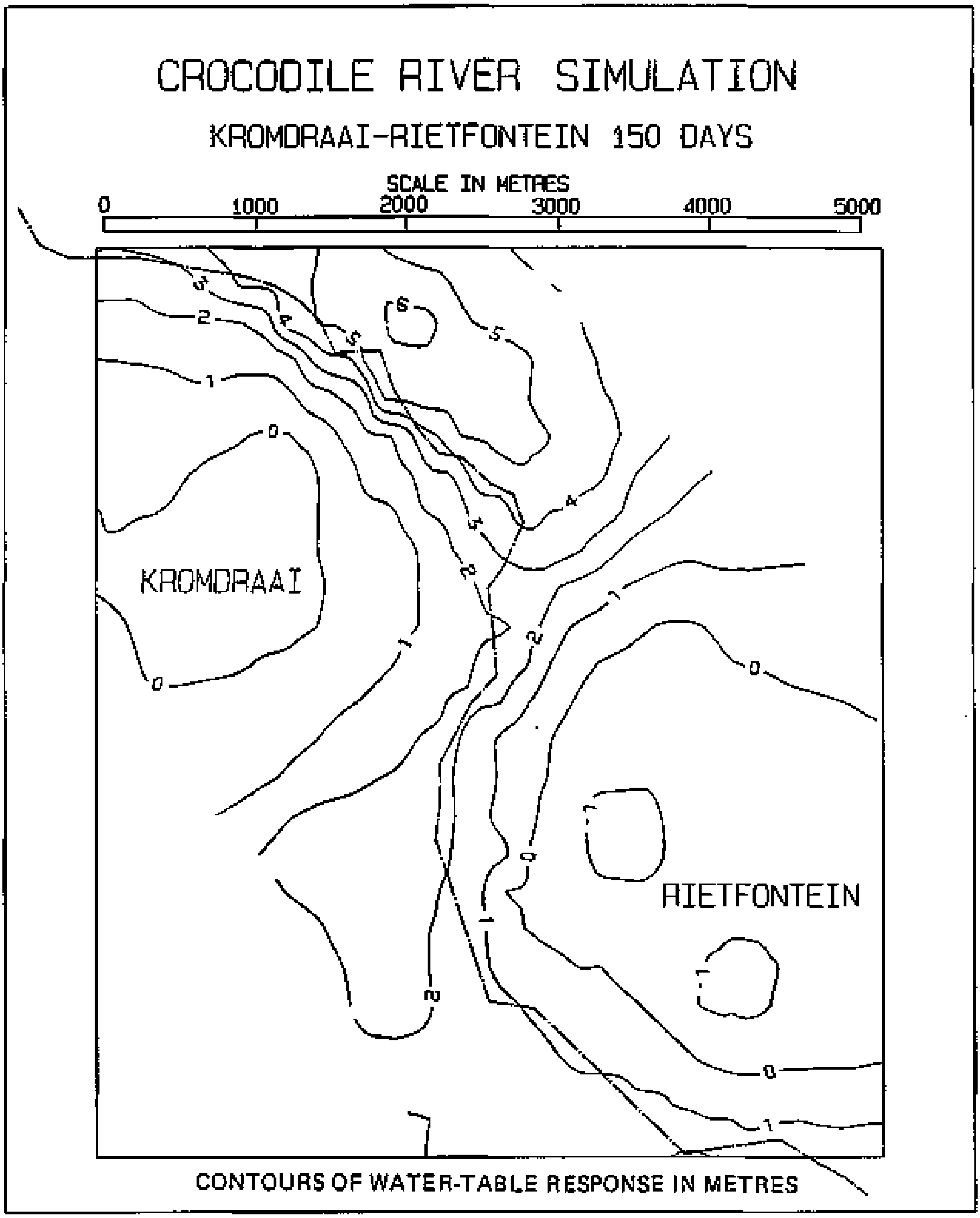

Figure 5.13. Contoured ground-water level response in the simulated area at 150 days.

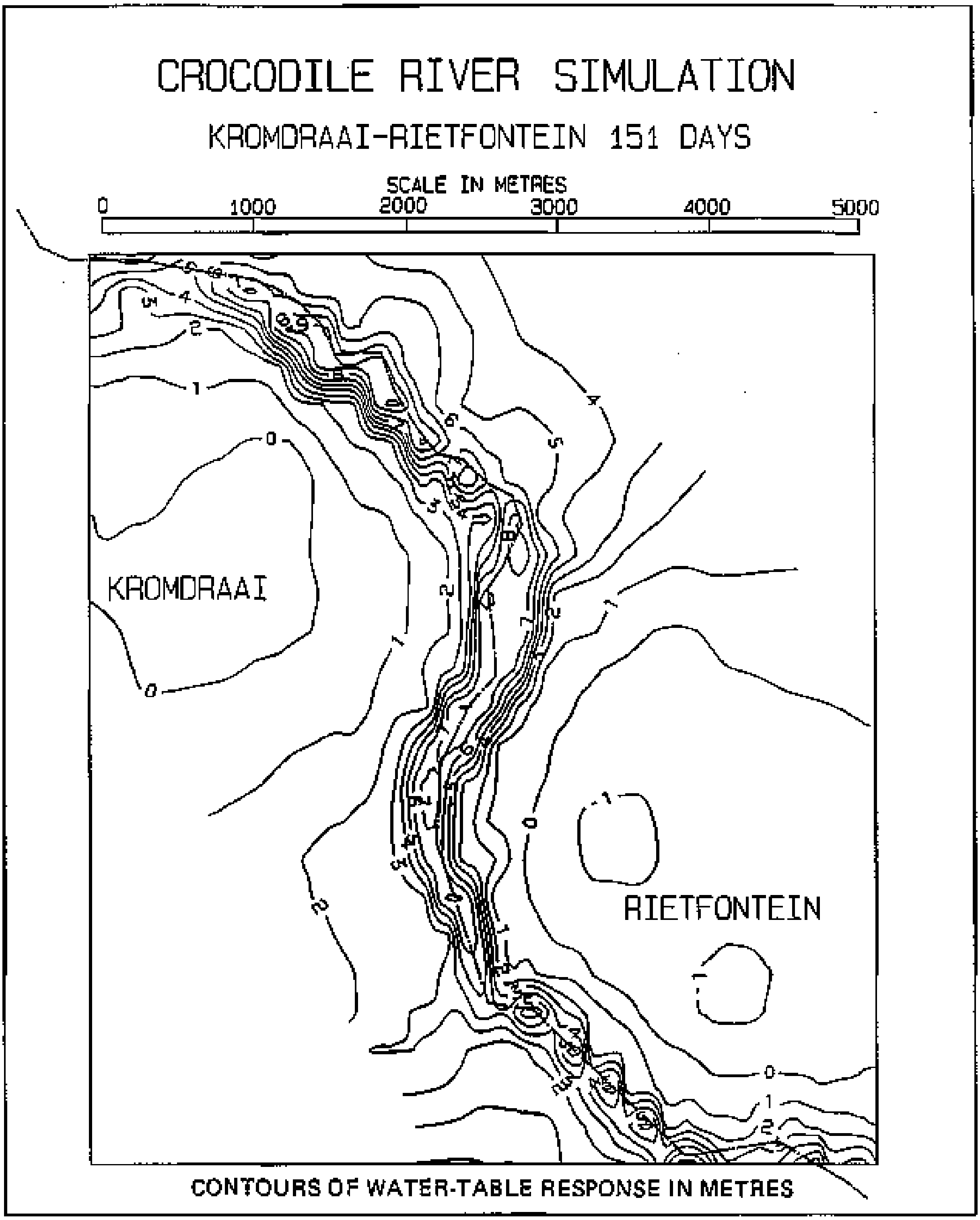

Figure 5.14. Contoured ground-water level response in the simulated area at 151 days.

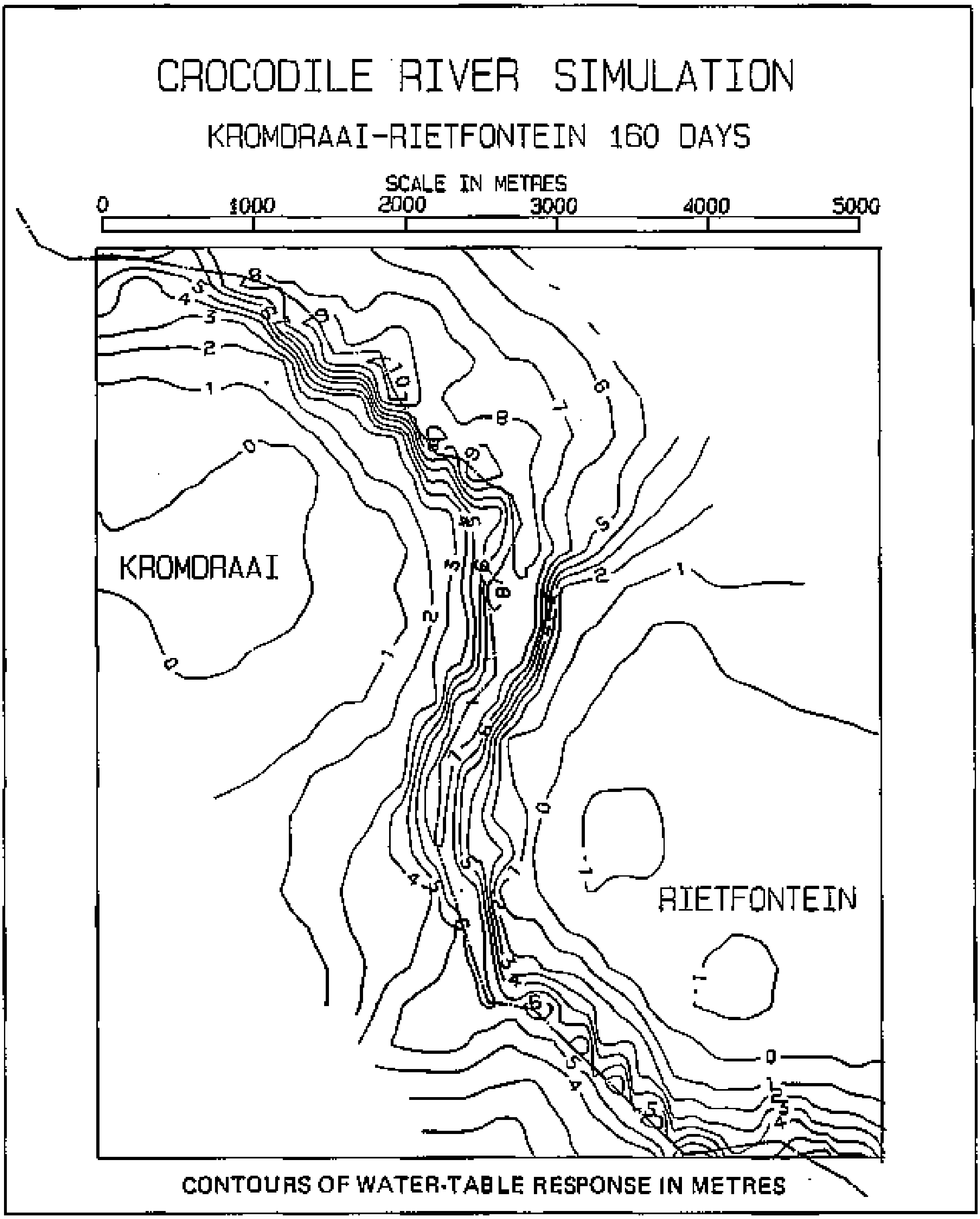

Figure 5.15. Contoured ground-water level response in the simulated area at 160 days.

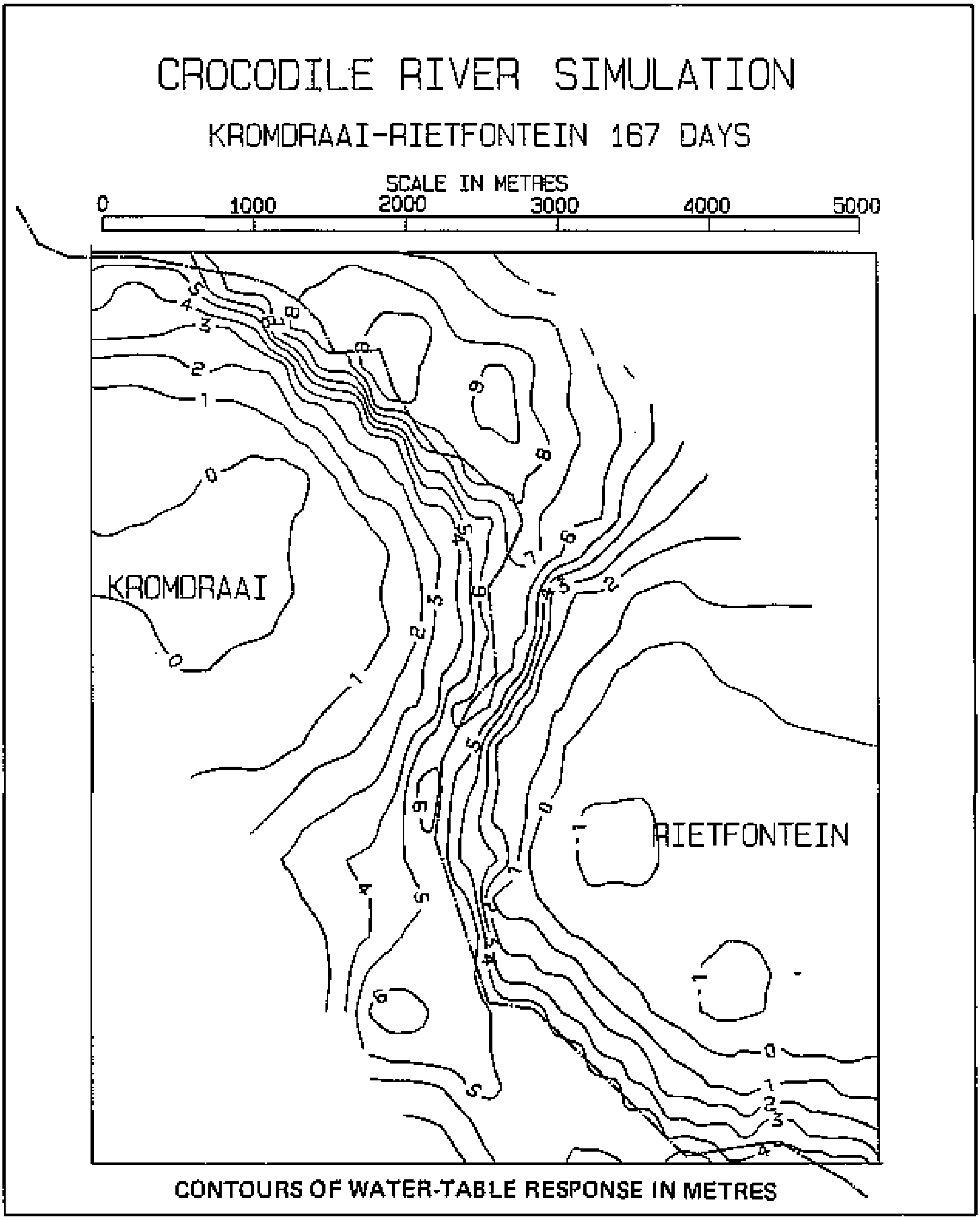

Figure 5.16. Contoured ground-water level response in the simulated area at 167 days.

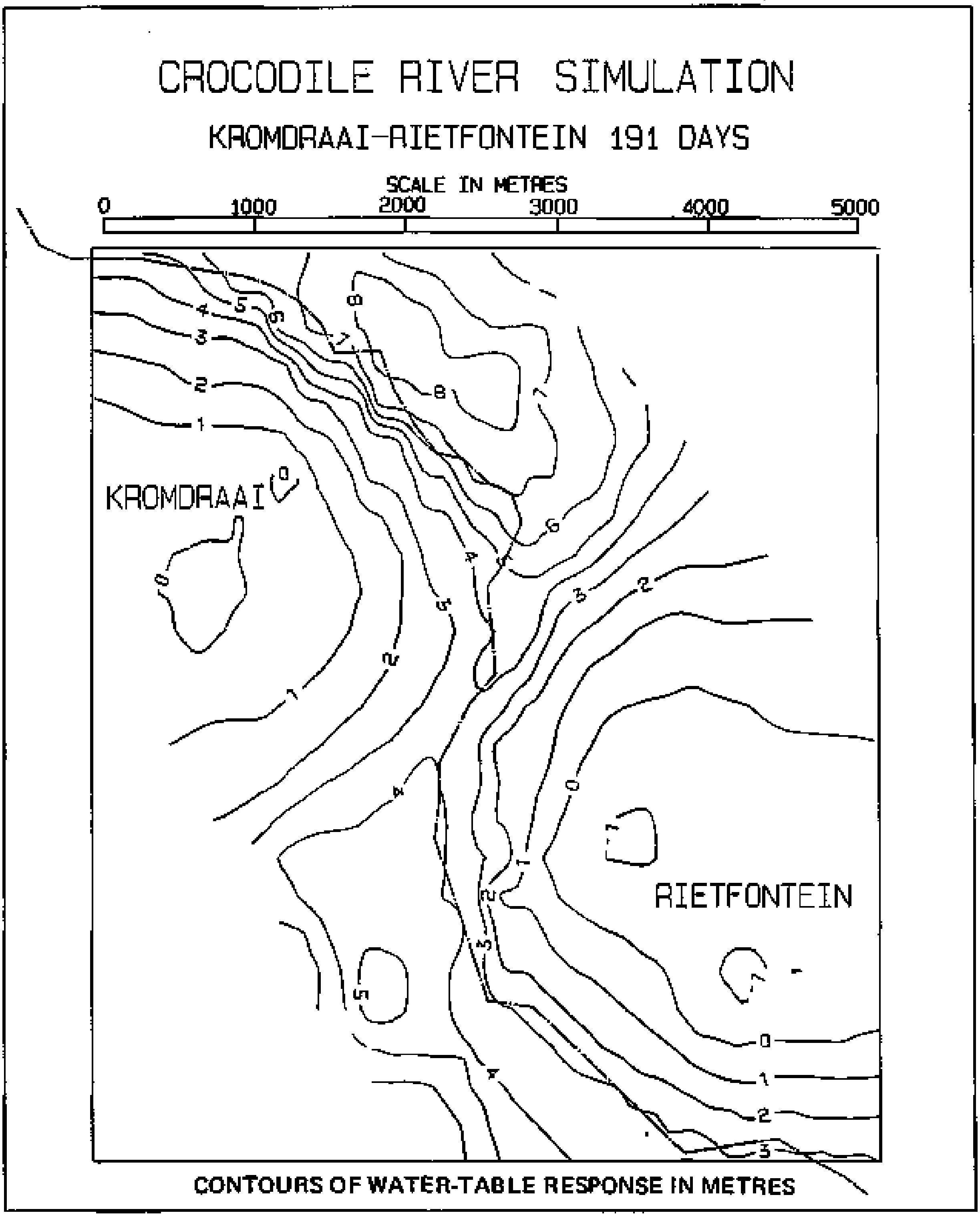

Figure 5.17. Contoured ground-water level response in the simulated area at 191 days.

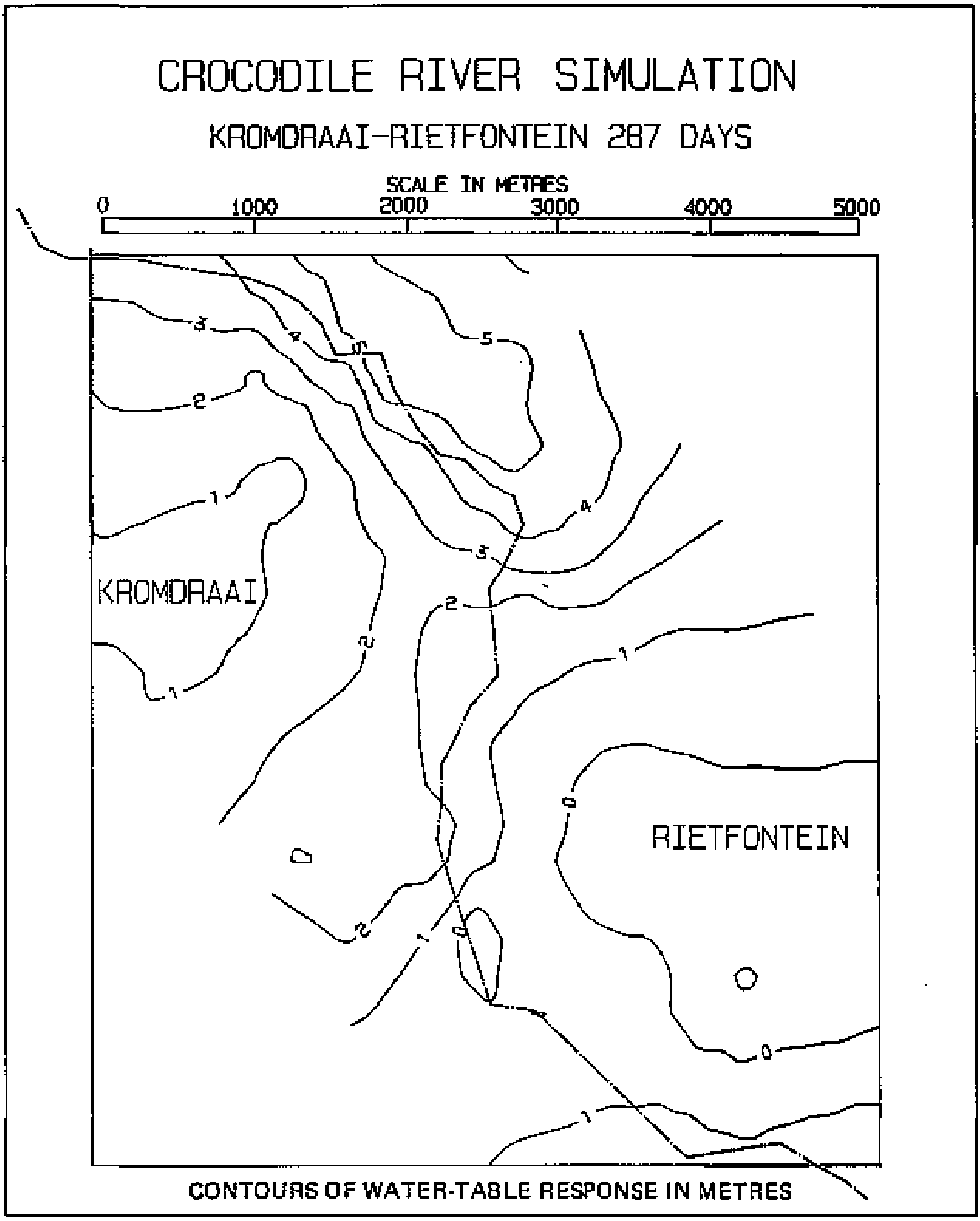

Figure 5.18. Contoured ground-water level response in the simulated area at 287 days.

The model is therefore very versatile. It can be applied along any stretch of the river and accommodate any necessary geometric configuration or parameter values.

The question of whether or not the model should presently be applied to other portions of the study area was considered. It was decided that the parameter values are not better known in any of the other areas along the river, and for that reason application of the model would be of no additional use. The type of questions which need to be answered from the present exercise can equally well be answered by modelling the present area and by changing the parameter values to obtain a sensitivity analysis.

5.3.2 SIMULATION OF LONG-TERM RECHARGE CONDITIONS

During 1978, for instance, the river flowed at a more or less constant level of 0.5 metres for months on end. This situation can easily be handled by the model by simply specifying the flood hydrograph for this period at say weekly intervals. The results of such a simulation are diagrammatically presented in Figures 5.19 to 5.22.

The most significant feature illustrated by this simulation is that after drought conditions, as is presently the case, it could take up to three years of continuous flow in the river before the system approaches equilibrium conditions. The rate of recharge is mainly a function of the thickness of the river bed and its permeability. These values have not yet been determined. The present simulation should therefore be regarded as a first indication of what could happen. Tests to determine flow through the river bed at various localities should be done before further models are run.

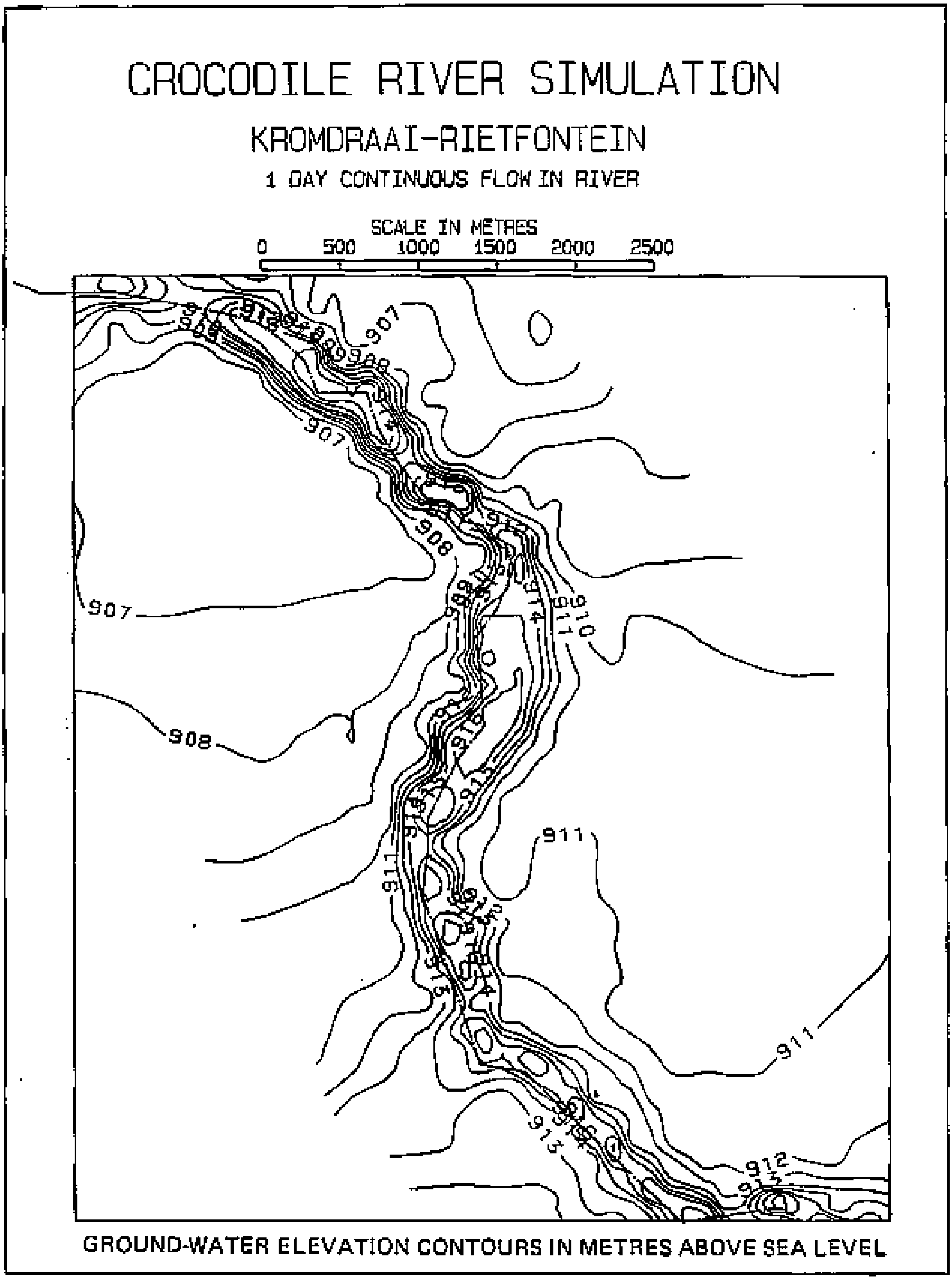

Figure 5.19. Contoured ground-water level response in the simulated area after 1 day of continuous flow in the river.

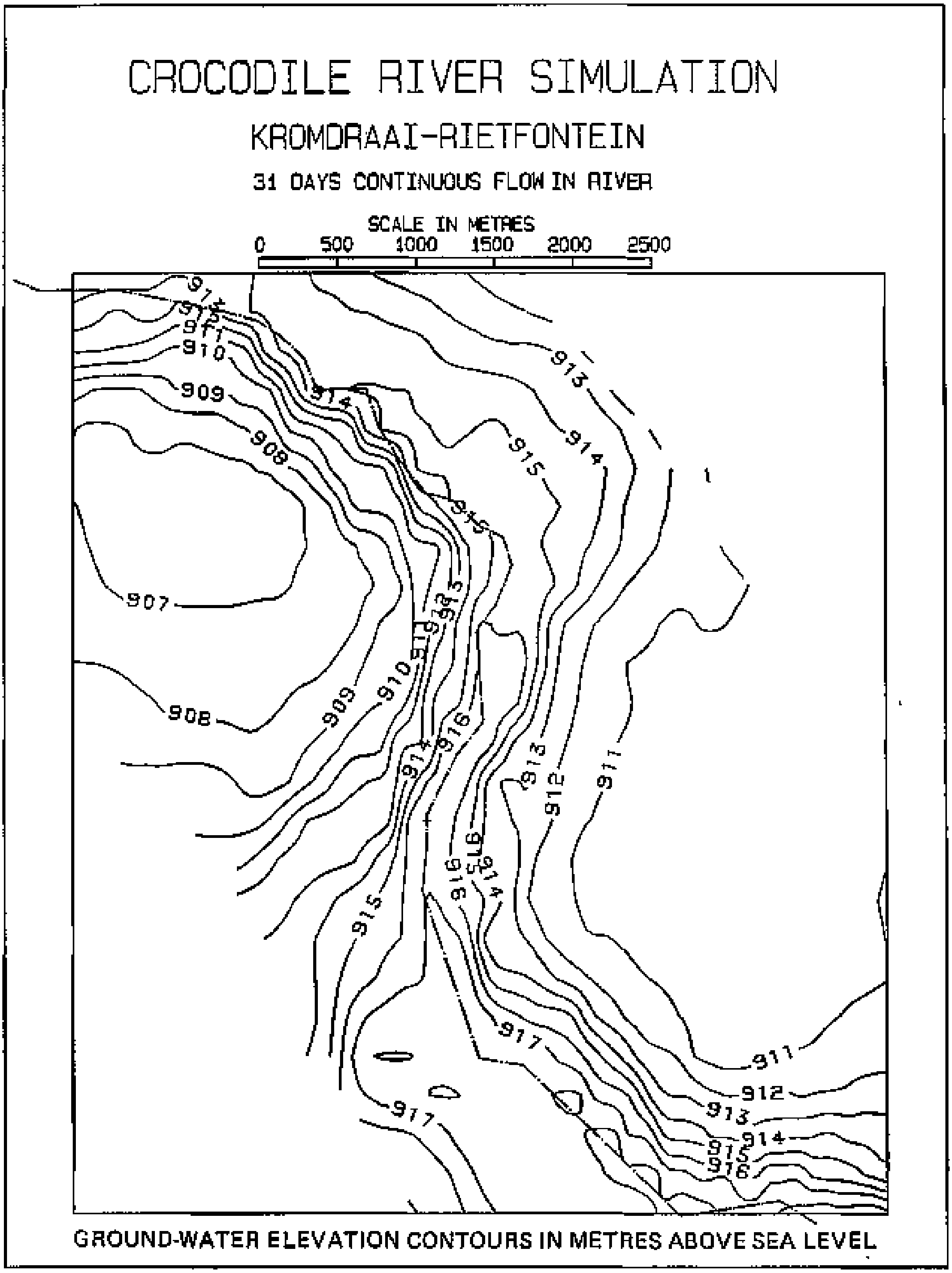

Figure 5.20. Contoured ground-water level response in the simulated area after 31 days of continuous flow in the river.

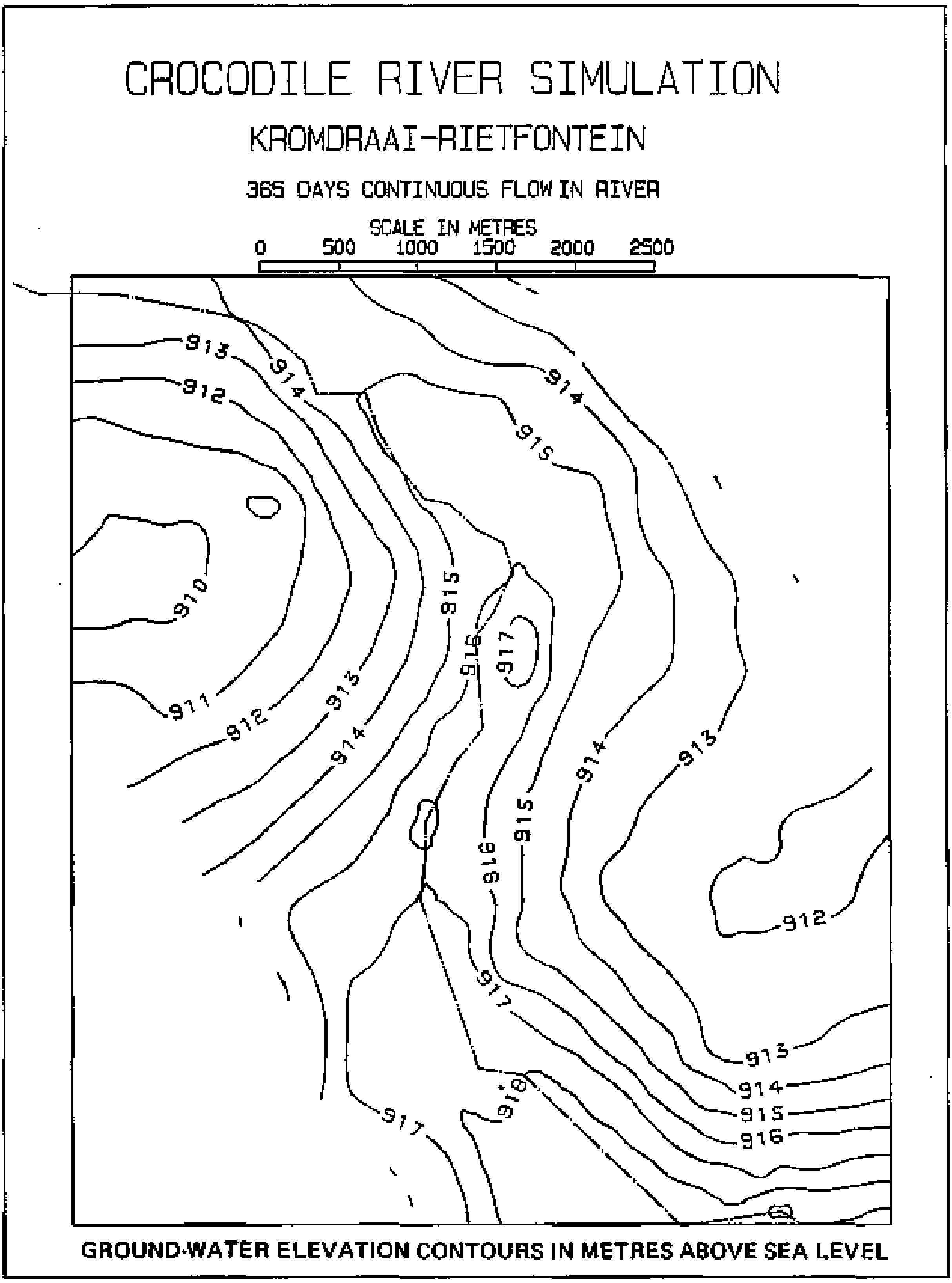

Figure 5.21. **Contoured ground-water level response in the simulated area after 365 days of continuous flow in the river.**

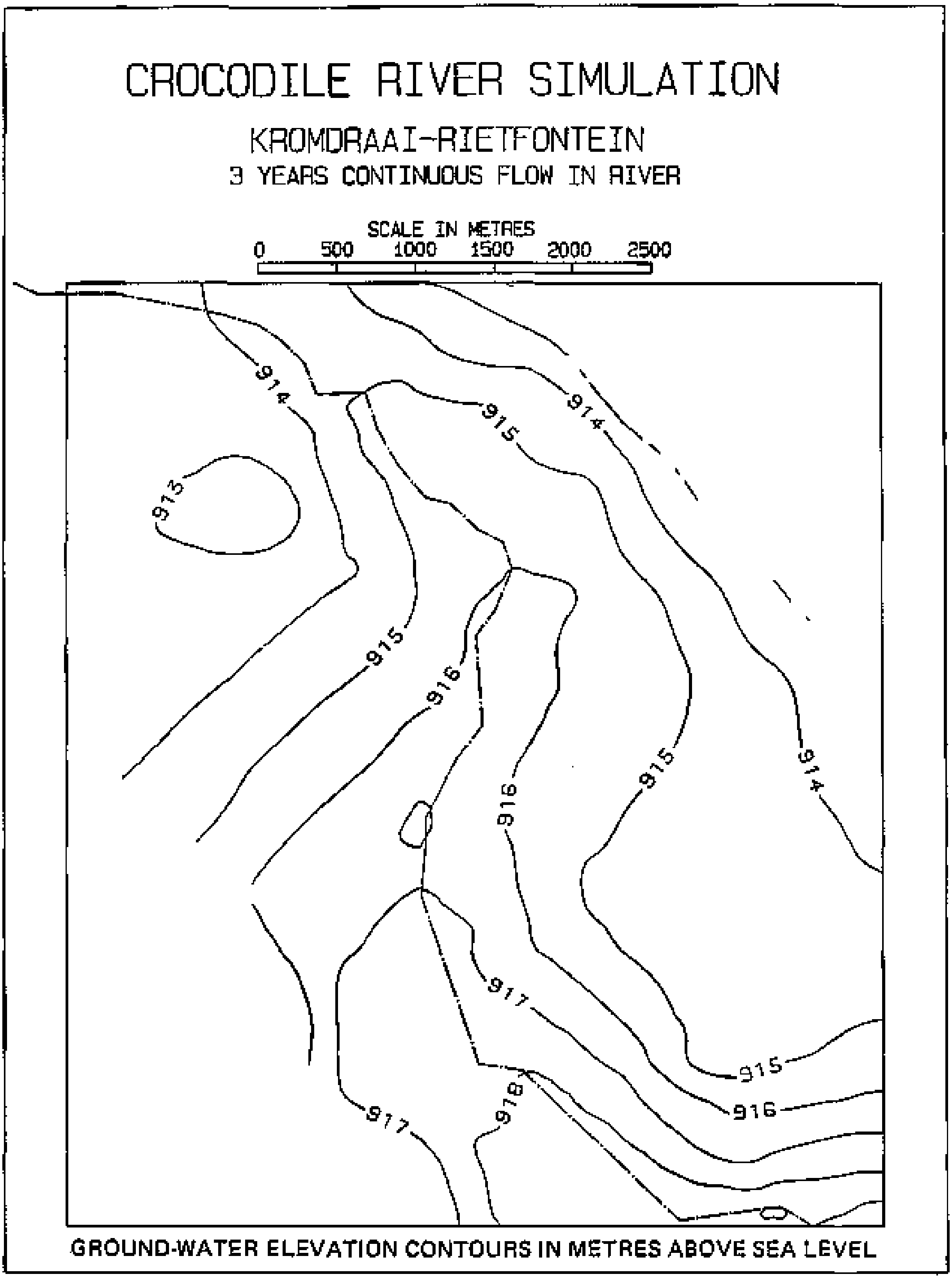

Figure 5.22. Contoured ground-water level response in the simulated area after 3 years of continuous flow in the river.

CHAPTER 6

CONCLUSIONS

It is the first time that a conjunctive stream/ground-water system has been modelled in South Africa.

Two main conclusions can be drawn from the modelling exercise:

- Modelling of conjunctive surface/ground-water systems can be done successfully by using triangular finite elements.
- Although the data presently available for modelling of the Crocodile Stream-River System on a management level is completely inadequate, much has been learnt about the respective contribution of the various parameters required as input to the model. It is now necessary that field staff generate data where and when required. The model should be updated as new information is obtained, thereby identifying further information requirements. Refinements to the theoretical facet of the model will not be required within the near future.

With regard to the latter conclusion, the parameters which should be investigated before meaningful further simulations can be made are, in order of importance:

- permeability of the river bottom. This can be tested in a number of ways, such as gauging losses from the river between weirs, or infiltration tests in the dry portions of the river;
- more accurate abstraction values from boreholes. Presently many of the boreholes are being equipped with water meters. It is essential for future modelling that an accurate record of abstraction be kept;
- ground-water level responses. These have been measured in the past. Continuous recorders should be installed along several sections perpendicular to the river. This will allow the effect of recharge from the river to be monitored. Three lines of recorders, consisting of four recorders in each line, are suggested.

The conjunctive stream-aquifer model for the Crocodile River Valley is universally applicable. It can be applied to other stream-aquifer systems. It is important that it be applied during the initial stages of any ground-water investigation. Even more important is the continuous updating of the model as more information becomes available. Each run of the model will indicate which parameters still require measurement in the field, and to what accuracy they are required. After several years of model refinement and validation, the stage will be reached where it will be able to predict the response of the system within specific bounds of accuracy.

It is rather unfortunate that data have been gathered for many years on the Crocodile Stream-River System without the aid of a model. The latter would certainly have assisted in gathering of meaningful data and in the interpretation thereof.

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Appendix A

EXAMPLE OF GEOHYDROLOGICAL DATA AND SIMULATED RESULTS:

THE EFFECT WHICH CONTINUOUS FLOW IN THE CROCODILE RIVER HAS ON GROUND-WATER LEVELS

INFORMATION USED FOR MODELLING OF CONTINUOUS FLOW IN RIVER

NODE	X-COORD (m)	Y-COORD (m)	PERMEABILITY (m/day)	STORAGE	PUMPAGE (m3/day)	NODE TYPE
1	5635.70	21625.50	1.0000	.0001	.0000	C
2	7985.20	22664.30	1.0000	.0001	.0000	C
3	9349.50	23201.60	1.0000	.0001	.0000	C
4	9724.60	23408.60	10.0000	.1000	.0000	C
5	10086.70	23602.60	10.0000	.1000	.0000	C
6	10358.20	23710.00	10.0000	.1000	.0000	C
7	10549.70	23822.40	1.0000	.0001	.0000	C
8	10996.70	23989.80	1.0000	.0001	.0000	C
9	14527.70	25657.70	1.0000	.0001	.0000	C
10	8274.00	22125.60	1.0000	.0001	.0000	
11	9039.00	22542.00	1.0000	.0001	.0000	
12	9659.90	22283.30	1.0000	.0001	.0000	
13	10164.30	22360.90	10.0000	.1000	.0000	
14	10461.80	22438.50	10.0000	.1000	.0000	C
15	10703.40	23447.20	9.9000	.1000	.0000	
16	10875.10	23521.50	1.0000	.0001	.0000	
17	11106.20	22445.10	10.0000	.1000	.0000	
18	11280.70	22477.90	1.0000	.0001	.0000	
19	11416.30	23187.00	1.0000	.0001	.0000	
20	12550.20	23886.40	1.0000	.0001	.0000	
21	12286.00	22664.10	1.0000	.0001	.0000	
22	15198.00	24181.60	1.0000	.0001	.0000	C
23	6230.30	19910.30	1.0000	.0001	.0000	C
24	9000.20	20692.30	1.0000	.0001	.0000	
25	9241.80	21608.70	1.0000	.0001	.0000	
26	10035.00	21313.20	1.0000	.0001	.0000	
27	10361.50	21451.00	10.0000	.1000	.0000	
28	10759.60	21612.00	10.0000	.1000	.0000	C
29	11398.10	21885.60	9.9000	.1000	.0000	
30	11434.60	21982.90	1.0000	.0001	.0000	
31	11593.90	22231.50	1.0000	.0001	.0000	
32	10319.50	20563.00	1.0000	.0001	.0000	
33	10694.60	20744.10	10.0000	.1000	.0000	
34	11380.20	21364.90	10.0000	.1000	.0000	
35	11393.10	21559.00	10.0000	.1000	.0000	C
36	11509.50	20718.20	9.9000	.1000	.0000	
37	11912.70	21051.20	10.0000	.1000	.0000	
38	12169.10	21416.70	10.0000	.1000	.0000	C
39	12182.10	21520.10	9.9000	.1000	.0000	
40	12231.30	21605.90	1.0000	.0001	.0000	
41	12454.90	21218.80	10.0000	.1000	.0000	C
42	12545.20	21332.40	9.9000	.1000	.0000	
43	12611.80	21409.20	1.0000	.0001	.0000	
44	13198.20	21563.30	1.0000	.0001	.0000	
45	14009.20	22125.60	1.0000	.0001	.0000	
46	16189.90	23068.30	1.0000	.0001	.0000	C
47	6787.10	18594.50	1.0000	.0001	.0000	C
48	9530.50	19373.00	1.0000	.0001	.0000	
49	12066.80	20067.60	10.0000	.1000	.0000	
50	10875.70	19981.00	1.0000	.0001	.0000	
51	11121.50	20123.20	10.0000	.1000	.0000	
52	11640.70	20289.70	10.0000	.1000	.0000	
53	11912.70	20507.30	10.0000	.1000	.0000	
54	12081.90	20792.00	10.0000	.1000	.0000	
55	12279.90	20652.30	10.0000	.1000	.0000	
56	12194.90	20907.80	10.0000	.1000	-468.0000	
57	12548.20	20678.40	10.0000	.1000	-450.0000	
58	12696.70	20906.00	10.0000	.1000	.0000	C

59	12622.00	21107.10	9.9000	.1000	.0000	C
60	12816.50	21122.50	9.9000	.1000	.0000	
61	12898.40	21224.90	1.0000	.0001	.0000	
62	12996.50	20926.30	10.0000	.1000	.0000	C
63	13046.90	20999.60	9.9000	.1000	.0000	
64	13118.60	21055.90	1.0000	.0001	.0000	
65	13533.20	21240.20	1.0000	.0001	.0000	
66	11270.80	19735.20	1.0000	.0001	.0000	
67	11545.80	19460.30	1.0000	.0001	.0000	
68	11359.70	19845.40	10.0000	.1000	.0000	
69	11515.40	20074.60	10.0000	.1000	.0000	
70	11595.30	19937.00	10.0000	.1000	.0000	
71	11623.80	20049.70	10.0000	.1000	.0000	
72	11695.10	19668.70	10.0000	.1000	.0000	
73	11811.30	19479.20	10.0000	.1000	.0000	
74	11976.20	19519.10	10.0000	.1000	.0000	
75	11953.50	19831.80	10.0000	.1000	.0000	
76	11871.90	20158.20	10.0000	.1000	.0000	
77	10525.00	19753.40	1.0000	.0001	.0000	
78	12070.90	20237.50	10.0000	.1000	-53.0000	
79	12140.50	20214.10	10.0000	.1000	-53.0000	
80	12167.70	20303.00	10.0000	.1000	-26.0000	
81	12225.50	19863.60	10.0000	.1000	.0000	
82	12239.10	20094.80	10.0000	.1000	.0000	
83	12370.40	20056.00	10.0000	.1000	.0000	
84	12316.10	20184.30	10.0000	.1000	-353.0000	
85	12311.60	20349.00	10.0000	.1000	.0000	
86	12383.20	20134.60	10.0000	.1000	-353.0000	
87	12359.30	20239.60	10.0000	.1000	-353.0000	
88	12465.70	20457.40	10.0000	.1000	.0000	
89	12619.90	20276.10	10.0000	.1000	.0000	
90	12769.90	20546.80	10.0000	.1000	.0000	
91	13078.80	20682.00	10.0000	.1000	.0000	C
92	13231.20	20794.90	9.9000	.1000	.0000	
93	13308.00	20846.10	1.0000	.0001	.0000	
94	13584.40	20533.80	1.0000	.0001	.0000	
95	14162.80	20605.50	1.0000	.0001	.0000	
96	14897.90	21085.90	1.0000	.0001	.0000	
97	16810.40	22447.20	1.0000	.0001	.0000	C
98	7202.00	17521.60	1.0000	.0001	.0000	C
99	9874.80	18626.90	1.0000	.0001	.0000	
100	11356.20	18995.70	1.0000	.0001	.0000	
101	11725.90	19365.40	1.0000	.0001	.0000	
102	11962.90	19147.40	1.0000	.0001	.0000	
103	12048.70	19265.20	10.0000	.1000	.0000	
104	12209.40	18834.50	1.0000	.0001	.0000	
105	12474.80	18789.30	10.0000	.1000	.0000	
106	12455.90	18968.50	10.0000	.1000	.0000	
107	12429.50	19179.10	10.0000	.1000	.0000	
108	12225.50	19514.50	10.0000	.1000	.0000	
109	12551.90	19623.30	10.0000	.1000	.0000	
110	12483.90	19850.00	10.0000	.1000	.0000	
111	12619.90	20054.00	10.0000	.1000	.0000	
112	12726.30	19846.60	10.0000	.1000	.0000	
113	12678.80	19446.50	10.0000	.1000	.0000	
114	12775.90	19664.80	10.0000	.1000	.0000	
115	12828.30	19696.90	10.0000	.1000	.0000	
116	12900.90	19528.10	10.0000	.1000	.0000	
117	12928.20	19720.10	10.0000	.1000	-129.0000	
118	12903.90	19786.80	10.0000	.1000	.0000	
119	12970.80	19795.30	10.0000	.1000	-129.0000	
120	12924.70	19908.10	10.0000	.1000	.0000	
121	13038.10	19799.70	10.0000	.1000	-129.0000	
122	12964.40	20276.10	10.0000	.1000	.0000	
123	13145.70	20022.20	10.0000	.1000	.0000	
124	13385.90	20085.70	10.0000	.1000	.0000	

125	13395.00	20247.50	10.0000	.1000	-362.0000	C
126	13512.70	20441.70	9.9000	.1000	.0000	
127	10208.80	17763.80	1.0000	.0001	.0000	
128	13666.30	20298.30	9.9000	.1000	.0000	
129	13732.80	20349.50	1.0000	.0001	.0000	
130	12801.20	19201.80	10.0000	.1000	.0000	
131	13161.80	19327.10	10.0000	.1000	.0000	
132	13114.00	19573.50	10.0000	.1000	-189.0000	
133	13390.50	19491.90	10.0000	.1000	.0000	
134	13345.10	19791.00	10.0000	.1000	.0000	
135	13721.40	19845.40	10.0000	.1000	.0000	
136	13862.80	19989.60	10.0000	.1000	.0000	C
137	13891.50	20088.50	10.0000	.1000	.0000	
138	13988.80	20149.90	9.9000	.0001	.0000	
139	13922.20	19801.80	10.0000	.1000	.0000	C
140	14116.80	19847.90	9.9000	.1000	.0000	
141	14270.30	19929.80	1.0000	.0001	.0000	
142	14807.20	20056.50	1.0000	.0001	.0000	
143	15514.20	20446.10	1.0000	.0001	.0000	
144	17364.00	21853.70	1.0000	.0001	.0000	C
145	7760.00	16307.50	1.0000	.0001	.0000	C
146	13550.10	20241.20	10.0000	.1000	.0000	C
147	11953.50	18436.30	1.0000	.0001	.0000	
148	12370.60	18559.60	1.0000	.0001	.0000	
149	12656.10	18567.10	10.0000	.1000	.0000	
150	12719.60	18821.00	10.0000	.1000	.0000	
151	13093.60	19067.10	10.0000	.1000	.0000	
152	12835.20	18009.70	1.0000	.0001	.0000	
153	12978.00	18268.00	10.0000	.1000	.0000	
154	12993.80	18649.70	10.0000	.1000	.0000	
155	13249.90	18598.90	10.0000	.1000	.0000	
156	13419.90	18226.60	10.0000	.1000	-305.0000	C
157	13564.40	18595.90	9.9000	.1000	-191.0000	C
158	13531.00	19006.80	9.9000	.1000	.0000	
15	13501.60	19291.00	10.0000	.1000	-317.0000	
160	13738.30	18825.20	10.0000	.1000	.0000	C
161	13717.10	19206.20	9.9000	.1000	-367.0000	C
162	13603.50	19410.30	9.9000	.1000	.0000	
163	13697.80	19399.90	10.0000	.1000	.0000	C
164	14372.70	19269.40	9.9000	.1000	.0000	
165	14710.60	19382.00	1.0000	.0001	.0000	
166	13914.90	18250.80	10.0000	.1000	-306.0000	
167	13992.40	18467.30	10.0000	.1000	.0000	
168	14203.00	18708.00	10.0000	.1000	.0000	
169	14655.20	18830.10	10.0000	.1000	.0000	
170	14900.00	18921.30	1.0000	.0001	.0000	
171	15335.10	18880.40	1.0000	.0001	.0000	
172	15317.20	19425.70	1.0000	.0001	.0000	
173	16038.30	19928.80	1.0000	.0001	.0000	
174	17901.90	21082.80	1.0000	.0001	.0000	C
175	8295.10	15072.20	1.0000	.0001	.0000	C
176	10825.50	16388.00	1.0000	.0001	.0000	
177	12278.00	16935.30	1.0000	.0001	.0000	
178	12967.90	17639.90	1.0000	.0001	.0000	
179	13053.20	17327.10	1.0000	.0001	.0000	
180	13309.20	17042.70	1.0000	.0001	.0000	
181	13423.00	17118.50	10.0000	.1000	.0000	
182	13223.90	17355.50	10.0000	.1000	.0000	
183	13110.10	17715.80	10.0000	.1000	.0000	
184	13379.60	17755.70	10.0000	.1000	.0000	C
185	13560.70	18041.50	9.9000	.1000	.0000	
186	13555.50	17195.40	10.0000	.1000	-543.0000	C
187	13472.20	17454.30	9.9000	.1000	.0000	C
188	13576.80	17715.30	9.9000	.1000	.0000	
189	13794.20	17952.90	10.0000	.1000	.0000	
190	13816.30	17286.50	10.0000	.1000	.0000	

191	14230.10	17610.70	10.0000	.1000	.0000	
192	14147.50	17950.70	10.0000	.1000	.0000	
193	14538.80	17707.40	10.0000	.1000	-271.0000	
194	14550.80	18077.70	10.0000	.1000	.0000	
195	14281.00	18381.00	10.0000	.1000	.0000	
196	14361.10	18521.60	10.0000	.1000	-153.0000	
197	14641.60	18385.80	10.0000	.1000	.0000	
198	14872.80	18516.40	10.0000	.1000	.0000	
199	15145.70	18670.50	1.0000	.0001	.0000	
200	14651.40	17723.50	10.0000	.1000	-271.0000	
201	14993.60	17864.40	10.0000	.1000	.0000	
202	14966.50	18220.00	10.0000	.1000	.0000	
203	15240.30	18072.60	10.0000	.1000	.0000	
204	15304.40	18414.60	1.0000	.0001	.0000	
205	15585.90	17953.90	1.0000	.0001	.0000	
206	15853.80	18687.80	1.0000	.0001	.0000	
207	16628.50	19104.50	1.0000	.0001	.0000	
208	18416.70	20295.00	1.0000	.0001	.0000	C
209	9283.50	13692.40	1.0000	.0001	.0000	C
210	1919.50	14973.40	1.0000	.0001	.0000	
211	13283.60	15894.00	1.0000	.0001	.0000	
212	13546.20	16701.30	1.0000	.0001	.0000	
213	13814.20	16362.70	1.0000	.0001	.0000	
214	14074.70	16133.90	1.0000	.0001	.0000	
215	13660.00	16758.20	10.0000	.1000	-345.0000	C
216	13885.40	16489.40	9.9000	.1000	.0000	
217	14143.50	16227.30	10.0000	.1000	.0000	
218	13870.60	16926.60	10.0000	.1000	.0000	
219	14120.40	16803.30	10.0000	.1000	.0000	
220	13996.70	16614.40	10.0000	.1000	-284.0000	C
221	14304.70	16341.10	9.9000	.1000	-268.0000	C
222	14422.80	16427.80	9.9000	.1000	.0000	
223	14525.80	16806.60	10.0000	.1000	.0000	
224	14279.90	17228.60	10.0000	.1000	.0000	
225	14562.90	17538.40	10.0000	.1000	.0000	
226	14572.40	17225.30	10.0000	.1000	.0000	
227	14801.60	17168.80	10.0000	.1000	.0000	
228	14748.50	17477.80	10.0000	.1000	-172.0000	
229	14981.50	17582.60	10.0000	.1000	.0000	
230	15034.30	17358.20	10.0000	.1000	-172.0000	
231	15295.40	17687.30	10.0000	.1000	-172.0000	
232	15130.60	17192.00	10.0000	.1000	.0000	
233	15383.20	17374.80	10.0000	.1000	.0000	
234	15514.20	17667.20	10.0000	.1000	.0000	
235	14921.30	16500.90	10.0000	.1000	.0000	
236	14991.00	16839.60	10.0000	.1000	.0000	
237	15120.60	17012.60	10.0000	.1000	.0000	
238	15446.30	17105.60	10.0000	.1000	.0000	
239	15697.20	17249.50	10.0000	.1000	.0000	
240	15790.70	17288.40	10.0000	.1000	.0000	
241	15923.80	17416.40	1.0000	.0001	.0000	
242	16440.80	17677.40	1.0000	.0001	.0000	
243	17212.10	18251.80	1.0000	.0001	.0000	
244	19220.80	19377.30	1.0000	.0001	.0000	C
245	10477.90	12064.40	1.0000	.0001	.0000	C
246	14264.50	13836.90	1.0000	.0001	.0000	C
247	13850.10	15021.20	1.0000	.0001	.0000	
248	14227.90	15945.10	1.0000	.0001	.0000	
249	14507.60	15154.20	1.0000	.0001	.0000	
250	14585.20	15536.70	1.0000	.0001	.0000	
251	14683.90	15639.50	10.0000	.1000	.0000	
252	14406.50	15975.70	10.0000	.1000	.0000	
253	14551.20	16085.10	10.0000	.1000	.0000	C
254	14816.70	15810.20	9.9000	.1000	.0000	C
255	14663.50	16143.20	9.9000	.1000	.0000	
256	14914.60	15899.40	10.0000	.1000	.0000	

257	14937.90	16191.80	10.0000	.1000	.0000	
258	15113.70	16067.60	10.0000	.1000	.0000	
259	15191.60	16114.50	10.0000	.1000	-253.0000	
260	15223.70	16281.60	10.0000	.1000	.0000	
261	15173.80	16517.50	10.0000	.1000	.0000	
262	15143.90	16677.00	10.0000	.1000	-268.0000	
263	15242.10	16689.90	10.0000	.1000	-268.0000	
264	15240.30	16833.20	10.0000	.1000	.0000	
265	15310.00	16713.50	10.0000	.1000	-268.0000	
266	15366.50	16733.50	10.0000	.1000	-180.0000	
267	15396.40	15543.80	10.0000	.1000	-90.0000	
268	15426.30	16766.70	10.0000	.1000	-90.0000	
269	15296.80	16929.50	10.0000	.1000	-284.0000	
270	15313.40	16557.40	10.0000	.1000	.0000	
271	15428.70	16602.10	10.0000	.1000	-90.0000	
272	15575.90	16670.30	10.0000	.1000	.0000	
273	15602.50	16942.80	10.0000	.1000	.0000	
274	15738.70	16756.80	10.0000	.1000	-90.0000	
275	15413.10	16231.70	10.0000	.1000	-126.0000	
276	15629.00	16288.20	10.0000	.1000	.0000	
277	15532.70	16471.00	10.0000	.1000	.0000	
278	15761.20	16409.70	10.0000	.1000	-63.0000	
279	15811.80	16544.10	10.0000	.1000	-90.0000	
280	15974.90	16576.90	10.0000	.1000	.0000	
281	15980.10	16863.50	10.0000	.1000	.0000	
282	16097.80	16884.00	1.0000	.0001	.0000	
283	16271.80	16484.70	1.0000	.0001	.0000	
284	16993.60	16505.20	1.0000	.0001	.0000	
285	18434.40	15981.90	1.0000	.0001	.0000	C
286	20036.10	18432.60	1.0000	.0001	.0000	C
287	20778.50	17205.90	1.0000	.0001	.0000	C
288	15216.90	14509.20	1.0000	.0001	.0000	C
289	14704.70	14573.20	1.0000	.0001	.0000	
290	14912.80	14941.40	1.0000	.0001	.0000	
291	15361.00	14533.20	10.0000	.1000	.0000	C
292	15131.30	15092.60	10.0000	.1000	.0000	
293	14881.20	15444.80	10.0000	.1000	.0000	
294	15008.80	15654.10	10.0000	.1000	.0000	C
295	15329.00	15341.60	9.9000	.1000	.0000	
296	15569.10	15549.70	10.0000	.1000	.0000	
297	15577.10	15749.80	10.0000	.1000	.0000	C
298	15236.90	15842.90	9.9000	.1000	.0000	
299	15456.10	15959.90	10.0000	.1000	-562.0000	
300	15609.10	15879.50	10.0000	.1000	.0000	
301	15738.70	16105.40	10.0000	.1000	.0000	
302	15868.30	16334.70	10.0000	.1000	.0000	
303	15924.90	16025.20	10.0000	.1000	.0000	
304	16102.90	16095.70	10.0000	.1000	.0000	
305	16282.10	16131.50	1.0000	.0001	.0000	
306	16573.90	15527.50	1.0000	.0001	.0000	
307	17506.00	15565.70	1.0000	.0001	.0000	C
308	16825.70	15181.50	1.0000	.0001	.0000	C
309	15705.20	14677.30	10.0000	.1000	.0000	C
310	15641.10	15229.50	10.0000	.1000	.0000	
311	15905.30	15597.70	10.0000	.1000	.0000	C
312	15953.30	15677.70	9.9000	.1000	.0000	
313	16185.40	15405.60	10.0000	.1000	.0000	C
314	16449.50	15477.60	9.9000	.1000	.0000	
315	16577.60	15045.40	10.0000	.1000	.0000	C
316	16713.60	15141.50	9.9000	.1000	.0000	C

INITIAL HEAD CONDITIONS (NODE AND ELEVATION)

1	9.118+002	2	9.118+002	3	9.107+002	4	9.097+002
5	9.134+002	6	9.081+002				
7	9.080+002	8	9.068+002	9	9.056+002	10	9.114+002
11	9.109+002	12	9.104+002				
13	9.094+002	14	9.136+002	15	9.072+002	16	9.071+002
17	9.072+002	18	9.072+002				
19	9.069+002	20	9.064+002	21	9.066+002	22	9.054+002
23	9.123+002	24	9.105+002				
25	9.105+002	26	9.097+002	27	9.089+002	28	9.138+002
29	9.074+002	30	9.074+002				
31	9.072+002	32	9.088+002	33	9.079+002	34	9.072+002
35	9.140+002	36	9.066+002				
37	9.065+002	38	9.142+002	39	9.066+002	40	9.066+002
41	9.144+002	42	9.062+002				
43	9.062+002	44	9.062+002	45	9.063+002	46	9.055+002
47	9.123+002	48	9.097+002				
49	9.065+002	50	9.073+002	51	9.069+002	52	9.066+002
53	9.064+002	54	9.063+002				
55	9.063+002	56	9.063+002	57	9.062+002	58	9.148+002
59	9.146+002	60	9.059+002				
61	9.059+002	62	9.150+002	63	9.058+002	64	9.058+002
65	9.062+002	66	9.069+002				
67	9.070+002	68	9.068+002	69	9.067+002	70	9.067+002
71	9.067+002	72	9.068+002				
73	9.070+002	74	9.070+002	75	9.067+002	76	9.065+002
77	9.082+002	78	9.064+002				
79	9.064+002	80	9.064+002	81	9.066+002	82	9.064+002
83	9.064+002	84	9.064+002				
85	9.063+002	86	9.064+002	87	9.063+002	88	9.063+002
89	9.063+002	90	9.062+002				
91	9.152+002	92	9.058+002	93	9.058+002	94	9.061+002
95	9.070+002	96	9.071+002				
97	9.057+002	98	9.105+002	99	9.095+002	100	9.079+002
101	9.071+002	102	9.073+002				
103	9.072+002	104	9.077+002	105	9.079+002	106	9.077+002
107	9.075+002	108	9.070+002				
109	9.069+002	110	9.066+002	111	9.065+002	112	9.067+002
113	9.072+002	114	9.069+002				
115	9.069+002	116	9.072+002	117	9.069+002	118	9.068+002
119	9.068+002	120	9.067+002				
121	9.068+002	122	9.063+002	123	9.066+002	124	9.066+002
125	9.154+002	126	9.061+002				
127	9.096+002	128	9.064+002	129	9.064+002	130	9.076+002
131	9.077+002	132	9.072+002				
133	9.078+002	134	9.071+002	135	9.074+002	136	9.158+002
137	9.071+002	138	9.071+002				
139	9.160+002	140	9.081+002	141	9.082+002	142	9.085+002
143	9.082+002	144	9.068+002				
145	9.091+002	146	9.156+002	147	9.084+002	148	9.080+002
149	9.082+002	150	9.080+002				
151	9.080+002	152	9.092+002	153	9.089+002	154	9.085+002
155	9.090+002	156	9.170+002				
157	9.168+002	158	9.091+002	159	9.084+002	160	9.166+002
161	9.164+002	162	9.084+002				
163	9.162+002	164	9.101+002	165	9.102+002	166	9.108+002
167	9.107+002	168	9.107+002				
169	9.107+002	170	9.106+002	171	9.102+002	172	9.096+002
173	9.090+002	174	9.083+002				
175	9.094+002	176	9.105+002	177	9.105+002	178	9.101+002
179	9.107+002	180	9.113+002				
181	9.113+002	182	9.108+002	183	9.101+002	184	9.170+002

185	9.103+002	186	9.176+002				
187	9.174+002	188	9.108+002	189	9.108+002	190	9.115+002
191	9.113+002	192	9.111+002				
193	9.110+002	194	9.109+002	195	9.109+002	196	9.109+002
197	9.108+002	198	9.106+002				
199	9.104+002	200	9.108+002	201	9.105+002	202	9.105+002
203	9.103+002	204	9.103+002				
205	9.102+002	206	9.102+002	207	9.101+002	208	9.105+002
209	9.135+002	210	9.122+002				
211	9.121+002	212	9.119+002	213	9.123+002	214	9.126+002
215	9.178+002	216	9.122+002				
217	9.125+002	218	9.119+002	219	9.119+002	220	9.180+002
221	9.182+002	222	9.121+002				
223	9.114+002	224	9.114+002	225	9.110+002	226	9.110+002
227	9.107+002	228	9.108+002				
229	9.106+002	230	9.106+002	231	9.104+002	232	9.106+002
233	9.105+002	234	9.103+002				
235	9.113+002	236	9.108+002	237	9.106+002	238	9.106+002
239	9.107+002	240	9.107+002				
241	9.107+002	242	9.110+002	243	9.111+002	244	9.106+002
245	9.135+002	246	9.130+002				
247	9.126+002	248	9.127+002	249	9.127+002	250	9.126+002
251	9.125+002	252	9.126+002				
253	9.184+002	254	9.186+002	255	9.122+002	256	9.120+002
257	9.117+002	258	9.116+002				
259	9.114+002	260	9.113+002	261	9.111+002	262	9.109+002
263	9.108+002	264	9.107+002				
265	9.108+002	266	9.108+002	267	9.109+002	268	9.108+002
269	9.107+002	270	9.110+002				
271	9.110+002	272	9.110+002	273	9.108+002	274	9.111+002
275	9.113+002	276	9.114+002				
277	9.112+002	278	9.114+002	279	9.113+002	280	9.114+002
281	9.112+002	282	9.112+002				
283	9.118+002	284	9.127+002	285	9.141+002	286	9.130+002
287	9.137+002	288	9.125+002				
289	9.127+002	290	9.125+002	291	9.120+002	292	9.124+002
293	9.124+002	294	9.188+002				
295	9.122+002	296	9.121+002	297	9.190+002	298	9.117+002
299	9.116+002	300	9.117+002				
301	9.117+002	302	9.117+002	303	9.122+002	304	9.123+002
305	9.123+002	306	9.143+002				
307	9.144+002	308	9.147+002	309	9.124+002	310	9.125+002
311	9.192+002	312	9.129+002				
313	9.194+002	314	9.142+002	315	9.196+002	316	9.147+002

GROUND-WATER LEVEL RESPONSE IN METRES DURING CONTINUOUS FLOW IN THE CROCODILE RIVER

TIME STEP	NODE NUMBERS 1	2	3	4	5	6	7	8	9	10
1:	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
2:	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
3:	.0	.0	.0	.0	.0	.0	.0	.0	.0	-.1
4:	.0	.0	.0	.0	.0	.0	.0	.0	.0	-.1
5:	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
6:	.0	.0	.0	.0	.0	.0	.0	.0	.0	.2
7:	.0	.0	.0	.0	.0	.0	.0	.0	.0	.4
8:	.0	.0	.0	.0	.0	.0	.0	.0	.0	.5
9:	.0	.0	.0	.0	.0	.0	.0	.0	.0	.6
10:	.0	.0	.0	.0	.0	.0	.0	.0	.0	.7

11:	.0	.0	.0	.0	.0	.0	.0	.0	.0	.7
12:	.0	.0	.0	.0	.0	.0	.0	.0	.0	.7
13:	.0	.0	.0	.0	.0	.0	.0	.0	.0	.7
14:	.0	.0	.0	.0	.0	.0	.0	.0	.0	.7
15:	.0	.0	.0	.0	.0	.0	.0	.0	.0	.7

STEP	11	12	13	14	15	16	17	18	19	20
1:	.0	-.2	.4	.0	.1	.0	.1	.0	.0	.0
2:	-.1	-.3	.9	.0	.4	.1	.4	.2	.1	.1
3:	-.1	-.3	1.6	.0	.7	.4	.8	.6	.5	.3
4:	.0	.0	2.4	.0	1.3	.9	1.6	1.5	1.2	.7
5:	.2	.8	3.0	.0	2.0	1.7	3.0	2.9	2.1	1.2
6:	.5	1.5	3.4	.0	2.8	2.6	4.5	4.5	2.9	1.4
7:	.7	2.0	3.7	.0	3.4	3.3	5.6	5.5	3.5	1.6
8:	.8	2.2	3.8	.0	3.7	3.6	6.0	6.0	3.8	1.7
9:	.9	2.3	3.9	.0	3.8	3.7	6.1	6.1	3.8	1.7
10:	.9	2.3	3.9	.0	3.8	3.7	6.1	6.1	3.8	1.7
11:	.9	2.4	3.9	.0	3.8	3.7	6.1	6.1	3.8	1.7
12:	.9	2.4	3.9	.0	3.8	3.7	6.1	6.1	3.8	1.7
13:	.9	2.4	3.9	.0	3.8	3.7	6.1	6.1	3.8	1.7
14:	.9	2.4	3.9	.0	3.8	3.7	6.1	6.1	3.8	1.7
15:	.9	2.4	3.9	.0	3.8	3.7	6.1	6.1	3.6	1.7

STEP	21	22	23	24	25	26	27	28	29	30
1:	.1	.0	.0	.0	-.1	-.2	.2	.0	.2	.0
2:	.4	.0	.0	-.1	-.2	-.4	.6	.0	.8	.4
3:	1.3	.0	.0	-.2	-.3	-.5	1.1	.0	1.8	1.4
4:	2.5	.0	.0	-.2	-.1	-.2	1.7	.0	3.3	2.8
5:	3.5	.0	.0	.0	.3	.6	2.4	.0	4.7	4.3
6:	4.2	.0	.0	.4	.8	1.6	3.1	.0	5.6	5.4
7:	4.6	.0	.0	.9	1.3	2.4	3.7	.0	6.1	6.1
8:	4.7	.0	.0	1.4	1.7	3.1	4.1	.0	6.3	6.3
9:	4.8	.0	.0	1.9	2.0	3.5	4.5	.0	6.4	6.3
10:	4.8	.0	.0	2.2	2.2	3.7	4.6	.0	6.4	6.3
11:	4.8	.0	.0	2.3	2.2	3.8	4.7	.0	6.4	6.3
12:	4.8	.0	.0	2.3	2.2	3.9	4.7	.0	6.4	6.3
13:	4.8	.0	.0	2.3	2.2	3.9	4.7	.0	6.4	6.3
14:	4.8	.0	.0	2.3	2.2	3.9	4.7	.0	6.4	6.3
15:	4.8	.0	.0	2.3	2.2	3.9	4.7	.0	6.4	6.3

STEP	31	32	33	34	35	36	37	38	39	40
1:	.0	-.1	-.1	.5	.0	-.1	.2	.0	2.1	.8
2:	.1	-.3	-.2	1.4	.0	-.2	.5	.0	4.2	2.9
3:	.6	-.5	-.3	2.5	.0	-.2	1.1	.0	5.9	5.1
4:	1.9	-.8	-.2	3.7	.0	.1	2.1	.0	6.9	6.5
5:	3.5	-.7	.1	4.6	.0	.8	3.3	.0	7.3	7.2
6:	4.9	-.1	.9	5.3	.0	1.8	4.4	.0	7.5	7.4
7:	5.8	1.1	2.1	5.7	.0	3.2	5.3	.0	7.5	7.5
8:	6.1	2.5	3.5	6.1	.0	4.6	6.1	.0	7.5	7.5
9:	6.2	3.7	4.7	6.4	.0	5.9	6.7	.0	7.5	7.5
10:	6.2	4.5	5.4	6.6	.0	6.7	7.1	.0	7.5	7.5
11:	6.2	4.7	5.7	6.7	.0	7.0	7.2	.0	7.5	7.5
12:	6.2	4.8	5.7	6.7	.0	7.0	7.2	.0	7.5	7.5
13:	6.2	4.8	5.7	6.7	.0	7.1	7.2	.0	7.5	7.5
14:	6.2	4.8	5.7	6.7	.0	7.1	7.2	.0	7.5	7.5
15:	6.2	4.8	5.7	6.7	.0	7.1	7.2	.0	7.5	7.5

STEP	41	42	43	44	45	46	47	48	49	50
1:	.0	1.9	.5	.2	.1	.0	.0	.0	.0	.0
2:	.0	4.0	2.5	1.5	.5	.0	.0	.0	.0	.0
3:	.0	6.0	5.1	3.7	1.6	.0	.0	-.1	.0	.0
4:	.0	7.4	7.1	5.6	3.0	.0	.0	-.1	-.1	.0
5:	.0	8.0	7.9	6.6	3.9	.0	.0	.0	.0	-.1
6:	.0	8.2	8.1	7.0	4.3	.0	.0	.4	.6	.2
7:	.0	8.2	8.2	7.1	4.4	.0	.0	1.0	1.8	1.3
8:	.0	8.2	8.2	7.1	4.5	.0	.0	1.8	3.6	2.9
9:	.0	8.2	8.2	7.1	4.6	.0	.0	2.5	5.3	4.7
10:	.0	8.2	8.2	7.2	4.6	.0	.0	3.0	6.3	5.8
11:	.0	8.2	8.2	7.2	4.6	.0	.0	3.2	6.7	6.2
12:	.0	8.2	8.2	7.2	4.6	.0	.0	3.2	6.8	6.3
13:	.0	8.2	8.2	7.2	4.6	.0	.0	3.2	6.8	6.3
14:	.0	8.2	8.2	7.2	4.6	.0	.0	3.2	6.8	6.3
15:	.0	8.2	8.2	7.2	4.6	.0	.0	3.2	6.8	6.3

STEP	51	52	53	54	55	56	57	58	59	60
1:	.1	.0	.0	.0	.0	.2	.6	.0	.0	1.8
2:	.1	.0	.0	.1	.1	.7	1.4	.0	.0	4.0
3:	.1	.0	.0	.4	.4	1.3	2.4	.0	.0	6.2
4:	.1	.1	.2	1.1	1.1	2.2	3.3	.0	.0	7.9
5:	.1	.4	.7	2.1	2.1	3.2	4.2	.0	.0	8.6
6:	.4	.8	1.6	3.3	3.3	4.3	5.1	.0	.0	8.7
7:	1.5	2.0	2.9	4.5	4.4	5.2	5.9	.0	.0	8.8
8:	3.2	3.7	4.5	5.5	5.5	6.0	6.6	.0	.0	8.8
9:	5.0	5.5	5.8	6.4	6.4	6.6	7.1	.0	.0	8.8
10:	6.2	6.5	6.7	6.9	7.0	7.0	7.4	.0	.0	8.8
11:	6.6	6.9	7.0	7.1	7.2	7.1	7.5	.0	.0	8.8
12:	6.7	7.0	7.1	7.2	7.2	7.1	7.5	.0	.0	8.8
13:	6.7	7.0	7.1	7.2	7.2	7.1	7.5	.0	.0	8.8
14:	6.7	7.0	7.1	7.2	7.2	7.1	7.5	.0	.0	8.8
15:	6.7	7.0	7.1	7.2	7.2	7.1	7.5	.0	.0	8.8

STEP	61	62	63	64	65	66	67	68	69	70
1:	.1	.0	3.8	1.4	.4	.0	.0	.0	.0	.0
2:	2.0	.0	6.1	4.2	1.9	.0	.0	.0	.0	.0
3:	5.0	.0	7.7	6.7	4.1	.0	.0	.0	.0	.0
4:	7.3	.0	8.6	8.3	6.0	.1	.0	.0	.1	.0
5:	8.4	.0	9.0	8.9	7.0	.1	.0	.1	.1	.1
6:	8.7	.0	9.1	9.1	7.4	.3	.3	.3	.5	.4
7:	8.7	.0	9.1	9.1	7.5	1.3	1.2	1.3	1.6	1.4
8:	8.7	.0	9.1	9.1	7.5	3.0	3.0	3.1	3.3	3.2
9:	8.7	.0	9.1	9.1	7.6	5.0	5.0	5.0	5.2	5.1
10:	8.7	.0	9.1	9.1	7.6	6.2	6.2	6.3	6.4	6.3
11:	8.7	.0	9.1	9.1	7.6	6.7	6.7	6.7	6.8	6.8
12:	8.7	.0	9.1	9.1	7.6	6.7	6.8	6.8	6.9	6.9
13:	8.7	.0	9.1	9.1	7.6	6.8	6.8	6.8	6.9	6.9
14:	8.7	.0	9.1	9.1	7.6	6.8	6.8	6.8	6.9	6.9
15:	8.7	.0	9.1	9.1	7.6	6.8	6.8	6.8	6.9	6.9

STEP	71	72	73	74	75	76	77	78	79	80
1:	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
2:	.0	.0	.0	.0	.0	.0	.0	.0	-.1	.0

3:	.0	.0	.0	.0	.0	.0	-.1	-.1	-.2	-.1
4:	.0	.0	.0	.0	.0	.0	-.2	-.1	-.2	-.1
5:	.1	.0	.0	.0	.0	.1	-.1	.1	.0	.3
6:	.5	.3	.2	.2	.3	.6	.3	.8	.8	1.1
7:	1.5	1.2	1.2	1.3	1.4	1.8	1.2	2.1	2.1	2.5
8:	3.3	3.0	3.0	3.2	3.2	3.6	2.6	3.8	3.7	4.0
9:	5.2	5.0	5.1	5.2	5.2	5.3	4.0	5.4	5.3	5.5
10:	6.4	6.3	6.4	6.4	6.4	6.4	4.8	6.3	6.3	6.4
11:	6.8	6.8	6.8	6.9	6.8	6.8	5.2	6.7	6.6	6.7
12:	6.9	6.9	6.9	6.9	6.9	6.9	5.2	6.7	6.7	6.7
13:	6.9	6.9	6.9	6.9	6.9	6.9	5.2	6.7	6.7	6.7
14:	6.9	6.9	6.9	6.9	6.9	6.9	5.2	6.7	6.7	6.7
15:	6.9	6.9	6.9	6.9	6.9	6.9	5.2	6.7	6.7	6.7

STEP	81	82	83	84	85	86	87	88	89	90
1:	.0	.0	.0	-.2	.0	-.2	-.2	-.1	-.1	.6
2:	.0	-.1	-.1	-.5	-.1	-.4	-.4	.0	-.1	1.5
3:	.0	-.2	-.3	-.7	-.2	-.6	-.6	.3	.1	2.7
4:	.0	-.3	-.3	-.7	.0	-.6	-.6	.9	.8	3.9
5:	.0	-.1	-.1	-.4	.6	-.2	-.1	1.9	1.8	5.0
6:	.6	.6	.8	.5	1.7	.7	.9	3.1	3.0	6.0
7:	1.8	1.9	2.1	1.9	3.0	2.0	2.3	4.3	4.3	6.7
8:	3.6	3.6	3.8	3.5	4.4	3.7	3.8	5.5	5.5	7.3
9:	5.4	5.2	5.3	4.9	5.7	5.1	5.1	6.4	6.6	7.8
10:	6.5	6.2	6.3	5.8	6.4	6.0	5.9	7.0	7.2	8.1
11:	6.9	6.5	6.6	6.1	6.7	6.3	6.2	7.2	7.4	8.2
12:	6.9	6.6	6.6	6.2	6.7	6.3	6.3	7.2	7.4	8.2
13:	6.9	6.6	6.6	6.2	6.7	6.3	6.3	7.2	7.4	8.2
14:	6.9	6.6	6.6	6.2	6.8	6.3	6.3	7.2	7.4	8.2
15:	6.9	6.6	6.6	6.2	6.8	6.3	6.3	7.2	7.4	8.2

STEP	91	92	93	94	95	96	97	98	99	100
1:	.0	1.8	.9	.2	.8	.1	.0	.0	.0	.0
2:	.0	4.1	3.1	1.9	2.7	.6	.0	.0	.0	.0
3:	.0	6.5	5.8	4.9	4.8	1.6	.0	.0	.0	.0
4:	.0	8.2	7.9	7.5	6.3	2.9	.0	.0	.0	.1
5:	.0	9.1	8.9	8.8	7.1	3.7	.0	.0	.2	.3
6:	.0	9.3	9.2	9.2	7.4	4.1	.0	.0	.6	.7
7:	.0	9.3	9.3	9.3	7.6	4.4	.0	.0	1.2	1.7
8:	.0	9.3	9.3	9.3	7.6	4.5	.0	.0	2.0	3.2
9:	.0	9.3	9.3	9.3	7.7	4.7	.0	.0	2.7	4.7
10:	.0	9.3	9.3	9.3	7.7	4.8	.0	.0	3.2	5.6
11:	.0	9.3	9.3	9.3	7.8	4.8	.0	.0	3.4	6.0
12:	.0	9.3	9.3	9.3	7.8	4.8	.0	.0	3.4	6.0
13:	.0	9.3	9.3	9.3	7.8	4.8	.0	.0	3.4	6.0
14:	.0	9.3	9.3	9.3	7.8	4.8	.0	.0	3.4	6.0
15:	.0	9.3	9.3	9.3	7.8	4.8	.0	.0	3.4	6.0

STEP	101	102	103	104	105	106	107	108	109	110
1:	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
2:	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
3:	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
4:	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
5:	.0	.0	.0	.2	.3	.1	.1	.0	.2	.3
6:	.2	.3	.3	.8	1.2	.9	.6	.4	1.0	1.0
7:	1.2	1.4	1.4	2.2	2.8	2.4	2.0	1.6	2.4	2.4
8:	3.0	3.3	3.3	4.1	4.7	4.3	4.0	3.5	4.3	4.2

9:	5.1	5.3	5.3	5.8	6.2	5.9	5.8	5.4	5.9	5.8
10:	6.3	6.5	6.5	6.8	7.0	6.9	6.8	6.6	6.9	6.8
11:	6.8	6.9	6.9	7.1	7.3	7.2	7.1	7.0	7.2	7.1
12:	6.9	7.0	7.0	7.2	7.4	7.3	7.2	7.1	7.3	7.2
13:	6.9	7.0	7.0	7.2	7.4	7.3	7.2	7.1	7.3	7.2
14:	6.9	7.0	7.0	7.2	7.4	7.3	7.2	7.1	7.3	7.2
15:	6.9	7.0	7.0	7.2	7.4	7.3	7.2	7.1	7.3	7.2

STEP	111	112	113	114	115	116	117	118	119	120
1:	.0	.0	.0	.0	.0	.0	-.1	.0	-.1	.0
2:	-.1	.0	.0	.0	.0	.0	-.1	-.1	-.2	-.1
3:	-.1	.0	.0	.0	-.1	.0	-.2	-.1	-.2	.0
4:	.1	.1	.0	.1	.1	.1	.0	.1	.2	.5
5:	.8	.7	.3	.5	.6	.6	.8	1.0	1.1	1.5
6:	1.9	1.8	1.1	1.6	1.8	1.8	2.1	2.3	2.5	2.9
7:	3.4	3.3	2.7	3.2	3.4	3.5	3.7	3.9	4.1	4.4
8:	4.9	5.0	4.5	4.8	5.0	5.1	5.3	5.4	5.5	5.8
9:	6.2	6.3	6.1	6.3	6.4	6.4	6.4	6.5	6.6	6.8
10:	7.0	7.1	7.0	7.1	7.1	7.1	7.1	7.2	7.2	7.4
11:	7.2	7.3	7.3	7.3	7.3	7.4	7.3	7.4	7.4	7.6
12:	7.3	7.4	7.3	7.4	7.4	7.4	7.3	7.4	7.4	7.6
13:	7.3	7.4	7.3	7.4	7.4	7.4	7.3	7.4	7.4	7.7
14:	7.3	7.4	7.3	7.4	7.4	7.4	7.3	7.4	7.4	7.7
15:	7.3	7.4	7.3	7.4	7.4	7.4	7.3	7.4	7.4	7.7

STEP	121	122	123	124	125	126	127	128	129	130
1:	.0	.3	-.1	1.3	.0	1.3	.0	2.9	1.1	.0
2:	-.1	.9	.2	2.8	.0	3.3	.0	5.4	3.9	.0
3:	-.1	1.8	1.0	4.3	.0	5.8	.0	7.4	6.6	.0
4:	.3	3.0	2.3	5.7	.0	7.8	.2	8.5	8.2	.0
5:	1.5	4.3	3.7	6.7	.0	8.9	.5	9.0	8.9	.4
6:	3.0	5.5	5.1	7.5	.0	9.2	.9	9.1	9.1	1.5
7:	4.5	6.5	6.2	8.0	.0	9.3	1.4	9.2	9.1	3.1
8:	5.8	7.3	7.1	8.3	.0	9.3	2.1	9.2	9.1	4.9
9:	6.8	7.8	7.7	8.6	.0	9.3	2.8	9.2	9.2	6.3
10:	7.3	8.2	8.1	8.7	.0	9.3	3.2	9.2	9.2	7.1
11:	7.5	8.3	8.2	8.7	.0	9.3	3.3	9.2	9.2	7.4
12:	7.5	8.3	8.2	8.7	.0	9.3	3.4	9.2	9.2	7.4
13:	7.5	8.3	8.2	8.7	.0	9.3	3.4	9.2	9.2	7.4
14:	7.5	8.3	8.2	8.7	.0	9.3	3.4	9.2	9.2	7.4
15:	7.5	8.3	8.2	8.7	.0	9.3	3.4	9.2	9.2	7.4

STEP	131	132	133	134	135	136	137	138	139	140
1:	.0	.0	-.3	-.2	1.1	.0	3.0	1.5	.0	1.4
2:	.0	-.1	-.1	-.2	2.7	.0	5.5	3.9	.0	3.0
3:	.0	-.1	.7	.9	4.5	.0	7.2	6.0	.0	4.6
4:	.5	.2	1.9	1.9	6.0	.0	8.1	7.4	.0	5.9
5:	1.6	1.3	3.4	3.7	7.0	.0	8.5	8.0	.0	6.8
6:	3.1	2.8	4.8	5.2	7.6	.0	8.6	8.3	.0	7.2
7:	4.6	4.4	5.9	6.3	7.9	.0	8.6	8.4	.0	7.5
8:	5.9	5.7	6.7	7.1	8.1	.0	8.7	8.4	.0	7.6
9:	6.8	6.7	7.3	7.7	8.2	.0	8.7	8.5	.0	7.7
10:	7.3	7.2	7.5	8.0	8.3	.0	8.7	8.5	.0	7.7
11:	7.5	7.4	7.6	8.1	8.3	.0	8.7	8.5	.0	7.8
12:	7.5	7.5	7.6	8.1	8.3	.0	8.7	8.5	.0	7.8
13:	7.5	7.5	7.7	8.1	8.3	.0	8.7	8.5	.0	7.8
14:	7.5	7.5	7.7	8.1	8.3	.0	8.7	8.5	.0	7.8

15:	7.5	7.5	7.7	8.1	8.3	.0	8.7	8.5	.0	7.8

STEP	141	142	143	144	145	146	147	148	149	150
1:	-.2	.0	.0	.0	.0	.0	.0	.0	.0	.0
2:	.8	.5	.2	.0	.0	.0	.0	-.1	.0	.0
3:	2.8	1.5	.9	.0	.0	.0	.1	-.2	.1	.0
4:	4.9	2.8	1.8	.0	.0	.0	.3	-.1	.3	.1
5:	6.2	3.7	2.5	.0	.0	.0	.8	.3	1.0	.6
6:	6.9	4.4	2.9	.0	.0	.0	1.6	1.4	2.3	1.7
7:	7.2	4.9	3.3	.0	.0	.0	2.7	3.1	3.9	3.4
8:	7.4	5.3	3.6	.0	.0	.0	4.2	4.9	5.4	5.1
9:	7.5	5.6	3.9	.0	.0	.0	5.4	6.3	6.6	6.4
10:	7.6	5.7	4.0	.0	.0	.0	6.1	7.1	7.3	7.2
11:	7.6	5.8	4.1	.0	.0	.0	6.4	7.4	7.5	7.4
12:	7.6	5.8	4.1	.0	.0	.0	6.4	7.4	7.5	7.5
13:	7.6	5.8	4.1	.0	.0	.0	6.4	7.4	7.5	7.5
14:	7.6	5.8	4.1	.0	.0	.0	6.4	7.4	7.5	7.5
15:	7.6	5.8	4.1	.0	.0	.0	6.4	7.4	7.5	7.5

STEP	151	152	153	154	155	156	157	158	159	160
1:	-.2	-.1	.1	.0	.4	.0	.0	.7	.3	.0
2:	-.3	.0	.4	.1	1.0	.0	.0	1.6	1.0	.0
3:	-.2	.7	.9	.3	1.9	.0	.0	2.7	2.0	.0
4:	.3	1.8	1.9	1.0	2.9	.0	.0	3.9	3.2	.0
5:	1.4	3.3	3.2	2.0	3.9	.0	.0	4.9	4.3	.0
6:	2.8	4.7	4.6	3.3	4.9	.0	.0	5.6	5.3	.0
7:	4.4	5.7	5.7	4.7	5.8	.0	.0	6.2	6.0	.0
8:	5.8	6.5	6.6	6.0	6.6	.0	.0	6.6	6.6	.0
9:	6.8	7.0	7.1	6.9	7.0	.0	.0	6.9	6.9	.0
10:	7.3	7.2	7.4	7.4	7.3	.0	.0	7.0	7.1	.0
11:	7.5	7.3	7.5	7.5	7.4	.0	.0	7.1	7.2	.0
12:	7.5	7.3	7.5	7.5	7.4	.0	.0	7.1	7.2	.0
13:	7.5	7.3	7.5	7.5	7.4	.0	.0	7.1	7.2	.0
14:	7.5	7.3	7.5	7.5	7.4	.0	.0	7.1	7.2	.0
15:	7.5	7.3	7.5	7.5	7.4	.0	.0	7.1	7.2	.0

STEP	161	162	163	164	165	166	167	168	169	170
1:	.0	2.2	.0	.0	.0	.0	.3	.2	.0	.0
2:	.0	3.7	.0	.1	-.1	.1	.7	.4	-.1	.0
3:	.0	4.7	.0	.4	-.2	.5	1.1	.7	-.1	.0
4:	.0	5.5	.0	1.0	.2	1.2	1.7	1.2	-.1	.0
5:	.0	6.1	.0	2.0	1.1	2.1	2.4	1.8	.3	.2
6:	.0	6.6	.0	3.1	2.3	2.9	3.1	2.5	1.0	.9
7:	.0	7.0	.0	4.1	3.5	3.7	3.8	3.4	2.1	2.0
8:	.0	7.3	.0	4.9	4.4	4.3	4.5	4.1	3.2	3.1
9:	.0	7.4	.0	5.4	5.0	4.8	4.9	4.7	4.1	4.1
10:	.0	7.5	.0	5.6	5.3	5.1	5.2	5.1	4.7	4.6
11:	.0	7.6	.0	5.7	5.5	5.2	5.3	5.2	4.9	4.9
12:	.0	7.6	.0	5.8	5.5	5.2	5.4	5.2	4.9	4.9
13:	.0	7.6	.0	5.8	5.5	5.2	5.4	5.2	4.9	4.9
14:	.0	7.6	.0	5.8	5.5	5.2	5.4	5.2	4.9	4.9
15:	.0	7.6	.0	5.8	5.5	5.2	5.4	5.2	4.9	4.9

STEP	171	172	173	174	175	176	177	178	179	180

1:	.0	.0	.0	.0	.0	.0	.0	.0	-.3	.3
2:	.0	.1	.1	.0	.0	.0	.2	.5	.0	1.7
3:	.1	.3	.4	.0	.0	.1	.8	1.6	1.4	3.5
4:	.3	.8	.9	.0	.0	.5	1.8	3.1	3.3	4.9
5:	.6	1.4	1.4	.0	.0	1.0	2.7	4.6	4.9	5.7
6:	1.0	2.0	1.8	.0	.0	1.4	3.4	5.6	5.7	6.0
7:	1.8	2.7	2.2	.0	.0	1.8	3.9	6.2	6.1	6.1
8:	2.7	3.4	2.6	.0	.0	2.2	4.3	6.5	6.3	6.2
9:	3.6	4.0	3.0	.0	.0	2.6	4.7	6.7	6.4	6.2
10:	4.2	4.4	3.3	.0	.0	2.8	4.9	6.8	6.4	6.2
11:	4.5	4.6	3.4	.0	.0	2.8	4.9	6.8	6.4	6.2
12:	4.5	4.6	3.4	.0	.0	2.9	5.0	6.8	6.4	6.2
13:	4.5	4.6	3.4	.0	.0	2.9	5.0	6.8	6.4	6.2
14:	4.5	4.6	3.4	.0	.0	2.9	5.0	6.8	6.4	6.2
15:	4.5	4.6	3.4	.0	.0	2.9	5.0	6.8	6.4	6.2

STEP	181	182	183	184	185	186	187	188	189	190
1:	1.5	.4	.8	.0	1.3	.0	.0	.6	-.1	.0
2:	3.0	1.2	1.7	.0	2.6	.0	.0	1.5	.1	.0
3:	4.4	2.5	2.8	.0	3.8	.0	.0	2.7	.7	.3
4:	5.4	4.1	4.0	.0	4.6	.0	.0	3.7	1.7	.8
5:	5.9	5.3	5.1	.0	5.3	.0	.0	4.5	2.7	1.6
6:	6.2	6.0	5.9	.0	5.7	.0	.0	5.1	3.6	2.5
7:	6.2	6.3	6.3	.0	5.9	.0	.0	5.5	4.2	3.4
8:	6.3	6.4	6.6	.0	6.2	.0	.0	5.7	4.8	4.1
9:	6.3	6.4	6.7	.0	6.3	.0	.0	5.9	5.2	4.6
10:	6.3	6.4	6.8	.0	6.4	.0	.0	6.1	5.5	5.0
11:	6.3	6.5	6.8	.0	6.5	.0	.0	6.1	5.6	5.1
12:	6.3	6.5	6.8	.0	6.5	.0	.0	6.1	5.6	5.1
13:	6.3	6.5	6.8	.0	6.5	.0	.0	6.1	5.6	5.1
14:	6.3	6.5	6.8	.0	6.5	.0	.0	6.1	5.6	5.1
15:	6.3	6.5	6.8	.0	6.5	.0	.0	6.1	5.6	5.1

STEP	191	192	193	194	195	196	197	198	199	200
1:	-.1	.0	-.1	.0	.0	-.1	.0	.0	.0	-.1
2:	-.3	.0	-.1	.0	-.1	-.1	.0	.0	.0	-.2
3:	-.5	-.1	-.3	.0	.0	-.1	.0	.0	.0	-.3
4:	-.5	.1	-.5	-.1	.2	.1	-.1	.0	.1	-.4
5:	-.1	.6	-.5	-.1	.6	.5	.1	.1	.2	-.5
6:	.8	1.3	-.2	.3	1.3	1.2	.5	.5	.6	-.3
7:	1.8	2.3	.7	1.1	2.2	2.2	1.4	1.3	1.4	.5
8:	2.9	3.3	1.8	2.3	3.2	3.1	2.5	2.5	2.5	1.7
9:	3.8	4.1	3.0	3.4	4.0	4.0	3.6	3.6	3.6	2.9
10:	4.3	4.6	3.7	4.1	4.5	4.5	4.3	4.4	4.4	3.6
11:	4.5	4.8	4.0	4.4	4.7	4.7	4.5	4.6	4.7	3.9
12:	4.6	4.8	4.0	4.4	4.8	4.7	4.6	4.7	4.7	4.0
13:	4.6	4.8	4.0	4.4	4.8	4.7	4.6	4.7	4.7	4.0
14:	4.6	4.8	4.0	4.4	4.8	4.7	4.6	4.7	4.7	4.0
15:	4.6	4.8	4.0	4.4	4.8	4.7	4.6	4.7	4.7	4.0

STEP	201	202	203	204	205	206	207	208	209	210
1:	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
2:	.0	.0	.1	.0	.0	.0	.0	.0	.0	.0
3:	.0	.0	.1	.1	.1	.1	.1	.0	.0	.2
4:	.0	.1	.1	.1	.1	.3	.4	.0	.0	.6
5:	.0	.1	.2	.2	.2	.5	.7	.0	.0	1.1
6:	.1	.3	.3	.4	.3	.8	.9	.0	.0	1.5

7:	.6	.9	.8	1.0	.7	1.4	1.3	.0	.0	1.7
8:	1.8	2.1	1.9	2.2	1.8	2.2	1.8	.0	.0	1.9
9:	3.1	3.4	3.3	3.4	3.1	3.1	2.3	.0	.0	2.0
10:	4.0	4.2	4.2	4.3	4.1	3.7	2.6	.0	.0	2.1
11:	4.4	4.5	4.6	4.6	4.4	3.9	2.8	.0	.0	2.1
12:	4.4	4.6	4.6	4.7	4.5	3.9	2.8	.0	.0	2.2
13:	4.4	4.6	4.7	4.7	4.5	3.9	2.8	.0	.0	2.2
14:	4.4	4.6	4.7	4.7	4.5	3.9	2.8	.0	.0	2.2
15:	4.4	4.6	4.7	4.7	4.5	3.9	2.8	.0	.0	2.2

STEP	211	212	213	214	215	216	217	218	219	220
1:	.2	2.5	.0	.0	.0	1.3	.7	.8	.3	.0
2:	.7	4.1	1.2	.8	.0	2.8	1.8	1.7	.9	.0
3:	1.5	5.0	3.0	2.4	.0	4.1	3.2	2.7	1.8	.0
4:	2.5	5.5	4.5	4.0	.0	5.0	4.5	3.5	2.7	.0
5:	3.3	5.7	5.2	5.0	.0	5.5	5.2	4.2	3.6	.0
6:	3.7	5.8	5.5	5.4	.0	5.7	5.5	4.6	4.2	.0
7:	4.0	5.8	5.6	5.5	.0	5.7	5.6	5.0	4.6	.0
8:	4.1	5.8	5.6	5.5	.0	5.7	5.6	5.2	5.0	.0
9:	4.2	5.8	5.6	5.5	.0	5.7	5.6	5.4	5.3	.0
10:	4.3	5.8	5.6	5.5	.0	5.7	5.6	5.6	5.5	.0
11:	4.3	5.8	5.6	5.5	.0	5.7	5.6	5.6	5.5	.0
12:	4.3	5.8	5.6	5.5	.0	5.7	5.6	5.6	5.5	.0
13:	4.3	5.8	5.6	5.5	.0	5.7	5.6	5.6	5.5	.0
14:	4.3	5.8	5.6	5.5	.0	5.7	5.6	5.6	5.5	.0
15:	4.3	5.8	5.6	5.5	.0	5.7	5.6	5.6	5.5	.0

STEP	221	222	223	224	225	226	227	228	229	230
1:	.0	.6	-.1	-.1	.0	.0	.0	.0	.0	.0
2:	.0	1.6	-.1	-.2	.0	.0	.1	-.1	.0	-.1
3:	.0	2.6	.1	-.3	-.1	.0	.1	-.1	.0	-.1
4:	.0	3.6	.6	.0	-.3	.0	.1	-.2	-.1	-.1
5:	.0	4.2	1.4	.5	-.3	.3	.2	-.3	-.1	-.1
6:	.0	4.7	2.4	1.4	.1	.9	.6	.0	.0	.0
7:	.0	5.0	3.2	2.4	1.0	1.8	1.5	.8	.6	.6
8:	.0	5.3	4.0	3.3	2.1	2.8	2.6	1.9	1.7	1.8
9:	.0	5.5	4.7	4.1	3.3	3.8	3.6	3.1	3.0	3.0
10:	.0	5.6	5.1	4.6	4.0	4.5	4.4	3.9	3.9	3.9
11:	.0	5.7	5.2	4.8	4.2	4.7	4.6	4.2	4.2	4.2
12:	.0	5.7	5.3	4.9	4.3	4.8	4.7	4.2	4.3	4.3
13:	.0	5.7	5.3	4.9	4.3	4.8	4.7	4.2	4.3	4.3
14:	.0	5.7	5.3	4.9	4.3	4.8	4.7	4.2	4.3	4.3
15:	.0	5.7	5.3	4.9	4.3	4.8	4.7	4.2	4.3	4.3

STEP	231	232	233	234	235	236	237	238	239	240
1:	.0	.0	.0	.0	-.2	.1	.0	.0	.0	.0
2:	.0	.0	.0	.0	-.3	.1	.0	.0	.0	.0
3:	-.1	.0	.0	.0	-.3	.0	.0	.0	.0	.0
4:	-.1	.0	.0	.1	.2	.0	-.1	.0	.0	.0
5:	-.1	.0	.0	.1	1.0	.2	-.1	-.1	.0	.0
6:	.0	.2	.1	.1	2.1	.8	.3	.0	.0	.0
7:	.5	.8	.6	.5	3.0	1.7	1.0	.6	.5	.5
8:	1.6	1.9	1.7	1.6	3.8	2.7	2.1	1.7	1.6	1.6
9:	2.9	3.2	3.0	3.0	4.5	3.7	3.3	3.0	2.9	2.9
10:	3.9	4.0	3.9	3.9	4.9	4.3	4.0	3.8	3.8	3.8
11:	4.2	4.3	4.2	4.3	5.1	4.6	4.3	4.1	4.1	4.1
12:	4.3	4.4	4.3	4.4	5.1	4.6	4.4	4.2	4.2	4.2

13:	4.3	4.4	4.3	4.4	5.1	4.6	4.4	4.2	4.2	4.2
14:	4.3	4.4	4.3	4.4	5.1	4.6	4.4	4.2	4.2	4.2
15:	4.3	4.4	4.3	4.4	5.1	4.6	4.4	4.2	4.2	4.2

STEP	241	242	243	244	245	246	247	248	249	250
1:	.0	.0	.0	.0	.0	.0	.0	.0	-.2	.0
2:	.0	.0	.0	.0	.0	.0	.1	.7	-.4	.5
3:	.0	.0	.0	.0	.0	.0	.4	2.1	-.1	1.7
4:	.0	.1	.2	.0	.0	.0	1.1	3.7	.7	3.1
5:	.0	.2	.3	.0	.0	.0	1.8	4.9	2.0	4.3
6:	.1	.4	.5	.0	.0	.0	2.4	5.4	3.3	5.1
7:	.5	.8	.8	.0	.0	.0	2.7	5.5	4.0	5.4
8:	1.6	1.6	1.3	.0	.0	.0	2.8	5.5	4.3	5.5
9:	2.8	2.5	1.8	.0	.0	.0	2.9	5.5	4.3	5.6
10:	3.7	3.1	2.1	.0	.0	.0	2.9	5.5	4.3	5.6
11:	4.1	3.3	2.2	.0	.0	.0	2.9	5.5	4.3	5.6
12:	4.2	3.4	2.3	.0	.0	.0	2.9	5.5	4.3	5.6
13:	4.2	3.4	2.3	.0	.0	.0	2.9	5.5	4.3	5.6
14:	4.2	3.4	2.3	.0	.0	.0	2.9	5.5	4.3	5.6
15:	4.2	3.4	2.3	.0	.0	.0	2.9	5.5	4.3	5.6

STEP	251	252	253	254	255	256	257	258	259	260
1:	.6	1.0	.0	.0	1.0	1.1	-.2	-.2	-.2	.0
2:	1.6	2.1	.0	.0	2.1	2.4	.0	.0	-.2	.0
3:	2.9	3.3	.0	.0	3.2	3.6	.6	.8	.3	.0
4:	4.1	4.5	.0	.0	4.1	4.6	1.7	1.9	1.2	.4
5:	5.0	5.2	.0	.0	4.7	5.2	2.8	3.1	2.4	1.3
6:	5.5	5.6	.0	.0	5.1	5.6	3.7	4.0	3.4	2.3
7:	5.8	5.7	.0	.0	5.4	5.9	4.4	4.7	4.2	3.3
8:	5.8	5.7	.0	.0	5.6	6.1	4.9	5.1	4.7	4.0
9:	5.9	5.7	.0	.0	5.7	6.2	5.3	5.5	5.1	4.6
10:	5.9	5.7	.0	.0	5.8	6.2	5.5	5.7	5.4	5.0
11:	5.9	5.7	.0	.0	5.8	6.2	5.6	5.7	5.5	5.1
12:	5.9	5.7	.0	.0	5.8	6.3	5.6	5.8	5.5	5.2
13:	5.9	5.7	.0	.0	5.9	6.3	5.6	5.8	5.5	5.2
14:	5.9	5.7	.0	.0	5.9	6.3	5.6	5.8	5.5	5.2
15:	5.9	5.7	.0	.0	5.9	6.3	5.6	5.8	5.5	5.2

STEP	261	262	263	264	265	266	267	268	269	270
1:	.0	-.1	-.2	.0	-.2	-.2	-.1	-.1	-.1	.0
2:	.0	-.2	-.4	-.1	-.5	-.4	-.2	-.2	-.2	.0
3:	-.1	-.4	-.6	-.2	-.6	-.5	-.4	-.3	-.3	-2
4:	-.1	-.5	-.7	-.4	-.8	-.7	-.5	-.5	-.4	-.2
5:	.4	-.3	-.6	-.4	-.8	-.7	-.4	-.5	-.5	.0
6:	1.2	.4	-.1	.0	-.3	-.3	.1	-.1	-.2	.7
7:	2.1	1.3	.9	.8	.6	.6	1.0	.7	.6	1.6
8:	3.1	2.3	1.9	1.9	1.7	1.7	2.1	1.8	1.7	2.6
9:	3.9	3.3	2.9	3.0	2.7	2.7	3.0	2.8	2.8	3.5
10:	4.4	3.8	3.5	3.7	3.3	3.4	3.7	3.5	3.5	4.1
11:	4.6	4.1	3.7	3.9	3.6	3.6	3.9	3.8	3.8	4.3
12:	4.6	4.1	3.8	4.0	3.6	3.7	3.9	3.8	3.9	4.3
13:	4.6	4.1	3.8	4.0	3.6	3.7	4.0	3.8	3.9	4.3
14:	4.6	4.1	3.8	4.0	3.6	3.7	4.0	3.8	3.9	4.3
15:	4.6	4.1	3.8	4.0	3.6	3.7	4.0	3.8	3.9	4.3

STEP	271	272	273	274	275	276	277	278	279	280
1:	-.1	.0	.0	.0	.0	.0	.0	.0	.0	.0
2:	-.1	.0	.0	.0	.0	.0	.0	.0	-.1	.0
3:	-.3	-.1	.0	-.1	.0	.1	.0	-.1	-.1	.0
4:	-.4	-.2	-.1	-.2	.5	.4	.0	.0	-.1	-.1
5:	-.2	-.2	-.2	-.2	1.3	1.0	.3	.4	.0	.0
6:	.3	.3	.0	.1	2.3	1.9	1.0	1.1	.6	.5
7:	1.2	1.1	.7	.9	3.3	2.9	1.9	2.1	1.5	1.4
8:	2.3	2.2	1.8	2.0	4.0	3.8	2.9	3.1	2.6	2.5
9:	3.2	3.2	3.0	3.1	4.6	4.4	3.8	3.9	3.5	3.5
10:	3.8	3.9	3.8	3.8	5.0	4.9	4.3	4.4	4.1	4.1
11:	4.1	4.1	4.1	4.1	5.1	5.0	4.5	4.6	4.3	4.3
12:	4.1	4.2	4.1	4.1	5.2	5.0	4.6	4.7	4.4	4.4
13:	4.1	4.2	4.1	4.1	5.2	5.1	4.6	4.7	4.4	4.4
14:	4.1	4.2	4.1	4.1	5.2	5.1	4.6	4.7	4.4	4.4
15:	4.1	4.2	4.1	4.1	5.2	5.1	4.6	4.7	4.4	4.4

STEP	281	282	283	284	285	286	287	288	289	290
1:	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
2:	.0	.0	.0	.0	.0	.0	.0	.0	-.1	-.1
3:	-.1	.0	-.1	.0	.0	.0	.0	.0	.0	-.1
4:	-.1	-.1	.0	.1	.0	.0	.0	.0	.2	.3
5:	-.1	-.1	.3	.4	.0	.0	.0	.0	.7	1.3
6:	.1	.2	1.0	.8	.0	.0	.0	.0	1.2	2.5
7:	.8	.9	2.0	1.2	.0	.0	.0	.0	1.5	3.2
8:	1.9	2.0	2.9	1.7	.0	.0	.0	.0	1.6	3.5
9:	3.0	3.0	3.7	2.1	.0	.0	.0	.0	1.6	3.6
10:	3.8	3.8	4.2	2.4	.0	.0	.0	.0	1.6	3.6
11:	4.1	4.0	4.4	2.5	.0	.0	.0	.0	1.6	3.6
12:	4.1	4.1	4.4	2.5	.0	.0	.0	.0	1.6	3.6
13:	4.1	4.1	4.4	2.5	.0	.0	.0	.0	1.6	3.6
14:	4.1	4.1	4.4	2.5	.0	.0	.0	.0	1.6	3.6
15:	4.1	4.1	4.4	2.5	.0	.0	.0	.0	1.6	3.6

STEP	291	292	293	294	295	296	297	298	299	300
1:	.0	-.1	.8	.0	.2	1.1	.0	1.0	.0	1.1
2:	.0	-.2	1.8	.0	.7	2.3	.0	2.3	.5	2.3
3:	.0	-.1	2.7	.0	1.5	3.8	.0	3.5	1.4	3.4
4:	.0	.5	3.5	.0	2.6	4.8	.0	4.5	2.5	4.3
5:	.0	1.6	4.3	.0	3.6	5.5	.0	5.3	3.5	4.9
6:	.0	2.9	5.0	.0	4.5	5.9	.0	5.7	4.3	5.4
7:	.0	3.7	5.4	.0	5.0	6.1	.0	6.0	4.8	5.8
8:	.0	4.0	5.6	.0	5.1	6.2	.0	6.2	5.2	6.1
9:	.0	4.0	5.6	.0	5.2	6.2	.0	6.4	5.5	6.3
10:	.0	4.1	5.6	.0	5.2	6.2	.0	6.5	5.7	6.4
11:	.0	4.1	5.6	.0	5.2	6.2	.0	6.5	5.8	6.4
12:	.0	4.1	5.6	.0	5.2	6.2	.0	6.5	5.8	6.4
13:	.0	4.1	5.6	.0	5.2	6.2	.0	6.5	5.8	6.4
14:	.0	4.1	5.6	.0	5.2	6.2	.0	6.5	5.8	6.4
15:	.0	4.1	5.6	.0	5.2	6.2	.0	6.5	5.8	6.4

STEP	301	302	303	304	305	306	307	308	309	310
1:	.0	.1	-.3	-.2	-.1	.1	.0	.0	.0	.1
2:	.1	.0	-.2	-.4	-.2	.4	.0	.0	.0	.5
3:	.5	-.1	.3	-.3	-.2	1.2	.0	.0	.0	1.1
4:	1.2	.1	1.2	.3	.2	2.2	.0	.0	.0	2.1

5:	2.1	.6	2.2	1.3	1.2	3.0	.0	.0	.0	3.0
6:	3.1	1.5	3.3	2.6	2.4	3.4	.0	.0	.0	3.7
7:	4.0	2.5	4.1	3.7	3.5	3.7	.0	.0	.0	4.1
8:	4.6	3.5	4.8	4.4	4.2	3.8	.0	.0	.0	4.2
9:	5.1	4.2	5.2	4.9	4.7	3.9	.0	.0	.0	4.2
10:	5.4	4.6	5.4	5.2	5.0	3.9	.0	.0	.0	4.2
11:	5.5	4.8	5.5	5.3	5.1	3.9	.0	.0	.0	4.2
12:	5.6	4.9	5.6	5.3	5.1	3.9	.0	.0	.0	4.2
13:	5.6	4.9	5.6	5.3	5.1	3.9	.0	.0	.0	4.2
14:	5.6	4.9	5.6	5.3	5.1	3.9	.0	.0	.0	4.2
15:	5.6	4.9	5.6	5.3	5.1	3.9	.0	.0	.0	4.2

STEP	311	312	313	314	315	316	317	318	319	320
1:	.0	1.4	.0	.3	.0	.0	.0	.0	.0	.0
2:	.0	2.9	.0	.9	.0	.0	.0	.0	.0	.0
3:	.0	4.0	.0	1.8	.0	.0	.0	.0	.0	.0
4:	.0	4.7	.0	2.8	.0	.0	.0	.0	.0	.0
5:	.0	5.1	.0	3.5	.0	.0	.0	.0	.0	.0
6:	.0	5.4	.0	4.0	.0	.0	.0	.0	.0	.0
7:	.0	5.7	.0	4.2	.0	.0	.0	.0	.0	.0
8:	.0	5.8	.0	4.3	.0	.0	.0	.0	.0	.0
9:	.0	5.9	.0	4.3	.0	.0	.0	.0	.0	.0
10:	.0	5.9	.0	4.4	.0	.0	.0	.0	.0	.0
11:	.0	6.0	.0	4.4	.0	.0	.0	.0	.0	.0
12:	.0	6.0	.0	4.4	.0	.0	.0	.0	.0	.0
13:	.0	6.0	.0	4.4	.0	.0	.0	.0	.0	.0
14:	.0	6.0	.0	4.4	.0	.0	.0	.0	.0	.0
15:	.0	6.0	.0	4.4	.0	.0	.0	.0	.0	.0